



Characteristics of Eco-Friendly Metakaolin Based Geopolymer Concrete Pavement Bricks

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ABSTRACT

The purpose of this work is to investigate the possibility to recycled and reused of waste clay brick and waste plastic as constituents in the production of green Geopolymer concrete paving bricks. Powder of clay brick waste (WBP) was used as a partial replacement of Metakaolin (MK) in Geopolymer binder. Moreover, recycled clay brick waste aggregate (BA) and plastic waste aggregate (PL) were incorporated as coarse aggregate in mixtures of Metakaolin based Geopolymer concrete (MK-GPC) pavement bricks. Six types of mixtures were prepared and cast as pavement bricks with dimensions of 150×150×100 mm. All samples have been tested for compressive strength, water absorption and abrasion resistance at age of 28 days; and compared the results with the requirements of Iraqi specification No.1606-2006. The MK-GPC pavement bricks present a compressive strength of 31-47MPa, water absorption of 3.66% to 5.32% and abrasion resistance with groove length between 21.78mm to 18.91 mm. These types of pavement bricks are classified as a medium to light capacity for weight loading, and it is possible to be used in wide range of paving applications, especially in aggressive wearing environment.

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1. INTRODUCTION

Nowadays, the need for eco-friendly construction materials and products is very important for sustainable development. The extensive use of concrete has made it as one of the major contributor

of global warming [1]. The main drawbacks of concrete regarding the environmental aspects come from manufacturing of ordinary Portland cement (key-ingredient) of concrete. Since the cement industry is contribute to about 5-8% of global CO₂ emission, and this number could increase to 8-10% in coming years [2]. To mitigate these drawbacks, many researches have been focused on developing the "Geopolymer concrete" that does not use Portland cement as a binder. Generally, the Geopolymer is obtained by a chemical reaction known as a Geopolymerization process. In this process, amorphous aluminosilicate source like fly ash, slag, red mud, rice husk ash and Metakaolin (MK) are activated with a strong alkali solution which is usually consist from sodium silicate (Na₂SiO₃) and sodium hydroxide (NaOH) [3]. On the other hand, the increase of the amount and type of solid wastes has made the disposal of these wastes a serious environmental crisis. Worldwide, millions tons of construction and demolition waste (C&D) are generated every year. Since the clay bricks consider to taking the second level as a construction material after concrete, they are account for a large proportion of construction and demolition waste. The clay bricks are treated as C&D waste if they are damage during the manufacturing, construction and demolition activities [4]. Most of these wastes are left as landfill or illegally dumped to become a serious environmental problem. Another source of solid waste pollution comes from plastic products that have dramatically increased all over the world. Approximately, in 2002 the consumption of plastic was 200 million tons globally, and it jumped to 322 million tons in 2015, and this number expected to reach 485 million tons in 2030. Due to their non-biodegradable property, the plastic wastes persist and remain for hundreds and thousands of years in the environment [5] and causes a serious pollution problem not only for landfilling but for soil fertility and marine life [6]. However, replacements the natural aggregates of concrete with different types of wastes can be solve the environment pollution issues and prevent natural resources from depletion. Therefore, the use of waste materials to produce Geopolymer interlocking bricks has gain more interest amongst researches. Kewal et al. [7] have replaced the natural fine aggregate with foundry sand to produce fly ash based Geopolymer concrete paving block with lesser compressive strength at 41MPa, and 4-5% water absorption. Whilst, Muhammed and Varkey [8] have determined the mechanical properties of polypropylene fiber reinforced fly ash-Geopolymer concrete pavers. Based on them results, the paver blocks containing 0.2% of polypropylene fiber have relatively higher strength and good abrasion resistance. Also, Mohammed et al. [9] have been utilized crumb rubber as a fine aggregate in the production of Geopolymer interlock bricks. The rubberized interlock bricks have presented lower strength and a high water absorption capacity. However, data demonstrate the possibility of using Metakaolin, clay bricks waste and plastic waste to producing Geopolymer concrete pavement bricks, as well as a clear understanding of theirs properties are remain missed. Accordingly, this study aims to manufacture superior eco-friendly Geopolymer concrete pavement bricks based on the use of local MK, clay brick waste powder, crushed clay brick waste and shredded plastic waste as coarse aggregate. Moreover, the objectives of this research are to measure and evaluate the properties of final products, and then classify it according to the Iraqi specification No.1606-2006 [10].

2. EXPERIMENTAL PROGRAM

The experimental study was conducted to investigate the properties of MK-based Geopolymer concrete pavement bricks that contain different type of waste materials. Six Geopolymer concrete mixtures were used to prepare the pavement bricks and these mixes included the following variables; reference mix, mix with 15% replacement of Metakaolin with powder clay brick waste (WBP) by weight, two mixes with natural coarse aggregate replaced at dosage of 10% by volume with either recycled clay brick waste aggregate (BA) or shredded waste plastic aggregate (PL), in addition to other two mixes with blended waste materials as a binary of 15%WBP with 10%BA or 10%PL.

I. Materials

A. Metakaolin

Local kaolin clay was burnt in an electrical furnace at 700°C for two hours to produce the Metakaolin (MK) that used as source material in this study. Based on the oxides composition which obtained from X-ray fluorescence analysis and physical properties as shown in Table 1, the Metakaolin is comply with the requirements of ASTM C618-2017 [11] as a natural pozzolan class N.

B. Aggregates

Natural crushed gravel with maximum size of 14mm was used as coarse aggregate. While, natural sand (zone 1) of 3.3 fineness modulus was used as fine aggregate in all mixes. The coarse and fine aggregates are complied with Iraqi specification IQ.S No.45-1984 [12] as shown in Table 2 and Table 3, respectively.

TABLE I: Chemical and Physical Properties of (MK) and (WBP)

Oxides	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	L.O.I
<i>MK</i>	54.20	39.0	0.92	1.37	0.15	0.45	0.22	0.27	0.71
<i>WBP</i>	56.82	11.36	2.36	20.20	3.02	0.83	0.86	0.86	1.19
Physical properties						MK		WBP	
<i>Specific gravity</i>						2.64		2.84	
<i>Specific surface area, m²/kg</i>						14300		462	
<i>Strength activity index at 7 days, %</i>						113.3		89.2	
<i>Percent retained on 45μm (No. 325) sieve, %</i>						18.2		32	

TABLE II: Grading and Physical Properties of Coarse Aggregate

Sieve size (mm)	Passing%	Limits of Iraqi spec. No.45/1984
20	100	100
14	98.26	90-100
10	61.38	50-85
5	3.45	0-10
Physical properties		Limits of Iraqi spec. No.45/1984
Specific gravity		2.61
Absorption, %		1.3
SO ₃ , %		0.034
Dry rod density, kg/m ³		1595

TABLE I: Grading and Physical Properties of Fine Aggregate

Sieve size (mm)	Passing%	Limits of Iraqi spec. No.45/1984
10	100	100
4.75	90-100	96.43
2.36	60-95	74.41
1.18	30-70	50.40
0.6	15-34	29.1
0.3	20-5	12.43
0.15	0-10	2.9
Physical properties		Limits of Iraqi spec. No.45/1984
Specific gravity		2.58
Absorption, %		1.6
SO ₃ , %		0.063
Materials finer than 0.075 mm, %		2.1
Dry rod density, kg/m ³		1787

C. Alkaline solution

The mixture of sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃) at ratio of (1:2) has used as alkali activator solution. The NaOH pellets of 98% purity dissolved in distill water to get a solution with 14M concentration. This solution has mixed thoroughly with Na₂SiO₃ liquid. Because of the exothermic reaction, the final solution was left 24 hour to be cool at room temperature.

D. Water

Extra tap water was used for enhancing the mixing process and improving the workability of fresh mixture.

E. Superplasticizer

A high rang water reducer admixture, commercially known as Conplast 2000 was used in all mixes to improve the workability.

F. Crushed clay brick waste aggregate

The source of clay brick waste was the remaining of non-used clay brick units, were collected from house construction site in Karrada district –Baghdad. The quarters of waste brick units have been crushed into small pieces by a jaw crusher machine in laboratories of Building Research Center. By using electrical sieves shaker, crushed waste brick aggregate have been graded to comply with the grading of natural coarse aggregate. The obtained waste clay brick aggregate (BA) is shown in Figure 1 have 940 kg/m^3 of density, 24.0% water absorption and 1.57 of specific gravity.



Figure 1: Crushed clay brick waste aggregate [13].

G. Clay brick waste powder

The powder of clay brick waste has obtained from collecting dust and small particles of brick waste aggregate (less than 5 mm) that were produced from crushing process. These fine materials were re- grinded by a cyclone grinding machine in a privet factory at Bob-AL sham region, north of Baghdad. Figure 2 shows the waste clay brick powder. The chemical and physical properties of WBP are illustrated in Table 1, and the clay brick waste powder (WBP) can be classified as natural pozzolan according to ASTM C618-2017 [11].



Figure 2: Powder of clay brick waste

H. Shredded waste plastic

Waste of different plastic products of high density polyethylene (HDPE) type has collected from a disposal landfill in Baghdad city. The plastic wastes were shredded into small flaky particle using plastic scrap grinder machine at a private recycling plastic workshop in Bob-AL sham region, north of Baghdad. These shredded particles graded by sieves to be comply with natural coarse aggregate

size. The waste plastic aggregate (PL) has density of 455 kg/m³, 0.0% water absorption and flaky-chips shape with thickness between 1-3 mm and maximum length of 14 mm, as shown in Figure 3.



Figure 3: Shredded waste plastic aggregate [14].

II. Mix Proportions and Preparation of Test Samples

In this study, six Geopolymer concrete mixtures were prepared and these mixes included; reference mix, mix with 15% by weight of Metakaolin has substituted with WBP, two mixes with 10% of natural coarse aggregate volume has replaced with BA and the same for PL aggregate, in addition to the two mixes with blended of (15%WBP-10%BA) and (15%WBP-10%PL).

The mix proportions and nomenclature for all mixes are presented in Table 4. The mix design, mixing process, casting and curing method of reference mix and other mixtures have proposed and adopted similar to previous researches [13-15]. For all mixes the ratio of alkaline solution to binder source was 0.65, whilst the dosage of superplasticizer and extra water were fixed at 2% and 10% respectively.

The fresh Geopolymer concrete has cast in molds of 150×150×100 mm, and compacted by tamping 30 times with standard rod and followed with 30 seconds on vibrating table. After 24 hours, the demolded samples were covered with thick nylon and kept inside an electrical oven at 50°C for 4-5 hours. Then, all specimens exposed to heat of sunlight till test time.

TABLE II: Mix Proportions and Details of MK-GPC Pavement Bricks Units

Mixes Symbols	MK	C.A	F.A	WBP	BA	PL	Alkaline Sol.	SP
	(kg/m ³)							
0%R	415	1240	475	0	0	0	41.5	8.3
15%WBP	352.75	1240	475	62.25	0	0	41.5	8.3
10%BA	415	1116	475	0	73.08	0	41.5	8.3
10%PL	415	1116	475	0	0	35.373	41.5	8.3
WBP-BA	352.75	1116	475	62.25	73.08	0	41.5	8.3
WBP-PL	352.75	1116	475	62.25	0	35.373	41.5	8.3

Where: C.A: coarse aggregate, F.A: fine aggregate, SP: superplasticizer

The final shape and dimensions of the produced MK-GPC paving bricks are shown in Figure 4. All samples have provided a surface area of (22500) mm², with maximum length up to 150 mm and thickness of 100 mm. These values are complied with the dimensions requirements for pavement bricks according to Iraqi Specification No.1606-2006 [10], as shown in Table 5.

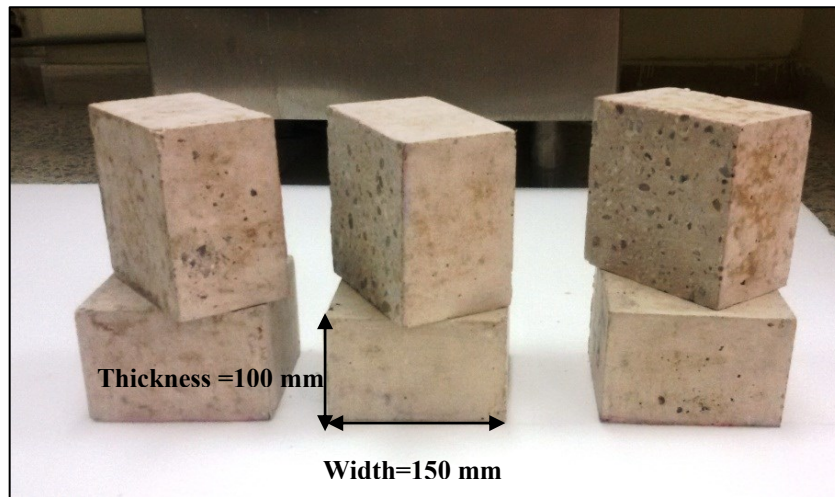


Figure 4: Final products of MK-GPC pavement brick units

TABLE III: Dimensions Requirements of Pavement Brick According to the IQ.S No. 1606-2006

Class of Pavement Bricks	Surface area (mm ²)		Length (mm)	Thickness (mm)	
	Min.	Max.	Max.	Min.	Max.
High Loading	5000	60000	290	80	140
Medium Loading	5000	60000	290	60	140
Light Loading	/	/	290	60	140

3. EXPERIMENTAL TESTS

The compressive strength and water absorption for all samples of MK-GPC pavement bricks have been tested and evaluated to be satisfied with Iraqi specification No.1606-2006 [10], whereas the abrasion resistance has achieved according to BS EN 1338-2003[16]. The groove length for each specimen was measured using wearing machine as shown in Figure 5. According to IQ.S1606-06 specification, the concrete paving bricks can be classified into three categories in related to its compressive strength, water absorption and abrasion resistance as illustrated in Table 6.



Figure 5: Abrasion resistance test machine

TABLE IV: Requirements of Iraqi specification No. 1606-2006 for Concrete Pavement Bricks

Class of Pavement Bricks	Compressive strength (MPa)		Water absorption (%)		Abrasion Resistance
	Minimum		Maximum		Maximum losing in thickness
	For one brick	For the mean	For one brick	For the mean	
High Loading	50	55	8	6	3 mm
Medium Loading	30	35	9	7	
Light Loading	25	30	12	10	

Where:

The **high loading class** is used in paving heavy industry arenas, ports, container yards, motorways with heavy loads, and for the arenas that have exposed to highly surface erosion.

The **medium loading class** is used for paving road vehicles with light loading and service areas.

The **light loading class** is used for paving pedestrian roads, places not exposed to cars, and areas not exposed to erosion.

4. RESULTS AND DISCUSSION

I. Water absorption

The results of water absorption for all MK-GPC pavement bricks are presented in Figure 6 and Table 7. It is clearly that the minimum value of water absorption was 3.66% for samples with 15%WBP; and that related to the effect of brick waste powder as filler material in the Geopolymer matrix. Whereas the samples with 10% BA have gave higher absorption of 5.32%. This behavior attributes to the porous structure of clay brick aggregate and it's highly absorption in comparison with natural aggregate. On the other hand, the incorporation of waste plastic has increased the water absorption of reference specimens by 11.67% due to the effect of flaky shape of PL aggregate that caused more pores and voids inside the Geopolymer mixture. Generally, it can be seen that the water absorption for all paving bricks samples were lower than the limitations of IQ.S No1606-2006 [10] shown in Table 5, which indicating the good quality of the produced concrete paving units.

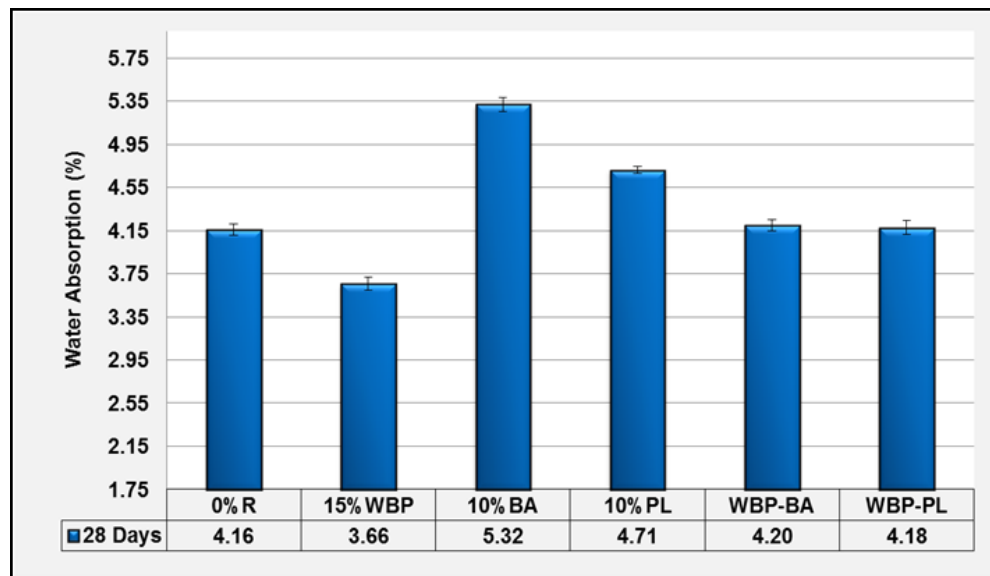


Figure 6: Water absorption of MK-GPC pavement bricks containing waste materials

II. Compressive strength

The results of compressive strength of MK-GPC pavement bricks are illustrated in Figure 7 and Table 7. The utilization of waste materials has provided a variety to synthesis different classes of MK-GPC pavement bricks. The highest compressive strength was 47.70 MPa for reference mix. The

inclusion of 15% WBP decreases the compressive strength of 0%R by 10.42%, because of the differences in the fineness (specific surface area) and strength activity index between MK and BP [15]. Also, the usage of 10%BA and 10%PL minimizes the strength of pavement units by 9.16% and 32.70% respectively. This is related to weakness of clay brick aggregate and plastic waste aggregate in comparison with natural coarse aggregate [13, 14]. On the other hand, the double use of WBP and BA has provided minimum reduction in strength by 4.96% in compare with reference mix, due to the compatibility between both types of clay brick wastes. Meanwhile, the lowest compressive strength was 31.43 MPa for the hybrid specimen of mix WBP-PL.

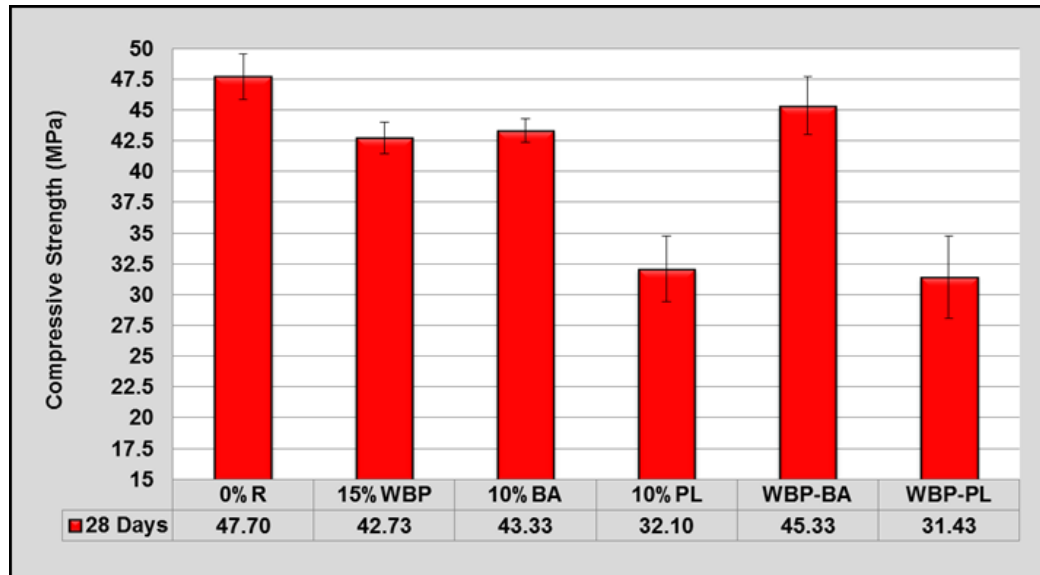


Figure 7: Compressive strength of MK-GPC pavement bricks containing waste materials

III. Abrasion resistance

As shown in Figure 8 and Table 7, the abrasion resistance based on grooves length for all MK-GPC pavement bricks has ranged from 18.91 to 21.78 mm. These values are comply with BS EN 1338:2003, as class 3 (groove ≤ 23 mm) and class 4 (groove ≤ 20 mm). Compared with reference MK-GPC sample, the dosage of 15%WBP has reduced the abrasion resistance up to 4.32%, while the reduction of blended WBP-BA mix reaches to 11.52%. In spite of the lower compressive strength of the pavement bricks containing PL particles, but it has shown a great wearing resistance. The paving brick samples of 10%PL and blended WBP-PL have improved the abrasion resistance of control specimen by 1.87% and 0.78%, on respect. Generally, this improvement in abrasion resistance is similar to that of ordinary Portland cement concrete which includes waste plastic aggregate and complies with the previous studies [17]. This behavior can be attributed to the characteristic of waste plastic particles to withstanding the wearing force.

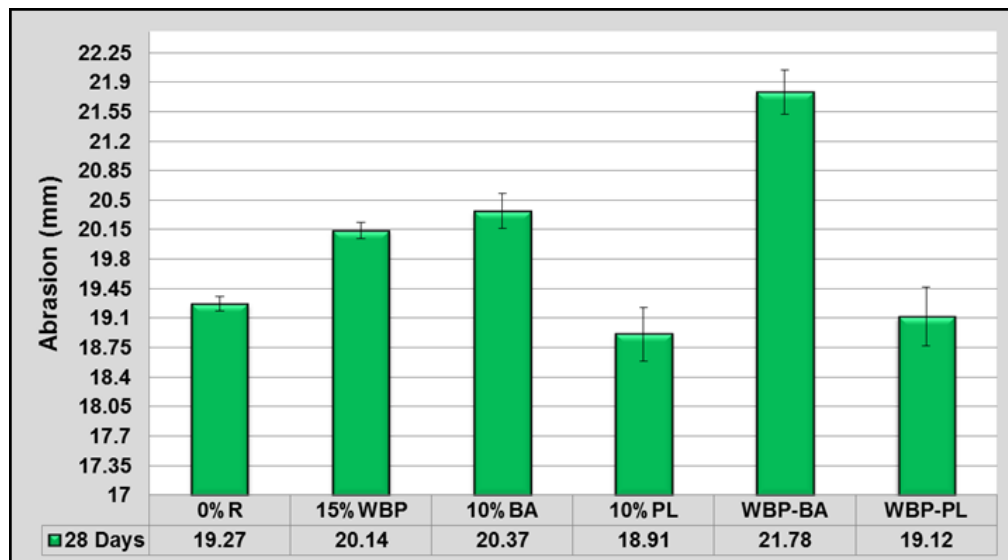


Figure 8: Abrasion resistance of MK-GPC pavement bricks containing waste materials

IV. Classification of MK-GPC pavement bricks

Based on the results of the experimental tests, all samples of MK-GPC pavement bricks are comply with Iraqi specification 1606-2006 [10]. According to the specification limits for water absorption, all samples of MK-GPC pavement bricks are classifying for a high loading using. Also, the abrasion resistance for all samples is lay within the specification limits. On the other hand, the classification of MK-GPC pavement bricks according to the compressive strength is illustrated in Table 7. It is clear that all produced pavement bricks are classified as medium or lightweight loading classes. Thus, these pavement bricks are capable to be used in wide applications of the paving that exposed to aggressive environments and high abrasion forces, especially for the mixes contains waste plastic aggregate.

TABLE V: Properties and Classification of MK Geopolymer Concrete Pavement Bricks

Type of Mixes	Water Absorption (%)	Compressive Strength (MPa)	Abrasion Resistance (mm)	Classification according to IQ.S 1606-2006
0%R	4.16	47.70	19.27	Medium Loading
15%WBP	3.66	42.73	20.14	
10%BA	5.32	43.33	20.37	
10%PL	4.71	32.10	18.91	Light Loading
WBP-BA	4.20	45.33	21.78	Medium Loading
WBP-PL	4.18	31.43	19.12	Light Loading

5. CONCLUSIONS

Based on the experimental results of this study, the following conclusions can be drawn:

- Generally, it is possible to use clay brick waste powder, waste brick aggregate and shredded waste plastic aggregate to produce super sustainable MK-Geopolymer concrete pavement bricks.
- Using of waste materials individually or as a blended will minimized the compressive strength of Geopolymer concrete pavement bricks samples, especially for the mixes that containing waste plastic aggregate. Despite of this negative impact, it is possible to produce MK-GPC pavement bricks with compressive strength ranged from 47.70 to 31.43 MPa.
- Due to the filling effect of WBP, the use of 15% WBP displayed significant improvement in minimizes water absorption of MK-GPC pavement bricks over other

- mixes. Also, the blended of waste brick powder with clay brick waste aggregate or plastic waste aggregate showed a reduction in water absorption compared with 10%BA and 10%PL mixes.
- The incorporation of waste clay brick as a powder or crushed aggregate leads to reduce the abrasion resistance of MK-GPC paving bricks. Meanwhile, the specimens with plastic waste aggregate have provided less groove length which mean better wearing resistance.
 - Depending on its strength that ranged from 47.70 to 31.43 MPa, these pavement bricks can classified as a medium to light loading capacity class, with a low water absorption between 3.66% to 5.32% and a good abrasion resistance. These characteristics will provide a variety in using the superior eco-friendly pavement bricks for paving the roads, service areas and sidewalks, especially when a little absorption and high wearing resistance are wanted.

References

- [1] M. A. Abd Elaty, M. F. Ghazy, and M. F. Abd El Hameed, "Optimization of Geopolymer concrete by principal component analysis," *ACI Materials Journal*, Vol. 114, No. 2, pp.253-264, 2017.DOI: 10.14359/51689563.
- [2] Parveen, D. Singhal, M. T. Junaid, B. B. Jindal, and A. Mehta, "Mechanical and microstructural properties of fly ash based Geopolymer concrete incorporating alccofine at ambient curing", *Construction and Building Materials*, Vol. 180, pp. 298-307, August 2018.DOI: 10.1016/j.conbuildmat.2018.05.286.
- [3] J. He, "Synthesis and characterization of Geopolymers for infrastructural applications", Ph.D. Thesis, Civil and Environmental Engineering Dept., Louisiana State Univ., USA, 2012.
- [4] M. Adamson, A. Razmjoo, and A. Poursaei, "Durability of concrete incorporating crushed brick as coarse aggregate," *Construction and Building Materials*, Vol. 94, pp. 426-432, July, 2015.DOI: 10.1016/j.conbuildmat.2015.07.056.
- [5] R. Sharma, and P. P. Bansal, "Use of different forms of waste plastic in concrete – A review," *Journal of Cleaner Production*, Vol. 112, part 1 , pp. 473- 482, 2016.DOI: 10.1016/j.jclepro.2015.08.042.
- [6] United Nations Environment Programme (UNEP), "Single-use plastics: A road map for sustainability," 2018.
- [7] Kewall, S. K. Sharma, and H. Gupta, "Development of paver block by using foundry sand based Geopolymer concrete," *Journal of Today's Ideas – Tomorrow's Technologies*, Vol. 3, No. 2, pp. 129–144, December, 2015.DOI: 10.15415/jotitt.2015.32009.
- [8] R. Muhammed and D. Varkey, "An experimental study on fly ash based Geopolymer pavement block with polypropylene fiber", *International Journal of Innovative Science, Engineering & Technology*, Vol. 3, Issue 8, pp. 548-553, 2016.
- [9] B. S. Mohammed, M. S. Liewa, W. S. Alaloula, A. Al-Fakiha, W. Ibrahima and M. Adamua, "Development of rubberized Geopolymer interlocking bricks", *Case Studies in Construction Materials*, Vol. 8, pp. 401-408, 2018.DOI:10.1016/j.cscm.2018.03.007.
- [10] Iraqi specification No.1606 (IQ.S 1606) "Concrete pavement bricks," Central Organization for Standardization and Quality Control, Bagdad, 2006.
- [11] ASTM C618, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete," American Society for Testing and Materials, 2017.
- [12] Iraqi specification No.45 (IQ.S 45) "Aggregate from Natural Sources for Concrete and Construction," Central Organization for Standardization and Quality Control, Bagdad, 1984.
- [13] W. I. Khalil, Q. J. Frayyeh, and M. F. Ahmed, "Evaluation of sustainable Metakaolin-Geopolymer concrete with crushed waste clay brick", *The 2nd int. conference on sustainable engineering techniques- ICSET*, Baghdad, Iraq, 2019. DOI:10.1088/1757-899X/518/2/022053.
- [14] W. I. Khalil, Q. J. Frayyeh, and M. F. Ahmed, "Sustainable Metakaolin-based Geopolymer concrete with waste plastic aggregate," *The 4th int. sustainable buildings symposium-ISBS*, Dallas, Texas, USA, 2019.DOI: <http://dx.doi.org/10.5772/intechopen.87836>

- [15] M. F. Ahmed, W. I. Khalil, and Q. J. Frayyeh, "Blended Metakaolin and waste clay brick powder as source material in sustainable Geopolymer concrete," 10th int. structural engineering and construction conference-(ISEC 10), Chicago, United States, May 20-25, 2019. DOI: 10.14455/ISEC.res.2019.31.
- [16] BS EN 1338, "Concrete paving blocks — Requirements and test methods," British Standard, 2003.
- [17] K. J. Khalaf, "Studying the utilization of polymeric wastes to produce sustainable concrete," MSc. Thesis, Building & Construction Dept., Univ. of Technology, Iraq, 2015.