Recent Trends in Civil Engineering and Built Environment Vol. 3 No. 1 (2022) 1977-1986
© Universiti Tun Hussein Onn Malaysia Publisher's Office

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

A Review on Mechanical and Durability Performance With Industrial Waste as Concrete Material

Noor Syakila Mohd Isa[1], Nurazuwa Md Noor[1]*

[1]Faculty of Civil Engineering and Built Environment
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, Johor, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rtcebe.2022.03.01.219
Received 4 July 2021; Accepted 13 December 2021; Available online 15 July 2022

Abstract: Rising urbanization and industrialization in a growing nation will increase the manufacturing of industrial waste which could lead to environmental issues and deterioration of human health. An alternative to reduce the rate of industrial waste in the country is by using the wastes as concrete materials in the construction sector. The objectives of this study are to systematically review the current research of industrial waste as concrete material for the construction industry. Besides, the effect on the mechanical properties and durability while industrial waste was used to substitute cement and aggregate in concrete were reviewed through searching using Scopus database and performing snowball method. This study was conducted based on several steps of systematic literature review and the data used are from past research papers from the year 2010 until now. Compared with other industrial wastes for instance waste foundry sand (WFS), coal bottom ash (CBA) and cement kiln dust (CKD), some industrial wastes like fly ash class F (FA) and blast furnace slag (BFS) are very suitable materials for cement, aggregates and concrete substitutes as it showed good improvement towards mechanical properties and durability of concrete. Therefore, using industrial waste in the construction sector could reduce the generated wastes in the country and prevent environmental issues and health problems.

Keywords: Industrial Waste, Mechanical Properties, Durability

1. Introduction

Every year, several million tons of various types of waste are produced worldwide, and this is predicted to continue rising in the future. The conventional approaches for the disposal of such waste are either waste dumping or recycling. Industrial waste is among the highest wastes developed in the world. It is generated from industrial activities involving all elements made useless during the production procedure, such as chemical and food industries, mining operations, mills and factories. Dirt and gravel, scrap metal, scrap wood, solvents, gasoline, concrete and masonry, chemicals, plastics, even vegetable matter from restaurants that can be released into the atmosphere are forms of industrial waste and can cause harm [1, 2]. This problem becomes even worse when there is no appropriate disposal of

*Corresponding author: nurazuwa@uthm.edu.my

industrial waste by the industries due to the increase of operating landfills costs and the scarcity of landfill sites.

Excessive industrial waste in-country could give an impact both on environmental issues and human health deterioration. Extensive research projects have been carried out in recent years to turn waste into potential material use in the manufacture of concrete in the construction sector. Because of the lower quality materials standards, concrete is the most common choice for the integration of recycled waste materials. To solve the above problem, this research focused on the assessment of using industrial waste as concrete materials in the construction work. In the construction sector, concrete is a common building material. As large quantities of building materials are used in the country, industrial waste will be consumed in substantial amounts. The environmental issues and health problems can be prevented and the cost for concrete production can be reduced as well as help the industry to approach sustainability.

The primary objectives of this review are to systematically review the current research of industrial waste as concrete material for the construction industry. However, the two objectives of the study have been specified to obtain the expected outcomes. Those objectives were to review the effect of substitute cement and aggregate with industrial waste on the mechanical properties and durability of concrete.

2. Literature Review

The attempts to reuse and recycle the waste materials had encouraged enormous studies being conducted to integrate the wastes into the medium used in the manufacturing of concrete that has shown interest in controlling the enormous amount of waste produced each year. The common industrial waste that has been used as concrete material such as fly ash (FA), coal bottom ash (CBA), blast furnace slag (BFS), waste foundry sand (WFS) and cement kiln dust (CKD) were discussed in this study. Those industrial wastes were mainly produced by the integrated iron and steel mills, thermal power plants, industry of cement and industry of non-ferrous materials.

2.1 Fly Ash Class F (FA)

Fly ash can be described as a waste residue generated in electric power stations from the process of coal combustion [3]. Fly ash is the incomplete combustion residue generated by the flue gases from the boiler's burning zone and was accumulated whether by mechanical or electrostatic separation processes [4]. According to the amount of silica, iron, aluminium, and content of calcium that has found in it, two main categories of fly ash, which are Class C and F. Besides, FA consist of powdery, fine, solid or hollow particles, usually spherical in form and majority amorphous in nature. FA Class F contains mainly alumino-silicate glass which is also found in mullite, quartz, and magnetite. FA for Class F or low calcium contains less amount of CaO which is 10%.

2.2 Coal Bottom Ash (CBA)

This waste material is non-combustible particles of agglomerated ash formed in coal furnaces by coal-fired thermal power stations. The non-combustible particles are very large to carry along the flow of gases. So, at the bottom of the furnace, it tumbles into an ash hopper through open grates. CBA has irregular, angular and porous particles and it also has a rough surface texture. The dimension range of the particles varies from fine sand to fine gravel. CBA consists mostly of alumina, silica, and iron with small quantities of magnesium, sulphate, etc [5]. Different types of coal and burning methods used will vary the bottom ash chemical composition.

2.3 Blast Furnace Slag (BFS)

The industrial waste of blast furnace slag is derived from iron ore during the steel and iron smelting procedure in a blast furnace. The slag obtained is a granular and glassy material that is made by molten slag quenching of iron in the water. It is then left to dry before being finely powdered [6]. BFS is a coarse sand-sized, amorphous substance. Besides, it has an off-white or near-white presence and showed higher cement properties when finely ground was blended into Portland cement (PC). The two major elements of BFS are silica (SiO2) and limestone (CaO). Magnesium oxide (MgO), alumina (Al_2O_3) and a small volume of sulphur (S) were the other elements for BFS.

2.4 Waste Foundry Sand (WFS)

WFS is high-quality silica sand that could be a waste material of the non-ferrous and ferrous steel casting industries [5]. During its moulding and casting operations, foundries use specific silica sands that have a high-quality size. If sand in the foundry can no longer be utilized, it will be removed from the process and referred to as WFS [5]. WFS has sub-angular to spherical. Besides, green sands are grey or black, while off-white and medium tan colour is chemically bonded sands [5].

2.5 Cement Kiln Dust (CKD)

Cement kiln dust would be a substance that looks like fine powder which was produced in greater amounts during Portland cement manufacturing. During the cement clinker process, cement kiln dust was accumulated in the control devices like baghouse, cyclone or electrostatic precipitator. Besides, CKD consists of several compounds such as silica, iron, alumina and lime. Several trace metals like cadmium, radionuclides, selenium and lead are commonly present in CKD at concentrations below 0.05% by weight [7].

3. Methodology

This study was carried out according to the steps of conducting systematic literature which consist of five major steps. Figure 3 below shows the detail of systematic literature review steps in form of a flow chart.

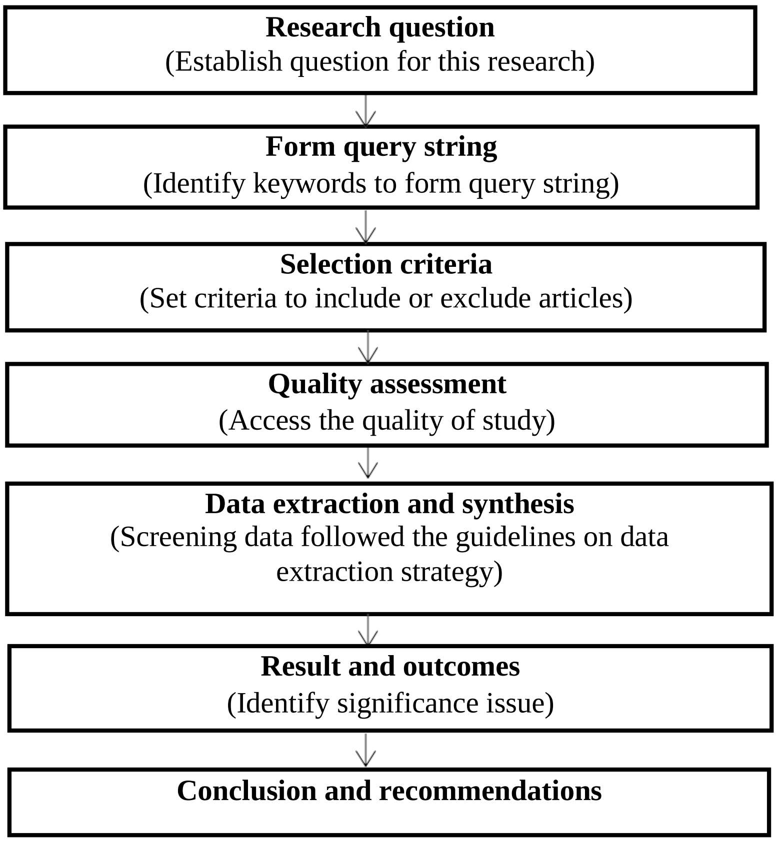

Figure 1: Flowchart of systematic literature review steps

3.1 Research question

Having specific questions that need to be addressed after the whole literature has been reviewed is very important. Thus, the research questions must be held before performing this study to evaluate the quality of the work. This study essentially gives a throughout understanding of these research questions. The list below shows the research questions of this study:

- **RQ1**: How to utilize industrial waste as concrete material.
- **RQ2**: How does industrial waste affect concrete properties when used as cementitious material?
- **RQ3**: How does industrial waste affect concrete properties when used as aggregate material?

3.2 Search space and query string

The keywords obtained from research questions are “review”, “on”, “industrial”, “waste”, “as”, “cementitious” and “material”. All the collection of materials to find the research studies from 2010 until now was conducted via the Scopus database. Scopus has been selected for this study because it is having a high degree of individuality which is described by Scholars and as a database with broader coverage of data. Besides, it is also well established as the most extensive and comprehensive science and engineering database. On top of that, the article was chosen as an open-access article with Engineering as the subject area. This review concentrates more on the impact of using industrial waste on the mechanical and durability performance of concrete A total of 2 papers related to the keywords and search queries were found in the Scopus database.

3.3 Selection criteria

The inclusion and exclusion criteria were used to evaluate each study collected from the literature databases and to make the selection decisions. Inclusion criteria consist of the rules to extract material related to this systematic literature review while exclusion criteria consist of the rules to remove unrelated material for this study.

Inclusion criteria included:

- Articles that are written in English
- Articles that have clear results or findings of the use of industrial waste as concrete material.
- Articles that provide information about the effect of industrial waste on concrete.
- Articles that published in the last ten years

Exclusion criteria excluded:

- Articles that are not written in English.
- Articles that are not related to the research topic.
- Articles that are not available as full-text.
- Non-peer-reviewed research articles, white papers, technical reports.

3.4 Quality assessment

There are about 64 articles that were found from Scopus. Next, the articles have been evaluated for quality assessment. The quality of the selecting 64 studies was evaluated to guarantee the accuracy of the studies. We went through certain studies which were unclear and were not explicit from abstract screening and thorough reading of the entire text. Thus, the evaluation of the quality criteria process was conducted with a full-text screening process. This process helps to verify and determine the quality and reliability of the articles or papers selected.

3.5 Data extraction and synthesis

To address the research question, the data extraction was primarily performed by reading the full text of each selected study and extracting the data items involved. After screening the articles, there is only 2 selected article which most relevant studies for review. For further synthesis, the parameters such as the title, year of publications, author's name, author's ID and DOI has been extracted from our primary studies. Besides, the data synthesis aims to simplify the data extracted in data extraction and gives new researchers a good overview of past work and guidelines.

3.6 Snowball method

To find more information related to this study, the snowball method has been performed. The snowball approach is a method of locating literature that begins with a crucial document related to the topic required. This method required the consultation of bibliography in the key document to find other relevant titles on the topic used. In this study, the snowball method was done by using two main review papers found in the Scopus database. The bibliography of the review papers was examined to find the related title to the chemical and physical properties of various industrial wastes. In addition, research papers related to mechanical properties and durability were also reviewed.

4. Results and Discussion

From the Scopus database, there are several research papers published which related to industrial waste as concrete constituents. Because the industrial waste generated in the countries keep increasing each year, an alternative way to reuse and recycle industrial waste like FA Class F, CBA, BFS, WFS, and CKD has been developed. Thus, there were many studies involved industrial waste by researchers since the year 1978.

4.1 Effect of industrial waste as aggregate on concrete mechanical properties

By using FA into concrete as aggregate and increased the replacement rate of Class F FA, the compressive strength is increased [8]. He stated that FA concrete's flexural activity of Class F reacted almost the same pattern with compressive strength and it will increase as the replacement percentage increases. He concluded through his study that increasing the quantity of Class F FA replacement can improve the concrete split tensile strength.

On the other hand, the concrete compressive strength that contains CBA is increasing if the sand is replaced with bottom ash is decreasing [9]. Besides, it has been found an improvement of flexural strength when using up to 20 per cent of CBA replacement while the flexural strength will diminish if use CBA for more than 20 per cent. Other than that, the study discovered that split tensile strength will decrease when the amount of CBA replacement is increasing [10].

Next, the concrete with higher BFS replaced fine aggregate result in comparable compressive strength with reference concrete during the early ages [11]. It was observed that as the quantity of BFS utilized in concrete increases, the flexural strength of the concrete diminished [12]. The authors determined the improvement of 10 per cent for flexural strength as compared with the control mix while the usage of 10 per cent of slag replacement. Next, the split tensile strength is lower whilst the amount of BFS substitute is increased [10].

Then, utilizing WFS in concrete as aggregate does not increase the compressive strength [13]. However, if concrete mixtures were replaced more than 20 per cent, it produces lower strength than the control mix. Other than that, there is a slight improvement of flexural strength when the content of WFS increased [14]. It has been mentioned that 5 and 15 per cent of the splitting tensile strength of WFS concrete turned into lesser compare with the control mix, whereas 10 per cent of WFS specimens had moderately greater levels than the control mix strength value [15].

Besides, concrete that contains up to 5 per cent of CKD will not affect the compressive strength [16]. Meanwhile, the replacement in concrete for up to 10 per cent of CKD will grow the strength at 91 days of curing. However, the control mix which consists of 0 per cent of CKD displayed a range between 4.70 until 3.80 MPa of flexural strengths for 3, 7 and 28 days with all water-to-binder ratios (0.50, 0.60 and 0.70) [17]. It was found that there is no major decrease was observed in flexural strength at 5 per cent and 10 per cent CKD replacement in concrete.

Table 1: Comparison of mechanical properties for different industrial waste

Mechanical Properties	Compressive Strength	Flexural Strength	Tensile Strength
FA Class F	Increase	Increase	Increase
CBA	Increase	Decrease	Decrease
BFS	Increase	Increase	Decrease
WFS	Decrease	Increase	Increase
CKD	Increase	Decrease	-

4.2 Effect on concrete fresh and hardened properties with waste material as cementitious material

The performance of concrete constituents can be demonstrated through mechanical properties like fresh and hardened properties. In terms of fresh properties of concrete, it was observed a decrement in slump value when there is an increment of FA Class F replacement in concrete [8]. It has been investigated that the more inclusion of FA Class F in concrete, the higher the slump flow which means higher workability [18]. Meanwhile, the air content of concrete contained in FA Class F is lowered than the normal weight concrete. In terms of hardened properties, the density of fresh concrete that was replaced by up to 50% of FA Class F showed a value that was almost similar to control concrete [8]. The author additionally found the concrete compressive strength and tensile strength became improve because the FA Class F substitute was increased.

The slump value showed an increment when the replacement of CBA is about 20% [10]. However, the replacement of CBA more than 20% resulted in a decrement in slump value. Then, the increase CBA addition in concrete has increased water demand, thus, reducing the workability of concrete [19]. The increase of CBA replacement in concrete has linearly decreased the concrete density during the hardened stage [20]. It discovered the increment of CBA with fixed water to cement ratio in concrete results in diminished compressive strength throughout all ages [9]. However, in any respect ages, concrete compressive strength changed with the aid of using CBA with constant slump showed comparable value to that of manage concrete. In addition, the increase of CBA substitution in concrete results in a decrement of split tensile strength [10].

For the replacement of BFS in concrete, it was discovered that the value of slump increased if substitution of BFS increased [10]. In addition, the increase of BFS replacement in concrete decreased the ratio of water to a binder which resulted in a good effect on workability [21]. However, it has been found that the compressive strength was diminished when the replacement of BFS increased [12]. It also discovered that the decreased of split tensile strength when the BFS replacement in concrete increased [10].

Apart from that, the concrete with increasing WFS replacement resulted decreasing in slump value [13]. Besides, the increasing percentage replacement by WFS in concrete at a constant ratio of water to binder has increased the slump value, thus resulted in better workability [22]. It stated that the replacement of WFS in concrete indicated about 2.1% to 3.4% of air content [23]. Next, it found that as the amount of WFS replacement had risen, the concrete density was reduced [13]. The authors also mentioned that concrete compressive strength showed no significant development and tensile strength were diminished when replaced with WFS in concrete.

Furthermore, the concrete containing higher CKD resulted in a lower slump value [24]. The author found through his study that the increment of CKD content has reduced the workability of the concrete. On top of that, the author noticed that the decrement of compressive strength when there were increments in CKD replacement at a constant water-cement ratio. For the presence of CKD in concrete, the tensile strength appeared to be increased at all ages when the replacement of CKD decreased.

Table 2: Comparison of mechanical properties for cementitious material

	`	FA Class F	CBA	BFS	WFS	CKD
Fresh Properties	Slump Test	Decrease	Increase	Increase	Decrease	Decrease
	Workability	Increase	Decrease	Increase	Decrease	Decrease
	Air Content	Decrease	Decrease	Decrease	Decrease	-
Hardened Properties	Density	No change	Decrease	No change	No change	-
	Compressive Strength	Increase	Decrease	Decrease	Decrease	Decrease
	Tensile Strength	Increase	Decrease	Decrease	Decrease	Decrease

4.3 Effect on concrete durability with waste material as cementitious material

The durability of different cementitious materials reported in this study is included permeability, rapid chloride ion penetration (RCPT) test and abrasion test. As the increased of cement replacement by FA Class F for 0.5 water-cement ratios, the rate of water absorption decreased [25]. It has been investigated that the decrement of RCPT value when the content of FA Class F in concrete increased at constant water to binder ratio [26]. When the quantity of FA Class F supplanting increased, the concrete mixture abrasion resistance was improved irrespective of the curing age [27].

Subsequently, the replacement by either BFS, CBA or both in concrete showed an increment of water absorption ratios [10]. However, as the amount of CBA replacement increased, water absorption increased as well. It was examined that with increasing CBA presence in concrete, there was an increase in resistance to chloride-ion penetration [28]. Besides, the increment of CBA supplanting within the concrete mixture resulted in an increment of abrasion resistance [29].

For the replacement of BFS in concrete, the water absorption was lowered when BFS replacement in concrete has been raised [30]. Then, the charge moving through the concrete in RCPT had been diminished when the replacement of BFS in concrete increased. In addition, the abrasion resistance of concrete replaced by BFS showed almost the same as that CBA which is up to 20% replacement in concrete [29]. Furthermore, concrete with a higher percentage of WFS showed a higher rate of water absorption during the age of 28 days [31]. Other than that, it can be concluded that the value of RCPT has been lowered with the WFS proportion increment in the concrete mix [32]. Next, it stated that the abrasion resistance was increasing as the quantity of WFS replacement increased [33].

For the CKD in concrete, it was discovered that when the quantity of CKD replacement is greater, the water absorption of concrete additionally became increased [34]. Moreover, it reported that with an improvement of CKD substitution in concrete, the chloride permeability increased [35]. Lastly, researchers revealed the higher replacement of CKD in concrete, lowered the abrasion resistance of concrete [36].

Table 3: Comparison of durability for cementitious material

Properties	Water Absorption	RCPT Test	Abrasion Resistance
FA Class F	Decrease	Decrease	Increase
CBA	Increase	Decrease	Increase
BFS	Increase	Increase	Decrease
WFS	Decrease	Decrease	Decrease
CKD	Decrease	Decrease	-

5. Conclusion

This study reviews the existing literature towards the impact of the usage of industrial waste as concrete material on mechanical properties and durability of concrete. Through the studies from the past research paper, it is shown that FA Class F has capabilities for being used as aggregate and cement replacement in concrete than the other industrial waste. The existence of FA Class F in concrete indicated a good improvement for concrete performance due to the properties of FA Class F that are almost similar to ordinary Portland cement. Besides, CBA is an industrial waste that is commonly studied by many researchers and getting used to substitute cementitious material in concrete. The concrete contains CBA resulted in higher abrasion resistance and shows higher compressive strength when it was used as a substitution for aggregate in concrete. The previous studies revealed that there is some improvement for the compressive strength, flexural strength and workability while BFS became used as an aggregate substitute in concrete. Thus, the usage of BFS in concrete has become endorsed because of the high-quality impact that has been proven in this research.

Next, it found that flexural and tensile strength experienced improvement while both compressive and tensile strength showed decrement when WFS was used as cement replacement. Hence, WFS was not so relevant to be replaced in concrete due to higher water absorption and less favourable performance effect. Besides, the researchers revealed that after the quantity of CKD in concrete increased, better compressive strength and lower flexural strength can be obtained. Both compressive and tensile strength was decreasing when CKD is used as cement replacement. Therefore, the utilisation of certain industrial waste in the construction sector is a good solution as it improves the concrete performance as well as reduced wastes generated each year in each country. In addition, environmental issues and human health deterioration can be further reduced.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, UniversitiTun Hussein Onn Malaysia for their support.

References

[1] Awuchi, Chinaza Godswill and Awuchi, Chibueze Gospel (2019a). Physiological Effects of Plastic Wastes on the Endocrine System (Bisphenol A, Phthalates, Bisphenol S, PBDEs, TBBPA). International Journal of Bioinformatics and Computational Biology. Vol. 4, No. 2, 2019, pp. 11-29

[2] Awuchi, Chinaza Godswill and Awuchi, Chibueze Gospel (2019b). Impacts of Plastic Pollution on the Sustainability of Seafood Value Chain and Human Health. International Journal of Advanced Academic Research, 5 (11); 46 – 138

[3] Nadesan, M. S. & Dinakar, P. (2017). Mix design and properties of fly ash waste lightweight aggregates in structural lightweight concrete, Case Studies in Const. Mater. 7 336–347

[4] Naik, T.R. and Singh, S.S. 1993 Fly Ash Generation and Utilization – An Overview. Retrieved from http://www4test.uwm.edu/cbu/Papers/1993%20CBU%20Reports/ REP-190.pdf

[5] Siddique, R. (2014). Utilization of Industrial By-products in Concrete. Procedia Engineering, 95, 335–347. doi:10.1016/j.proeng.2014.12.192

[6] Suda, V.B.R. and Rao, P.S. 2020 Experimental investigation on optimum usage of Micro silica and GGBS for the strength characteristics of concrete Mater. Today Proc.

[7] Corish, A., and Coleman, T. (1995). Cement kiln dust. Concrete, 29(5), 40–42.

[8] Siddique, R., 2003. Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete. Cem. Concr. Res. 33, 539–547.

[9] Bai, Y., Darcy, F., and Basheer, P.A.M. (2005). "Strength and drying shrinkage properties of concrete containing furnace bottom ash as fine aggregate." Constr. Build. Mater., 19, 691–697.

[10] Yuksel, I., and Genc, A. (2007). Properties of concrete containing non-ground ash and slag as fine aggregate. ACI Mater. J., 104(4), 397–403.

[11] Valcuende, M., Benito, F., Parra, C., Minano, I., 2015. Shrinkage of self compacting concrete made with blast furnace slag as fine aggregate. Constr. Build. Mater. 76, 1–9.

[12] Yuksel, I., Ozkan, O., Bilir, T., 2006. Use of granulated blast-furnace slag in concrete as fine aggregate. ACI Mater. J., 203–208

[13] Prabhu, G.G., Hyun, J.H., Kim, Y.Y., 2014. Effects of foundry sand as a fine aggregate in concrete production. Constr. Build. Mater. 70, 514–521.

[14] Siddique, R., Schutter, Geert de., and Noumowe, A. (2009). Effect of used-foundry sand on the mechanical properties of concrete. Constr. Build. Mater.,23(2), 976–980.

[15] Guney, Y., Sari, Y.D., Yalcin, M., Tuncan, A., and Donmez, S. (2010). Re-usage of waste foundry sand in high strength concrete. Waste Manag., 30, 1705–1713.

[16] El-Sayed, H.A., Gabr, N.A., Hanafi, S., and Mohran, M.A. (1991). Reutilization of by-pass kiln dust in cement manufacture. Proc. Intern. Conf. Blended Cement in Construction.

[17] Al-Harthy, A.S., Taha, R., and Al-Maamary, F. (2003). Effect of cement kiln dust (CKD) on mortar and concrete mixtures. Constr. Build. Mater., 17(5), 353–360.

[18] Siddique, R. (2004). Performance characteristics of high-volume Class F fly ash concrete. Cement and Concrete Research, 34(3), 487–493

[19] Aramraks, T. (2006) Experimental study of concrete mix with bottom ash as fine aggregate in Thailand. In: Symposium on infrastructure development and the environment, 1–5.

[20] Kim, H.K., and Lee, H.K. (2011). Use of power plant bottom ash as fine and coarse aggregate in high-strength concrete. Constr. Build. Mater., 25, 1115–1122.

[21] Oner, A., & Akyuz, S. (2007). An experimental study on optimum usage of GGBS for the compressive strength of concrete. Cement and Concrete Composites, 29(6), 505–514

[22] Elahi, A., Basheer, P. A. M., Nanukuttan, S. V., & Khan, Q. U. Z. (2010). Mechanical and durability properties of high-performance concrete containing supplementary cementitious materials. Construction and Building Materials, 24(3), 292–299

[23] Aggarwal, Y., Siddique, R., 2014. Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates. Constr. Build. Mater. 54, 210–223.

[24] Abdulabbas, Z. H. (2013). Utilization of Cement Kiln Dust in Concrete Manufacturing Zainab Hasan. Jordan Journal of Civil Engineering, 7(1), 111-125.

[25] Gingos, G.S., & Sutan, N., (2011). Effect of PFA on Strength and Water Absorption of Mortar. Journal of Civil Engineering, Science and Technology, 2(1), 7–11.

[26] Nath, P., & Sarker, P. (2011). Effect of Fly Ash on the Durability Properties of High Strength Concrete. Procedia Engineering, 14, 1149–1156.

[27] Siddique, R., & Khatib, J. M. (2009). Abrasion resistance and mechanical properties of high-volume fly ash concrete. Materials and Structures, 43(5), 709–718.

[28] Singh, M., Siddique, R., 2014. Compressive strength, drying shrinkage and chemical resistance of concrete incorporating coal bottom ash as a partial or total replacement of sand. Constr. Build. Mater. 68, 39–48.

[29] Bilir, T., Yüksel, I., Topcu, I. B., & Gencel, O. (2015). Effects of bottom ash and granulated blast furnace slag as fine aggregate on abrasion resistance of concrete. Science and Engineering of Composite Materials, 24(2)

[30] Aylin Akyildiz. (2018). Water Absorption and Sorptivity Properties of Concrete Containing Granulated Blast Furnace Slag. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), vol. 15, no. 6, 2018, pp. 66-69.

[31] Basar, H.M., Aksoy, N.D., 2012. The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and microstructural characteristics of ready-mixed concrete. Constr. Build. Mater. 35, 508–515.

[32] Singh, G., Siddique, R., 2012a. Effect of waste foundry sand (WFS) as partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete. Constr. Build. Mater. 26, 416–422.

[33] Singh, G., Siddique, R., 2012b. Abrasion resistance and strength properties of concrete containing waste foundry sand (WFS). Constr. Build. Mater. 28, 421–426.

[34] Ali, M. A. M., & Yang, H.-S. (2011). Utilization of Cement Kiln Dust in Industry Cement Bricks. Geosystem Engineering, 14(1), 29–34

[35] Maslehuddin, M., Al-Amoudi, O. S. B., Rahman, M. K., Ali, M. R., & Barry, M. S. (2009). Properties of cement kiln dust concrete. Construction and Building Materials, 23(6), 2357–2361

[36] Abdel-Ghani, N. T., El-Sayed, H. A., & El-Habak, A. A. (2018). Utilization of by-pass cement kiln dust and air-cooled blast-furnace steel slag in the production of some “green” cement products. HBRC Journal