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Studying the Possibility of Producing Paving Flags from Geopolymer Concrete Containing Local Wastes

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HIGHLIGHTS

- Producing paving flags from modified MK-based GPC and containing different waste materials according to IQS 1107
- Studying properties of GPC paving flags that contain recycled rubber wastes and/or steel fibers from the damaged tires
- Rupture load, weight, and total flexural energy are improved for GPC paving flags by including waste materials
- Achieving sustainability by using GPC without cement, and they save the environment from damaged tire waste

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ABSTRACT

Geopolymer concrete is an inorganic composite material created by interacting alkaline substances with an aluminosilicate source and aggregate. Precast building units are considered the most prominent uses of geopolymer concrete, and the utilization of recycled steel fibres and rubber from damaged tires that are non-biodegradable to reduce environmental pollution. The results of this investigation show the possibility of using geopolymer concrete with and without the inclusion of crumbed rubber and recycled steel fibers from damaged tires in the production of paving flags with dimensions of 400 × 200 × 50 mm class c according to IQS 1107. Four types of geopolymer concrete flags were prepared, including flag specimens without wastes, flag specimens reinforced with recycled steel fibres waste from damaged car tires with a volume fraction of 0.125%, flag specimens containing 10% crumbed rubber waste aggregate as a partial volumetric replacement to natural coarse aggregate, as well as flag specimens containing two wastes of 10% crumbed rubber as a partial replacement to natural coarse aggregate and 0.125% recycled steel fibres. The experimental tests illustrate that it is possible to reduce the thickness from 50 mm to 35 mm of the paving flags to reduce their weight and cost. In addition, it was discovered that the total flexural energy of paving flags containing recycled steel fibers and rubber aggregate wastes increased by 390% and 271%, respectively, concerning paving flags without wastes. The failure modes changed from brittle to ductile when these wastes were used.

1. Introduction

Geopolymer concrete is a sustainable material. It doesn't require cement, which leads to significant pollution and depletion of natural resources. Geopolymer concrete (GPC) is suited for producing sustainable precast concrete units due to its quick strength development. Precast concrete paving flags have been popular for 100 years. They are used to pave pedestrian walkways, gardens, and other places and range in size from 300 x 300 mm to 600 × 900 mm [1].

Due to the methods used in most of Iraq's manufacturing facilities, the quality of the raw materials used to make paving flags, the precision with which mixing proportions are done, and the curing, the likelihood of getting good and acceptable flags is limited. This research developed a new method to produce sustainable geopolymer concrete pavement flags using 10% recycled crumb rubber and 0.125% volume fraction of recycled tire steel fibers. Generally, very limited studies were conducted to produce different geopolymer concrete building units and investigate their behavior.

The mechanical properties of geopolymer paving blocks based on fly ash and alkali solution (sodium silicate/sodium hydroxide of 2.5, and the ratio of alkali solution/fly ash of 0.35), which were reinforced with polypropylene fibres (0.1-0.5% by volume), were studied by Mohammed and Varkey [2]. Coarse aggregate with a maximum size of 10 mm, fine aggregate with a size of less than 4.64 mm, and a fly ash binder with quantities of 350, 636, and 1060 kg/m^3 reinforced with 0.1, 0.2, 0.3, 0.4, and 0.5% by volume of polypropylene fibre, were used. The test specimens were placed at room temperature for two days (a rest period), and then the steam thermal treatment was carried out at 60°C for 24 hours. After that, the specimens were left in the room until the test time. The test results indicate that adding 0.2% polypropylene fibres improves abrasion resistance and flexural strength at 28 days.

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Mohammed et al. [3], developed rubber geopolymer bricks using crumb rubber waste prepared from scrap tires. The ratio of fly ash to the crumb rubber was fixed at (1:1) (250:250 kg/m^3). The surface response program (RSM) Design Experts software was used to determine the number of trial mixes adopted in the design of the geopolymer mixture for several variables, including the concentration of sodium hydroxide and the ratio of alkali solution/fly ash, based on that, the target compressive strength of the bricks, sodium hydroxide concentration, and alkali/fly ash ratio was 4 MPa, 18M and 0.8 respectively, which represents the optimum mix design. The properties studied include compressive, flexural strength, absorption, efflorescence, dimensions, and modulus of rupture. The results show that the compressive and flexural strength were decreased, while the water absorption increased for the geopolymer bricks with crumb rubber. The bricks were classified as Class 3, used in non-bearing structural members such as partitions.

Rachel [4], produced blocks (solid and hollow) from geopolymer concrete based on fly ash with different concentrations of sodium hydroxide (8, 10, 12, and 14 M) and with an alkali solution/solid ratio of 0.4, the ratio of sodium silicate to sodium hydroxide was 2.5. The mixture proportion of geopolymer concrete was 1:1.1:2.6, fly ash: fine aggregate: coarse aggregate. The results show that the compressive and splitting strengths were increased with increasing sodium hydroxide concentration and the specimens' age. The compressive strength of the solid geopolymer block at 60°C temperature was 36.96 MPa, while the compressive strength of the hollow geopolymer block was 22.14 MPa.

Niphadkar [5], investigated geopolymer concrete masonry blocks against cement blocks. Two mixtures were used to produce the blocks: a cement: sand ratio of 6:1 and water/cement ratio of 0.2, and a geopolymer mixture with fly ash: slag in an 80:20 ratio as a binder and an alkali-activated solution from sodium hydroxide at 14 M and sodium silicate at 0.2. A special machine was used to manually press the block, and its characteristics were studied after 7, 14, and 28 days of treatment. Geopolymer concrete block has a lower density, higher strength, and modulus of elasticity, with maximum strain and lower absorption than cement block. According to previous studies, geopolymer concrete paving flags using different waste components have not been produced or studied. Therefore this study investigates the possibility of producing sustainable, cement-free paving flags from a modified metakaolin-based geopolymer mixture containing recycled crumb rubber waste and/or recycled steel fibers from damaged tires according to Iraqi specification No.1107/87 [6]. Additionally, it reduces tire waste.

2. Experimental Work

2.1 Materials Used

Metakaolin was used after burning the Iraqi kaolin, which was brought from the western region of Iraq (Anbar), burned at 700°C for two hours [7], and ground. The properties of metakaolin are illustrated in Tables 1 and 2. The results show that the metakaolin is compatible with the requirements of American standard ASTM C618 [8] as a natural Pozzolan, class N.

Table 1: Chemical properties of metakaolin *

Components	Results	ASTM C 618 [8]
SiO_2	62.411	
Al_2O_3	35.025	SiO_2+ Al_2O_3+ Fe_2O_3= 98.327
Fe_2O_3	0.890	≥ 70
K_2O	0.909	
TiO_2	0.532	
CaO	0.144	
SO_3	0.026	≤4%
MnO	0.001	
L.O. I	0.71	≤10%

* Tests were carried out in the national center for construction laboratories/Baghdad.

Table 2: Physical properties of metakaolin *

Physical properties	MK	ASTM C 618 [8]
Strength activity index at 7 days	113**	≥75%
Retained on 45µm (%)	18.5	≤34%
Specific surface area (m^2/kg)	14300	--
Specific gravity	2.64	--
Color	White –pinky powder	--

* Tests were carried out in the national center for construction laboratories /Baghdad.

** Tests were carried out in Concrete and Materials Laboratories in University of Technology/Baghdad.

The alkaline solution used in this investigation consists of sodium hydroxide (NaOH) with purity of 99.5 and sodium silicate (Na_2SiO_3) as shown in Table 3.

Table 3: Properties of sodium silicate *

Chemical properties	Value
Na_2O	13.10-13.70
SiO_2	32.00-33.00
SiO_2/ Na_2O	2.4±0.05
Specific gravity	1.534-1.551
Viscosity	600-1200
Appearance	Hazy

* According to manufacturer [9].

Fine aggregate that conforms to Iraqi Standard (IQS) No. 45/2016, zone II [10], was brought from Al-Ukhaidir area. The properties of fine aggregate are shown in Table 4.

Table 4: Properties of natural fine aggregate*

Sieve size (mm) according to IQS No. 23 [11]	Cumulative passing (%)	Limits of IQS No. 45 for zone 2 [10]
10	100	100
5	94	90-100
2.36	82	75-100
1.18	68	55-90
0.6	51	35-59
0.3	27	8-30
0.15	8	0-10
Material passing from sieve 75 µm (%)	3	≤5%
Sulphate content (%)	0.085	≤0.5%
Fineness modulus	2.71	--
Absorption (%)	1.8	--
Specific gravity	2.6	--
Bulk density (kg/m^3)	1744	--

* Tests were carried out in the national center for construction laboratories/ Baghdad.

Coarse aggregate that conforms to Iraqi Standard (IQS) No. 45/2016, with a nominal single size of 10 mm, was brought from Al-Badrh region in Iraq. The properties of coarse aggregate are shown in Table 5. Potable water was used for the alkaline solution and extra water. Superplasticizer (Flocrete SP33) that agrees with ASTM C494 [12]. Types A and F were used. Table 6 shows some properties of this superplasticizer.

Table 5: Properties of natural coarse aggregate*

Cumulative passing (%)		Limits of IQS No. 45 for nominal single size 10 mm [10]
10	97	85-100
5	12	0-25
2.36	--	0-5
Material passing from sieve 75 µm (%)	0.3	≥3
Dry density (kg/m^3)	1627	--
Specific gravity	2.62	--
Absorption (%)	0.6	--
Sulphate content (%)		

* Tests were carried out in the national center for construction laboratories/ Baghdad.

Table 6: Properties of superplasticizer*

Description	
Appearance	Dark brown liquids
Specific gravity	1.17-1.21
Chloride content	Nil
PH	6.5
Recommended dosage	0.8-2.8 L/100 kg binder

* According to manufacturer [13].

Silica fume was brought from the Sika company[14], and it conforms to American Standard ASTM C 1240 [15] . Table 7 shows the properties of the used silica fume.

Calcium oxide used in this investigation is from Karbala factory to produce Al-Noura [16]. The properties of calcium oxide are illustrated in Table 8.

Table 7: Properties of silica fume

Physical properties		
Property	**Results**	**ASTM C1240 [15]**
Specific surface area (m^2/kg)	19200	≥15000
Strength activity index with Portland cement at 7 days (%)	122	≥ 105
Retained on sieve 45 µm, max (%)	9	≤ 10
Specific gravity	2.2	--
Color	Grey	--
Chemical properties *		
Oxides composition	**Results (%)**	**ASTM C1240 [15]**
SiO_2	88.593	≥85
Al_2O_3	--	--
Fe_2O_3	5.564	--
K_2O	4.777	--
TiO_2	--	--
CaO	0.666	--
SO_3	0.027	--
MnO	0.276	--

* Tests were carried out in the national center for construction laboratories/ Baghdad.

Table 8: Properties of calcium oxide*

Physical properties	
Property	**Results**
Specific surface area (m^2/kg)	16351
Specific gravity	3.3
Color	White
Chemical properties	
Oxides composition	**Results (%)**
SiO_2	4.313
Al_2O_3	--
Fe_2O_3	0.462
K_2O	1.666
TiO_2	--
CaO	93.41
SO_3	0.11
MnO	0.024

* Tests were carried out in the national center for construction laboratories/ Baghdad.

Recycling steel fibres (RSF) were brought from Al-Diwaniyah tire recycling plant in Iraq and were subjected to several stages to prepare them for use in geopolymer concrete. Plate 1 shows the recycled steel fibres in this study after recycling. Due to the difference in the lengths and diameters of the fibre extracted from tires, as shown in Plate 2, a statistical analysis was used to find the length and diameter of the fibres [17]. One thousand fibre pieces were taken as a random sample of the fibre used in this study. Their lengths and diameters were recorded using electronic tweezers with an error rate of 0.01 mm. The lengths and diameters were divided into seven and five groups, respectively, and the results are shown in Figure 1 (a and b).

The length of fibres ranged between 4-37mm, with a coefficient of variations of 67%. It can be seen that the recorded length, which includes the largest amount of fibres, was within the level of 30-40 mm by 27.5%, so the average length of the fibres used in this study is 35 mm. The diameter of the fibres was in the range of 0.2-0.35 mm, with a coefficient of variations of 74%. About 29% of fibers have a diameter value of 0.3-0.35 mm, so the average diameter is 0.33 mm.

Plate 1: Recycled Steel Fibre Used in this Investigation

Plate 2: Steel Fibre Geometry and Shape after Recycling

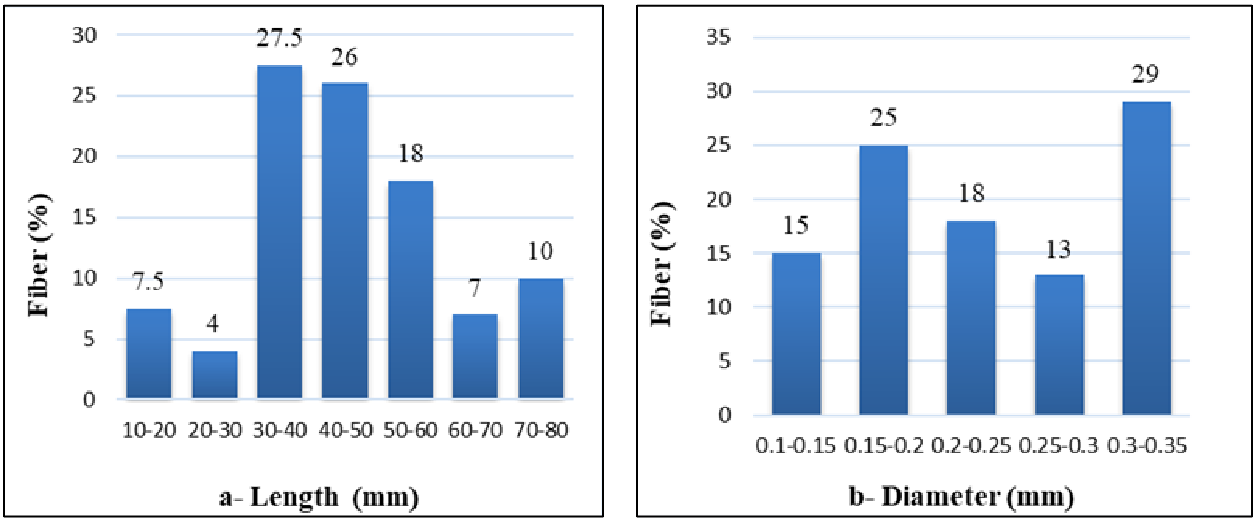

Figure 1: Relative Frequency of Fibres

The fiber aspect ratio is defined as the value obtained from dividing the fibre length and its diameter. The optimum aspect ratio of the fibres ranges from 60-100, while the length ranges from 4-76 m [18]. Increasing the aspect ratio of fibre increases the flexural strength of concrete, but it affects the workability of the mixture. The aspect ratio of the recycled waste fibres in this study was 106 (35/0.33). Experiments were conducted at Baghdad Central Laboratory at the National Center for Structural Laboratories.

Tires crumbed rubber of particle size range of 0.3-18 mm were collected by Al Diwaniyah Tire Recycling Plant in Iraq. The rubber crumbs were sieved on standard sieves to be compatible with the gradation of natural coarse aggregates according to Iraqi specification No.45 [10]. Afterward, the graded rubber crumbs were immersed in a diluted calcium hydroxide solution of 5% concentration for 48 hours to increase the surface roughness and enhance the bond strength between the crumbed rubber surfaces and the geopolymer matrix [19–21], Plate 3 (a-d) illustrate the preparation process for tires rubber waste aggregate. The properties and sieve analysis of tires crumbed rubber waste aggregate are shown in Table 9.

a. Collecting of crumb rubber

b. Washing the crumb rubber by water

c. Sieving the crumb rubber by standered sieves

d. Treatment the crumb rubber by $Ca(OH)_2$

Plate 3: Preparation Process for Tires Rubber Waste Aggregate

Table 9: Properties of Tires Rubber Waste Aggregate after Preparation*

Properties	Results	Specifications
Loose bulk density (kg/m^3)	--	ASTM C 29-15 [22]
Compacted bulk density (kg/m^3)	494	ASTM C 29-15 [22]
Specific gravity	1.10	ASTM C127-15 [23]
Water absorption (%)	4.8	ASTM C 127-15 [23]
	Sieve analysis	
Sieve size (mm)	**Passing (%)**	**IQS 45/2016 Limits for max. size 10 mm [10]**
14	100	100
10	97	85-100
5	12	0-25

2.2 Mixing Proportions, Mixing Process and Preparation of Paving Flags

The geopolymer mixture with 12 molarity of sodium hydroxide was prepared based on previous research and practical experience [7,24–29]. Then, many trials were carried out to choose the optimum mix proportions and the practical age. The metakaolin used in geopolymer concrete was modified by using calcium oxide and silica fumes as a partial replacement to metakaolin weight, then the optimum mix with higher compressive strength was selected; Table 10 gives some trial mixes and optimal geopolymer concrete mix that had the highest compressive strength up to 58 MPa, at the practical age of 7 days under conditions of sun curing during the summer at temperature range between 46℃ at day and 29℃ at night. The Iraqi Standard No. 1107/1987 [6], classified concrete flags according to their dimensions from A to F. The selected dimensions were 400* 200* 50 mm, classified as Class C according to Iraqi specifications. A wooden mold cast paving flag specimens with the required dimensions. The casting was conducted on two layers; each layer was compacted using a vibrating table for 60 seconds. Then, the molds were opened after 24 hours, and the specimens were cured at a temperature range between 46℃ during the day and 29℃ at night. Plates 4 and 5 show some specimens and wooden molds of geopolymer concrete paving flags.

Table 10: Mix Proportions and the Compressive Strength of the Selected Geopolymer Concrete mixture

Mix	GPC Mixture (kg/m^3)									Curing age (days)	Compressive strength (MPa)
	MK	SF	CaO	CA	FA	SS	SH	SP	W		
1	372	21	21	955	632	162	71	8.3	85	7	33.4
2	372	21	21	912	603	201	74	4	50		43.4
3	372	21	21	956	633	176	57	8.3	66		53.5
Optimum	372	21	21	911	603	192	83	4	52		58

MK: Metakaolin, SF: Silica Fume, CaO: Calcium Oxide, CA: Coarse Aggregate, FA: Fine Aggregate, SS: Sodium Silicate, SH: Sodium Hydroxide, SP: Superplasticizer, W: Water.

Plate 4: Wooden Molds used to Produce Geopolymer Concrete Paving Flags

Plate 5: Geopolymer Concrete Paving Flags

3. Results and Discussion

3.1 Rupture Force

Table 11 and Figure 2 show the rupture force for several geopolymer concrete flags prepared in this study. The results indicate that the reference concrete flags without recycled steel fibers and crumbed rubber waste aggregate had a rupture force of 5.12 kN. When adding 0.125% recycled steel fibers, the failure load increased to 6 kN, and the reason is due to the role of the fibers in resisting failure and its transmission, which led to an increase in the failure force; in addition, the reinforcement with recycled steel fibre improves the tensile strength in the flags' tensile zone and enhances their flexural strength [30].

However, the addition of crumbed rubber waste aggregate decreased the failure load to 4.5 kN, but it remained within the requirements of the Iraqi specification No. 1107/87 (not less than 4.4 kN). This is due to voids and the lack of bonding between the rubber surface and the geopolymer paste [6]. The results also indicate that reducing the thickness of the geopolymer concrete flags with 10% waste rubber and 0.125% waste steel fibers from 50 mm to 35 mm slightly decreases the maximum fractured force. However, it is still within the limits of the Iraqi specification. The reduction of flag thickness reduces the product's weight and cost. It can be concluded that the reduction of paving flags thickness to 25 mm causes a reduction in the rupture load to 3.2 kN, which is lower than that specified by Iraqi specifications.

Table 11: Details of Geopolymer Concrete Flags Tests*

Flag symbol	**Mixture definition**	**Dimensions (mm)**	**Rupture force** (kN)**	**Absorp. (½ hr.) (%)**	**Absorp. (24 hr.) (%)**	**Weight (g)**
R	GPC without waste	400×200×50	5.12	3.95	6.52	8446
PF	GPC with 0.125% fibres	400×200×50	6	3.31	6.46	8518
PT	GPC with 10% rubber aggregate	400×200×50	4.5	3.85	6.23	8000
PFT	GPC with 10% rubber aggregate and 0.125% fibres	400×200×50	4.88	4.0	6.6	8055
PF35	GPC with 10% rubber and 0.125% fibers of 35 mm thickness	400×200×35	4.5	3.37	5.94	6545
PF25	GPC with 10% rubber and 0.125% fibres, of 25 mm thickness	400×200×25	3.2	3.10	5.55	5009
Limits of IQS 1107/1987 Type C		400×200×50 ± (2×2×3)	4.4	4%	10%	--

* The experimental tests were conducted at Baghdad Central Laboratory at the National Center for Structural Laboratories.
** The experimental tests were conducted at the University of Technology/ Baghdad.

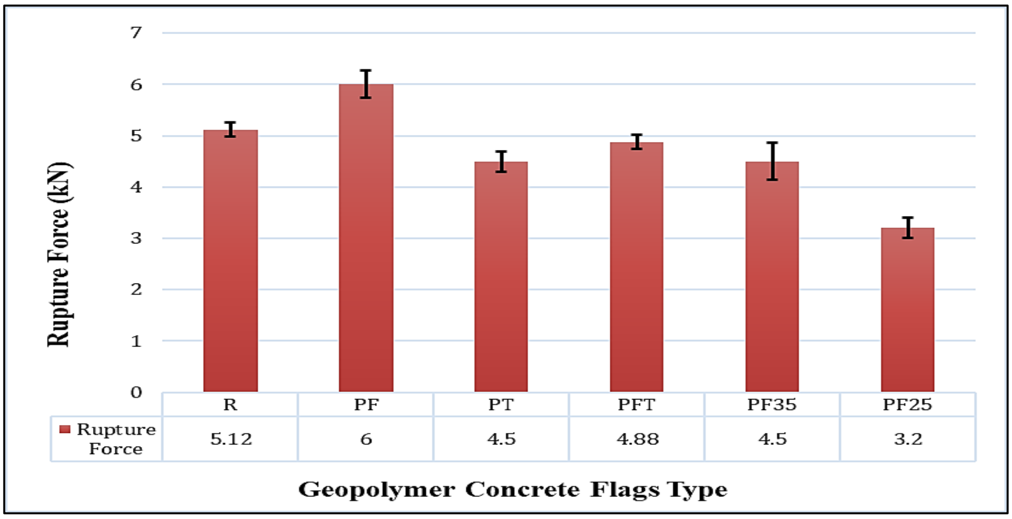

Figure 2: Effect of Crumbed Rubber Waste Aggregate and Recycle Steel Fibres on the Rupture Force of Geopolymer Concrete Paving Flags

3.2 Load- Deflection Relationship

Figure 3 provides a visual representation of the load-deflection relationships for paving flags specimens with various thicknesses reinforced with 0.125% recycled steel fibres waste, containing only 10% crumb rubber aggregate waste, or both types of waste. It can be seen from the shape of the load-deflection curve for the reference geopolymer concrete flag specimen without any waste material that there is a slight strain after the load reaches the failure load. A sudden drop in the curve occurs. When using 10% crumb rubber aggregate, the deflection increases dramatically after failure load, and the shape of the load-deflection curve changes so that the decline of the curve after failure is gradual, and this is a result of high energy absorption by the crumbed rubber waste aggregate despite the decrease in rupture load [31,32]. Also, when adding 0.125% recycled steel fibres, the shape of the curve is the same as the curve in the presence of 10% rubber, but with higher rupture load and greater deflection. This explains the role of fibre in transferring the load and changing the shape of the load-deflection curve [33–36].

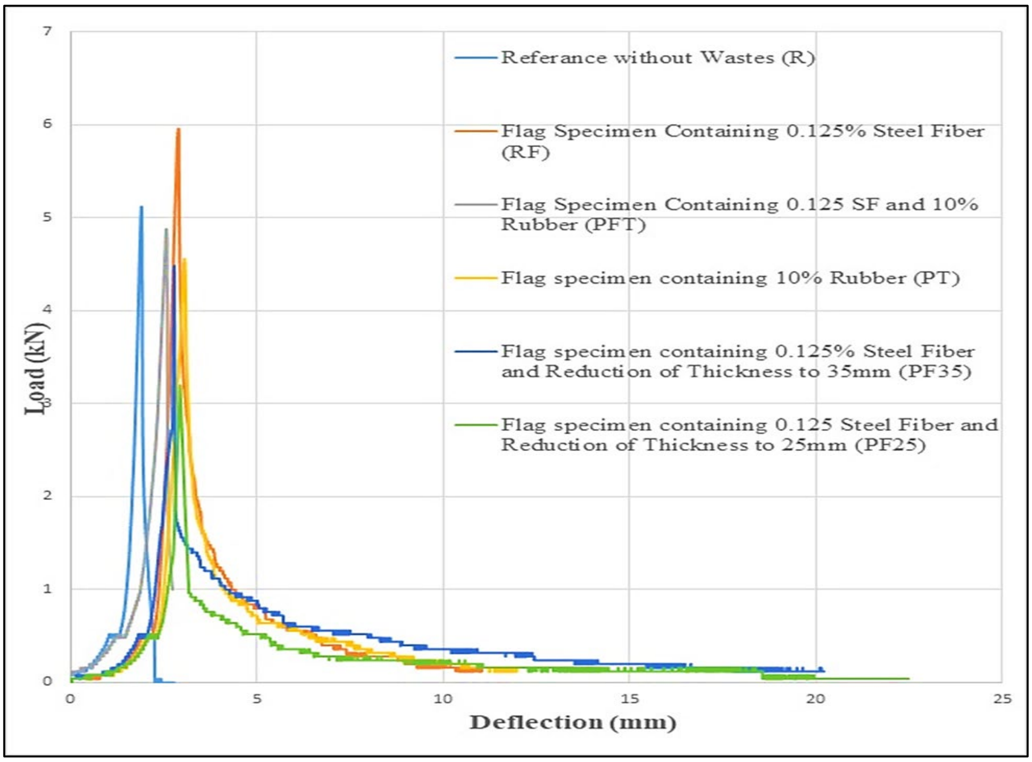

Figure 3: Load-deflection Curves for Geopolymer Concrete Paving Flags with Different Thicknesses Containing Recycle Steel Fibres and/or Crumbed Rubber Wate Aggregate

3.3 Total Flexural Energy

When bent, total flexural energy is the total area under a material's load-deflection curve [37]. Figure 4 shows a significant increase in the total flexural energy for the paving flags containing 0.125% recycled steel fibers or 10% rubber crumb separately, by about 390% or 271%, respectively, compared with the reference paving flags without wastes. Regarding the paving flags containing crumbed rubber waste aggregate, according to Ismail and Al Hashmi's findings [38], this improvement results from pulverized rubber aggregate's ability to absorb more energy than natural aggregate. As for recycled steel fiber the reason for this is due to the role of both the fibers and the rubber in restricting the resulting microcracks and transferring the load, but the role of the fiber work has a higher effectiveness than the rubber because of the high stiffness of the steel fibers compared to the crumbed rubber [39]. In any case, there is a decrease in the total energy when using steel fibers and crumbed rubber together, compared with specimens containing either crumbed rubber waste aggregate or recycled steel fibers. However, it is still higher than that for reference specimens without waste. This may be due to the presence of more voids in the geopolymer concrete microstructure in the case of using steel fibers and rubber together due to the lack of workability, leading to inappropriate compaction.

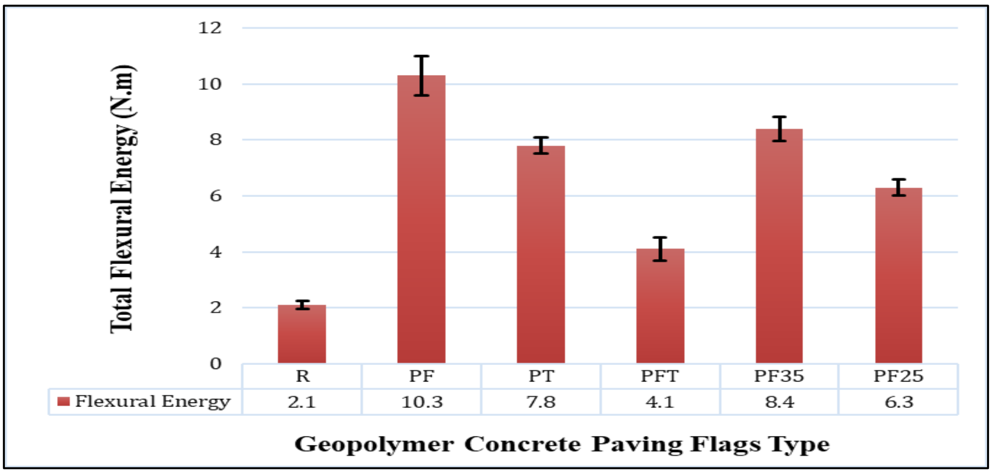

Figure 4: Effect of Crumbed Rubber Waste Aggregate and Recycle Steel Fibres on the Total Flexural Energy of Geopolymer Concrete Paving Flags

3.4 Failure Mode

Plate 6 shows the failure mode for the geopolymer concrete paving flags. It can be illustrated that the reference specimen that was not containing wastes shows a brittle failure; the geopolymeric flag specimen was divided into two separate parts; generally, this is the nature of concrete, as it does not bear the internal tensile forces, and therefore there is no significant strain after the load exceeds the maximum load of failure. Geopolymer concrete paving flags containing waste steel fibres or crumbed rubber aggregate showed a ductile failure, as the geopolymer concrete flags were not separated into two parts. In addition, flag specimens bear the stress imposed on them after failure, which indicates the fibers' role in transforming the failure from brittle to ductile. All specimens containing recycled steel fibre shown in Plate 6 (a-d) demonstrate that recycled steel fibres failed by debonding (pullout), which far exceeds the failure of the geopolymer matrix.

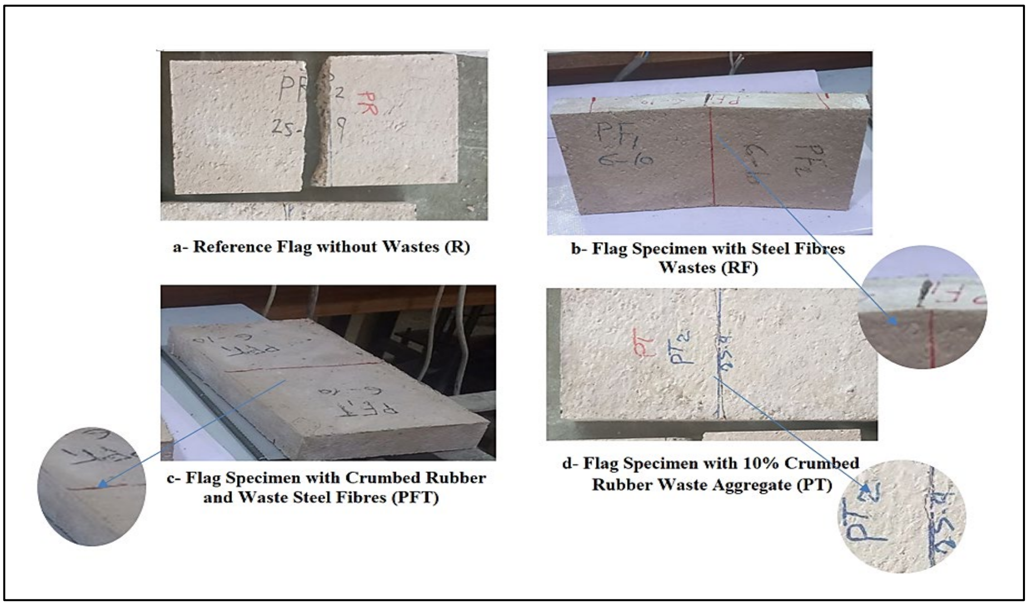

Plate 6: Failure Mode for Different Geopolymer Concrete Paving Flag Specimens

3.5 Water Absorption

In addition to the flexural force requirement, the durability requirements for geopolymer concrete paving flags must also be met the specification requirements. The use of a water absorption test may evaluate this criterion's compliance. The results of this investigation concerning the water absorption capacity of geopolymer concrete flags are shown in Table 11 and Figure 5. All paving flag specimens prepared in this investigation have water absorption values lower than the limitations of Iraqi Specification No.1107/1987 [6]. The results show a slight decrease in the absorption of the samples containing crumbed rubber wastes or recycled steel fibers relative to the reference without wastes. The maximum and minimum absorption for 0.5 hr. and 24 hr. were 3.1 and 4%; 6.6 and 6.46% for flags containing 0.125 RSF and flags containing 10% crumb rubber, respectively. This state may be explained by the capacity of recycled steel fibre reinforcement to regulate crack distribution, which reduces the water absorption capacity of geopolymer concrete flags. The ability of geopolymer concrete flags to retain the maximum degree of durability throughout the service life and resist harmful environmental conditions is possible when the absorption capacity of the flags is reduced. However, there is a slight increase in the absorption for paving flags containing crumbed rubber waste aggregate and recycled steel fibers compared to the reference paving flags without waste. This may be due to the increase in the voids due to the redaction of workability and thus increasing the water absorption.

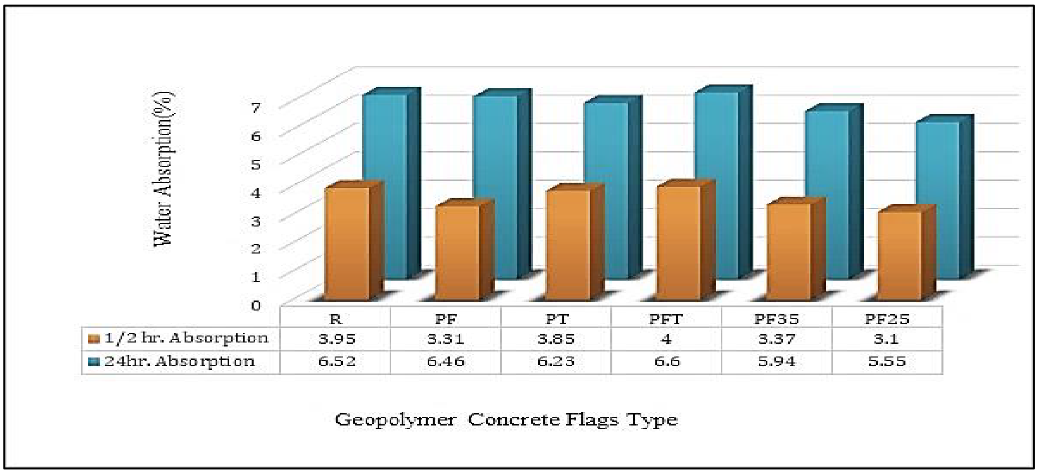

Figure 5: The Amount of Water Absorbed for Various Geopolymer Concrete Paving Flag Specimens

3.6 Weight

The influence of waste rubber and recycled steel fibres (0.125% volume fraction) on the weight of geopolymer concrete paving flags are shown in Table 11 and Figure 6. Also, it is observed that the weight of the geopolymer concrete flags decreases with decreasing paving flags thickness. Generally, the decrease of flag thickness from 50 mm, according to the Iraqi standard No. 1107 [6], to 35 mm causes a reduction in flag weight by around 22.5% of its original weight and 18.7% compared with paving flags with 10% rubber and 0.125% fibers. The results indicate that flags specimens with a thickness of 25 mm did not meet the requirements of the Iraqi specification in terms of the rupture load. The reduction of paving flag thickness from 50 mm to 35mm has a substantial benefit in reducing the quantities of the materials used in producing these flags, the total flag's weight, and the total flag's cost, while these flags are still meeting the requirements of Iraqi specification No.1107 [6].

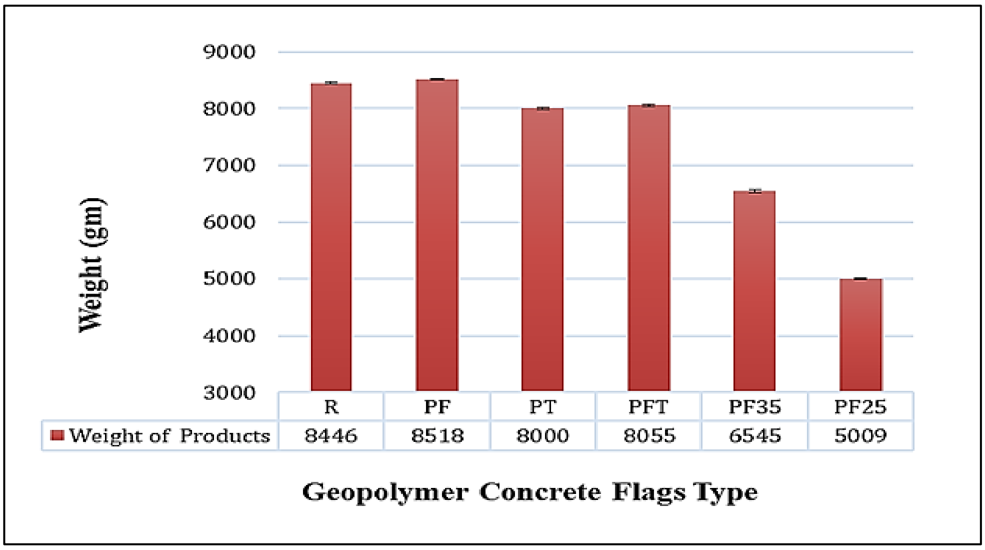

Figure 6: Difference in Weight Between Geopolymer Concrete Paving Flag Specimens

4. Conclusion

The following are the conclusions that may be reached based on the findings and arguments presented in this investigation:

1) It is possible to produce geopolymer concrete paving flags in three ways: without wastes, with 10% crumb rubber waste and/or with 0.125% recycled steel fibre waste that conforms to Iraqi specifications No. 1107.
2) For geopolymer concrete flag specimens with or without 10% crumb rubber aggregate, the inclusion of recycled tire steel fibres of 0.125% volume fraction in geopolymer concrete significantly improves the rupture load of the produced geopolymer concrete paving flags.
3) By incorporating 0.125% recycled steel fibre volume fraction, the thickness of the geopolymer concrete paving flags can be reduced from 50 mm to 35 mm. While these flags still meet Iraqi specification No.1107 requirements, resulting in materials cost and flag weight reduction.
4) Including 10% crumb rubber aggregate and/or 0.125 recycled steel fiber in paving flags improve the total fracture energy and the failure change from brittle to ductile.

Author contributions

Conceptualization, N. Al Obeidy. and W. Khalil; formal analysis, Al Obeidy. and W. Khalil; data curation, Al Obeidy. and W. Khalil; writing—original draft preparation, Al Obeidy. and W. Khalil; writing—review and editing, Al Obeidy. and W. Khalil. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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