Research on Engineering Structures & Materials

journal homepage: http://www.jresm.org

Research Article

Compression strength behaviour of fibre-reinforced concrete made with hoop-shaped waste polyethylene terephthalate fibre

Fadhluhartini Muftah[a], Norizah Omar[b], Ahmad Rasidi Osman[c], Mohd Syahrul Hisyam Mohd Sani[*d]

Civil Engineering Studies, College of Engineering, Universiti Teknologi MARA (UiTM) Cawangan Pahang, Bandar Jengka, Pahang, Malaysia

Article Info

Article history:

Received 28 Jan 2023
Revised 03 Jul 2023
Accepted 29 Jul 2023

Keywords:

Compression Strength Behaviour; Fibre-reinforced Concrete; Waste Polyethylene Terephthalate; Hoop-shaped Fibre; Environmental Problem

Abstract

Fibre-reinforced concrete (FRC) is a special concrete incorporated with fibre that can replace reinforced concrete for utilising in structural applications. FRC with plastic waste fibre is introduced in construction to resolve the corrosion problem of the reinforced steel bar in the concrete, resolve the cracking on the concrete and minimise the environmental problem which occurred due to plastic bottle waste disposal and non-biodegradable material. The main objective of this study is to determine the compression strength behaviour of waste Polyethylene Terephthalate (PET) fibre with hoop-shaped in FRC in percentages of 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7% and 0.8% weight to weight of cement. For that reason, the waste mineral bottle water is collected, cleaned and cut into 100 mm of length and 5 mm of width to propose hoop-shaped waste PET fibre. FRC with waste PET fibre is tested for its workability in fresh conditions and its water absorption and compression strength in hardened conditions. Furthermore, the tensile test is conducted for determining the stress and strain behaviour of waste PET fibre in two conditions; in single and hoop-shaped. From the experimental activity, the waste PET fibre of 0.5% produced the appropriate compression strength value and recorded a percentage difference approximately of 6.33% for 28 days duration as compared with a control mix. In addition, the percentage difference of the water absorption of all mixes is reported to have in the range of 0.25% to 25.96% when compared with the control mix which is tremendously affected the compressive strength.

1. Introduction

For the waste bottle which collected from the mineral water bottle is made of polyethylene terephthalate material. Waste bottle disposal is a known environmental problem faced by all countries in the world now and in the future. This is because the waste bottle is difficult to decompose and not easy to find a landfill site to dump all waste. The waste bottle in the area of dumpsite produced soil pollution, air pollution, water and groundwater pollution and harmful chemical components. Yong et al. [1] reported that the waste product in Malaysia must be managed and organised to ensure the environmental and economic issues can be resolved properly and noted that the waste product with more than 80% was disposed of at dumpsites. Awoyera et al. [2] discussed the effect that occurred due to a high percentage of plastic waste disposal such as drainage blockage which causes the breeding of mosquitoes that are aware of carrying a variety of dangerous diseases and also causes property damage as a result of the massive floods. Yong et al. [1] mentioned about the percentage of solid waste disposal by separating them into 45% of food and organic waste, 13% of plastics, 12% of diapers, 9% of paper and 6% of garden waste. Liang et al. [3] stated that the quantities of plastic waste in industrial solid waste were determined of 42 million

*Corresponding author: msyahrul210@uitm.edu.my
[a] orcid.org/0000-0002-3237-132X; [b] orcid.org/0000-0001-9255-3208; [c] orcid.org/0009-0003-9691-544X; [d] orcid.org/0000-0002-7389-483X
DOI: http://dx.doi.org/10.17515/resm2023.674ma0128

tonnes (Mt) and municipal solid waste of 79 Mt in the Asia region and reported total waste plastic in Malaysia for the years 2016, 2017 and 2018 were 2.45 Mt, 2.60 Mt and 2.65 Mt, respectively. Besides, Khoo et al. [4] recorded that the improper waste management of plastic waste, especially during the coronavirus disease (COVID-19) pandemic resulted in an unexpected surge of plastic waste which influenced human health and environmental impact. Plastic waste is disposed of in landfills (40%), disposed of in incinerators approximately (25%), recycled (16%) and left into the environment without any process (19%) [4].

Therefore, the waste bottle can be resolved technically similar to other waste products by going through the 3R process (Reduce, Reuse and Recycle) but reduce and reuse activity are classified as an impossible way for solving the limited dumping area availability. Undoubtedly, the recycling process is a determinant of a better future to reduce pollution and environmental impact that generally could change the world landscape and affect the lives of future generations. The recycling activity is necessary to reduce air pollution due to open burning, waste dumped into landfills, river and sea pollution due to widespread waste disposal and odour pollution due to unsystematic waste management. Recycling activity also is simple, time and energy-consuming practice that can reduce the utilisation of new resources to make new materials for producing consumer products which are harmless to human health. Khatab et al. [5] stated that plastic waste is split into two categories which are recognised as thermoplastic and thermosetting plastic. Thermoplastic is formed by melting with the heat process and hardening with the cooling process; however, thermosetting plastic cannot melt through the heating process [5]. Examples of thermoplastics include polyethylene terephthalate (PET), polypropylene, high-density polyethylene and polystyrene. Examples of thermosetting plastic are melamine, epoxy resin, polyurethane, silicone, phenolic and unsaturated polyester [5]. Ullah Khan and Ayub [6] stated that PET is used broadly in the world because of its properties such as high strength, thermal endurance, chemical endurance, high strength and damage resistance.

Fibre-reinforced concrete (FRC) is categorised as a special concrete added with fibre and the amount of fibre is referred to as the percentage of overall volume or weight of the concrete. Special concrete with outstanding availability and versatility could reduce the cost, especially in production, material and maintenance and also energy consumption. Additionally, reinforced steel bar in concrete is known in construction activity as having high costs in material production and maintenance. Sometimes, the FRC is also recognised as a composite material with the presence of fibre to increase the structural integrity such as durability, fatigue and deformation aspect. There are a lot of advantages of fibre in concrete such as cracking control, shrinkage control, water permeability reduction, strength improvement, segregation and bleeding reduction and shear capacity increment. Borg et al. [7] mentioned about fibre is not only able to reduce cracking due to shrinkage but affected the service period and also the aesthetics of the structure. The addition of fibre especially polymer or plastic to concrete has been investigated to alleviate structural failure or difficulties such as fractures produced by drying and hydraulic retraction (plastic) [8]. The fibre in concrete has existed in different shapes, sizes, lengths and origin materials for instance steel, carbon, glass, natural and synthetic fibre. Nowadays, FRC is becoming popular for adding in concrete in order to reduce the time of construction and cost of production, maintenance and labour and in applications such as pavement, tunnel lining, slope stabilisation, wall and heavy structure. FRC is suitable to classify into three large groups namely; natural fibre, industrial fibre and synthetic fibre. The selection of the fibre in concrete is depended on the application, design and suitability, for example, steel fibre is not appropriately used at offshore or adjacent to extreme chemical activity.

Fibres are observed in flat and circular conditions and verified their capability by using the aspect ratio (length to diameter ratio) of fibre. FRC can replace the traditional method for concreting the structural element which is known as reinforced concrete by using a steel bar in the concrete. In general, the concrete without reinforced is exposed to large cracks or fractures so the fibre in concrete is proposed as a role to form together to reduce cracks and increased the toughness. Furthermore, the utilisation of fibre in concrete which reacts as reinforcement is a technique to recycle and reuse the waste product for producing better strength. Fibre chosen from the waste product is more practical either from the construction site, residential, agricultural or industrial which produced a lot of environmental problems and incurred high costs to disposal or dumping. Industrial waste which is normally obtained from processing, manufacturing, packaging and engineering activity. The proper approach of handling all wastes is required to minimise the negative impacts on society, the economy and the environment. From the observation, the residential and construction activity which in parallel with the increasing of human population, urbanisation and economic development had generated major waste products in Malaysia. The waste bottle is one of the waste products from the residential. Plastic is the world's third largest waste product source and is collected from plastic bags, bottles, and plastic straws [9]. Chen et al. [9] reported that plastic waste contains bisphenols A (BPA), heavy metals, phthalates and flame retardants which caused the environmental problem and human health abnormalities issue. Ncube et al. [10] reported that plastic is a polymer group material with versatile, low cost and unique properties and is used in food packaging which protected the food from the physical, chemical and biological factors. The fibre in concrete is one of the most significant ways for modifying the brittleness of normal concrete and strengthening the concrete [11].

2. Waste PET Fibre in Concrete

The waste bottle is used in concrete either by replacement or added in such as fibre and fine aggregate. The waste bottle is utilised in normal concrete or special concrete. There are many studies on the waste bottle fibre in special concrete for example high strength concrete [12], self-compacting concrete [13], recycled aggregate concrete [14] and ultra-high-performance green concrete [15]. There are many studies on waste bottles as fine aggregate by Fakoor and Nematzadeh [16], Nematzadeh et al. [17], Noroozi et al. [18] and Colak et al. [19]. Besides, many researchers have discussed the combination of waste plastic fibre with other waste materials as replacing traditional material or as an additive. Bui et al. [14] combined the waste PET fibre with woven plastic sack waste and silica fume. Awoyera et al. [2] studied the waste PET fibre with recycled ceramic tile waste as the sand replacement and other combinations for instance palm oil fuel ash as cement replacement [15]. Many researchers have studied waste plastic fibre in concrete with a variety of plastic origins, dimensions, shapes and aspect ratios. Ganesh Prabhu et al. [20] reported studying the utilisation of waste PET fibre with the proportion of 0.5%, 1.0% and 1.5% of the weight of fine aggregate and with a different aspect ratio of 17, 33 and 50, respectively. Faisal et al. [21] recorded the result of the flexural toughness index of concrete with waste PET fibre in ring-shaped with a width of 5 mm is 23.1% and 10 mm is 39.9% of percentage increment. Usmani and Abdul Awal [22] mentioned about the experimental activity of concrete incorporated with waste PET fibre through a variety of fibre lengths of 10 mm, 20 mm and 30 mm and fibre volume of 0.5%, 1.0% and 1.5%, respectively, for hardened concrete testing of splitting tensile, compressive and flexural strength, and fresh concrete testing of density and workability. Aditya Krishna Reddy and Arun Kumar [23] studied the strength, stiffness, Young's modulus and deformation of the waste PET fibre in concrete with the percentage of cement weight of 0.25%, 0.5% and 0.75% and added superplasticiser in the concrete mix of 0.8% by cement weight. De Luna and Ahmed Shaikh [24] noted the experimental activity to determine the anisotropy and bond behaviour of waste PET fibre in concrete by using pullout, uni-axial tension and three-point flexural. Thomas and Moosvi [25] reported that the result of mechanical and fracture properties of concrete incorporating waste PET fibre of 0.2%, 0.4%, 0.6% and 0.8%, respectively and blended with ordinary Portland cement and metakaolin. Khalid et al. [26] studied the result of the pullout and splitting tensile strength behaviour of FRC made with the addition of waste PET fibre in ring-shaped with widths of 5 mm and 10 mm and compared concrete with synthetic fibre and concrete with waste wires fibre. The ring-shaped or sometimes known as circular and hoop-shaped fibre. Adnan and Dawood [27] stated that concrete with waste PET fibre has shown a decrease in flexural strength but increases the compression strength with 1.5% and 3% of concrete volume. Borg et al. [7] reported that the compression strength of FRC with waste PET fibre either in the straight or deformed condition is reduced by around 0.5% to 8.5% rather than the normal mix and showed that the fibre length of 30 mm provides a better result as compared with the fibre length of 50 mm. The fibre length is not significantly affected the compression strength of the concrete [7].

From the analysis of the literature review, the study on FRC with waste PET fibre is categorised as a study that is still popular nowadays and still ongoing. The size of the waste PET fibre that is normally used is less than 50 mm of length, less than 5 mm of width and added in the FRC with below 1% with various of proportions. There is no information on the previous study which used PET fibre length of more than 50 mm or 100 mm and PET fibre width of 5 mm. The proportion of waste PET fibre in FRC with various proportions with additional of 0.2%, 0.25% and 0.5% but there is an inadequate study with an additional of 0.1%. Additionally, there is no information on added PET fibre in FRC with a complete percentage from the lowest percentage of 0.1% to the highest percentage of 1.0%. The percentage of PET fibre in FRC is calculated based on weight to the weight of cement which is classified as very limited. Additionally, the study on the material and mechanical properties of hoop-shaped PET fibre is still limited and classified as important to ensure the combination of the fibre in FRC is significant. In general, all studies are started with compressive strength before continuing with other testing and thus, the compressive strength data can be considered very important. The main objective of the paper is to determine the compression strength behaviour of FRC with hoop-shaped waste PET fibre in different fibre proportions. The second objective is to determine the surface morphology and mechanical properties of hoop-shaped waste PET fibre before being used in FRC.

3. Specimen Preparation and Experimental Setup

The waste mineral bottle is collected and cleaned from the bottle's surface by using tap water. The specimen of the waste PET fibre is cut into 2 shapes; hoop-shaped (double) and straight (single) shape for the tensile test experiment. The hoop-shaped and straight (single) with 100 mm of length and 5 mm of width is used. The aspect ratio of the waste PET fibre is 20. The fibre is collected from the waste mineral bottle with the same shape and dimension which is chosen only in clear colour and cut accordingly to specific width as shown in Figure 1. The length of the cutting section is based on the circumference of the bottle. The mass of one of the hoop-shaped is 0.5 g. Firstly, the waste PET fibre is tested for determining its surface morphology by using scanning electron microscopy (SEM) and elemental analysis by energy-dispersive x-ray spectroscopy (EDS) technique. A full metallurgical procedure is offered by combining SEM and EDS analysis to provide a thorough chemical composition and elemental investigation.

The traditional materials such as composite Portland cement, natural sand, natural gravel and water are measured accordingly to the weight after calculating based on the density. All concrete ingredients are mixed together and the fibre is added into the mixer slowly at three intervals times to avoid segregation and clotted circumstances. The admixtures especially superplasticiser is not used in the study because to obtain only the solid result of the traditional concrete ingredient with fibres. Concrete with grade 30 and a water-cement ratio of 0.55 is designed and the waste PET fibre is mixed at 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7% and 0.8%, respectively, weight to weight of cement. These proportions are selected based on the study by Thomas and Moosvi [25] which was used with an increment of 0.2% and the highest percentage of the fibre is 0.8%. The percentage of the fibre is referred to as the weight of the cement. The mixture with 0% of fibre is known as the control mix. Three samples are prepared for each mix to make up the total number of specimens of 27. The description of the mixes is tabulated in Table 1. The standard procedure that is used and referred to is BS1881-108:1983 for the workability and water absorption test and BS EN12390-3:2002 for the compression strength test.

Fig. 1 Waste PET fibre

Table 1. The mix of the specimen with different percentages of the fibre

No.	Specimen	Percentage of the fibres in the FRC	Weight of the fibres in the FRC
1	M0	0%	0
2	M1	0.1%	10 g
3	M2	0.2%	20 g
4	M3	0.3%	30 g
5	M4	0.4%	40 g
6	M5	0.5%	50 g
7	M6	0.6%	60 g
8	M7	0.7%	70 g
9	M8	0.8%	80 g

The tensile test of the fibre is conducted using a universal testing machine (UTM) loaded with 100 kN load capacity with 0.5 mm/min. The ultimate load and deformation at the ultimate load of the fibre are investigated. The resulting stress versus strain graph of the fibre is analysed. The testing is important for checking the strength due to the bonding criteria before mixing with other concrete ingredients. The testing of the concrete is divided into fresh concrete conditions and hardened concrete conditions. For the fresh concrete condition, the workability test by using the slump test is conducted to obtain the height of the slump. Whilst, the testing of the hardened concrete condition is separated into two categories; water absorption test and compression strength of the FRC. The size of the cube mould of 150 mm × 150 mm × 150 mm is prepared for the compression strength. The compression strength test is utilised in the compression machine with a capacity of 2000 kN for determining the ultimate load and compression strength value. The compression strength test is conducted on samples curing ageing for 7 days (early strength) and for 28 days (mature strength).

4. Result and Discussion

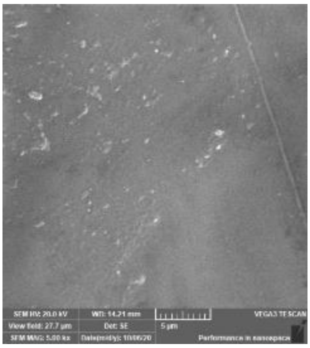
The result and discussion of the study are divided into four parts including surface morphology and elemental analysis of waste PET fibre, mechanical properties of hoop-shaped waste PET fibre, workability of the FRC in fresh conditions, and water absorption and compression strength of the FRC in the hardened condition.

4.1 Surface Morphology and Elemental Analysis of Waste PET Fibre

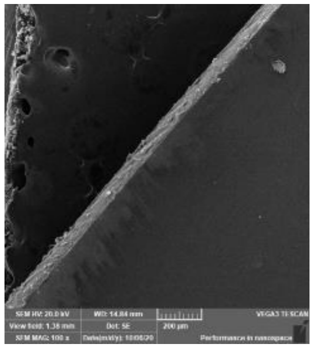
The surface morphology of the waste PET fibre is observed on the flat surface and the surface of the cut section by using the SEM micrograph. From the SEM micrograph, the analysis of the various materials for surface and surface fractures due to cut activity is completely reported by providing a high-resolution image. Whilst, EDS analysis is reported to provide additional thoughtful of the surface material through the SEM analysis process. The SEM micrograph on the flat surface of waste PET fibre is recorded to have a smooth surface, unfluctuating in terms of elevation and without any hilly conditions as shown in Figure 2(a). Furthermore, the SEM micrograph on the cut section of waste PET fibre is the smooth conditions on the nearest part of the cut section but the cut section region is stated to have an irregular condition as shown in Figure 2 (b) and Figure 2 (c). Figure 2 (c) is illustrated a grainy surface more clearly like a living fungus when compared to Figure 2 (b). This is because there are elements attached before cutting that have been damaged and caused high friction in that area. This condition is shown that it is very suitable when combined with other concrete materials and improved the bond with each other, especially sand and cement. Figure 3 (a) and Figure 3 (b) illustrate the EDS elemental analysis graph for a flat surface and cut section, respectively. The major element which detected in EDS is carbon and oxygen for a flat surface and cut section region as tabulated in Table 2. The percentage difference between the element carbon and oxygen for the flat surface is 54.61% and the cut section is 48.00%. The objective of the surface morphology and elemental analysis of the waste PET fibre is to ensure the waste PET fibre is appropriate when combined with other concrete ingredients.

4.2 Mechanical Properties of Hoop-shaped Waste Polyethylene Terephthalate (PET) Fibre

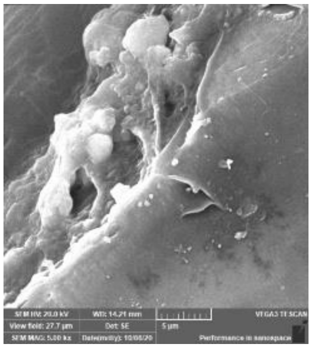
The ultimate load of the single and double (hoop-shaped) waste PET fibre is 91.773 kN and 236.195 kN, respectively. The result of the mechanical properties of the tensile test is shown in Figure 4. From the stress and strain graph, the single waste PET fibre obtained a low value of ultimate stress with 107.97 MPa when compared with double of hoop-shaped waste PET fibre of 138.94 MPa. The percentage of the difference between single and double (hoop-shaped) waste PET fibre is 22.29%. The strain of the ultimate load of a single waste PET fibre is 0.0234 mm/mm and the double of waste PET waste or hoop-shaped is 0.0397 mm/mm. The percentage difference between single and double (hoop-shaped) is e 41.06%. The elastic modulus (E) of the single and double (hoop-shaped) waste PET fibre is 6.50 GPa and 4.66 GPa, respectively. The elastic modulus of the waste PET fibre with 50 mm of length, 1 mm of diameter and an aspect ratio of 50 is 3.10 GPa (Awoyera et al., 2021). Lastly, the waste PET fibre in double (hoop-shaped) which produced good results is suitable for adding in the FRC and increasing the bond strength between the fibre and concrete material. This is because the hoop-shaped is reported to have two parts and every part has played its role and produced its own initial stress to sustain the tensile load from outside.



(a)



(b)



(c)

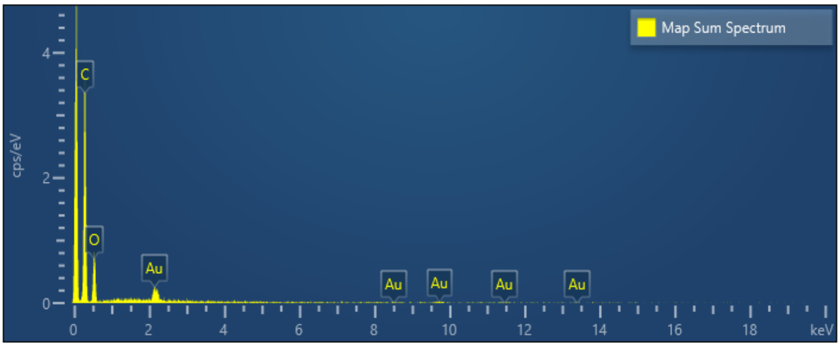
Fig. 2 Surface morphology of the waste PET fibre on (a) flat surface with 5 μm scale, (b) cut section with 200 μm scale and (c) cut section with 5 μm scale

Table 2. EDS Elemental analysis of waste PET fibre

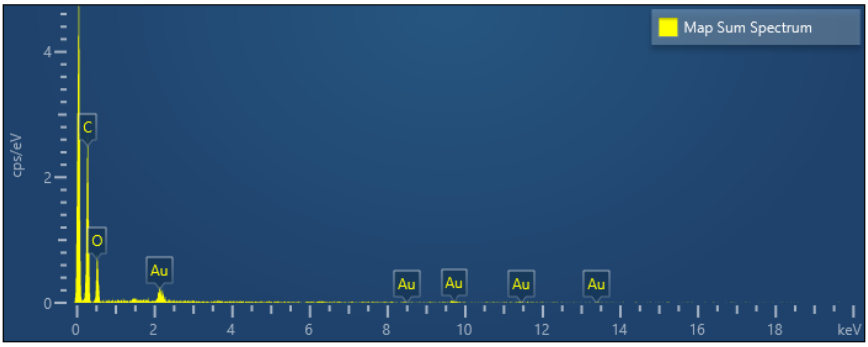
Name of element	Weight (%)	
	Flat Surface	Cut Section
Carbon (C)	68.78	65.79
Oxygen (O)	31.22	34.21

4.3 Workability Test by using Slump Test for Fresh Fibre-reinforced Concrete

The workability of the FRC is important to describe the ability of concrete for mixing, placing and finishing and influenced to strength, appearance and quality of concrete. The process to determine the workability of the FRC is by calculating the height of the slump. Figure 5 illustrates the example of the slump test for different specimens. The workability of the FRC is reduced when the amount of the waste PET fibre increased. The statement is supported by the study by Cui et al. [28] who mentioned about the slump value decreased with an increase in fibre content and length. The study by Nibudey et al. [29] stated the slump decreased with increasing of fibre content and grade of concrete. This situation is due to the waste PET fibre controlling the distribution of the water to overall mixtures. Besides, this fibre is observed to clump during the mixing process, but not too much, although the fibre is added in stages. The height of the slump of the FRC is shown in Figure 6. Smaoui et al. [30] stated that the evidence supports the hypothesis that as the percentage of plastic increases, the density of concrete decreases.



(a)



(b)

Fig. 3 EDS elemental analysis graph of (a) flat surface and (b) cut section.

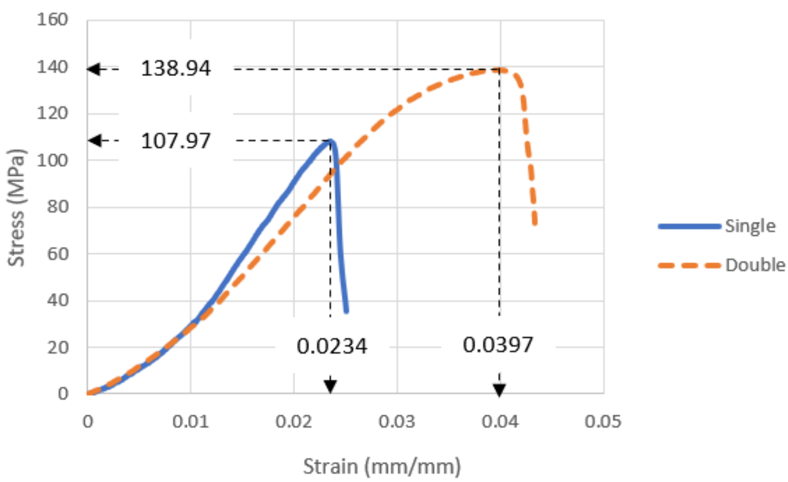


Fig. 4 The result of the stress and strain of the waste PET fibre

(a) (b) (c)

Fig. 5 The slump test of (a) M1 specimen, (b) M6 specimen and (c) M8 specimen

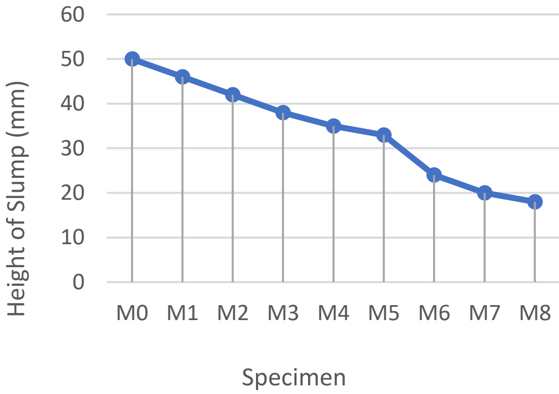


Fig. 6 The result of the slump with the proportion of fibre

The percentage difference between the control mix (M0) and other mixes is reported to have 8% for M1, 16% for M2, 24% for M3, 30% for M4, 34% for M5, 52% for M6, 60% for M7 and 64% for M8, respectively. The workability percentage difference between the highest value of the slump and the lowest value of the slump is 60.87%. The percentage difference between mix and the mix by adding 0.1% of fibre is approximately 8.00% for M0 and M1, 8.70% for M1 and M2, 9.52% for M2 and M3, 7.89% for M3 and M4, 5.71% for M4 and M5, 27.27% for M5 and M6, 16.67% for M6 and M7 and 10.00% for M7 and M8, respectively. From the calculations, the proportion between 0.1% with every mix is reported as below 10% from M1 until M5 but later, the percentage is stated as more than 10%. The degree of workability of the control mix is classified as medium workability and other mixes are categorised as low workability. The low degree of workability is appropriate for applications such as slabs, foundations and pavement.

4.4 Water Absorption Test for Hardened Fibre-reinforced Concrete

The water absorption value of the FRC is shown to increase when the proportion of waste PET fibre increased as illustrated in Figure 7 with a linear relationship. The statement of that water absorption is reduced with increasing of waste PET fibre is proven by the study of Awoyera et al. [2]. Furthermore, 25.77% is reported when comparing the highest value with the lowest value of water absorption. In general, the water absorption for hardened concrete is dependent on the workability of the fresh concrete. When the workability is low, the water absorption is classified as a high condition. Figure 8 shows the percentage difference of the water absorption between each mix with the control mix and between each mix with the mix added by 0.1% of fibre. The percentage difference of all mixes with control mix is recorded to obtain 0.25%, 1.99%, 8.13%, 12.24%, 19.21%, 20.99%, 21.39%, 25.96% for M1, M2, M3, M4, M5, M6, M7 and M8, respectively. The line of the graph for the percentage difference between each mix with the mix added 0.1% of the fibre is shown having a fluctuation and the graph line of the percentage difference between mix with control mix is illustrated having to approach the linear relationship. Thus, the proportion with an additional of 0.1% of the fibre is shown not significant for water absorption in FRC between each mix.

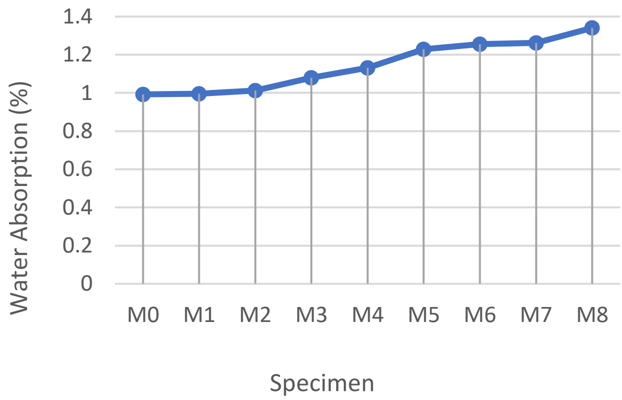


Fig. 7 The water absorption result of the control mix and other mixes

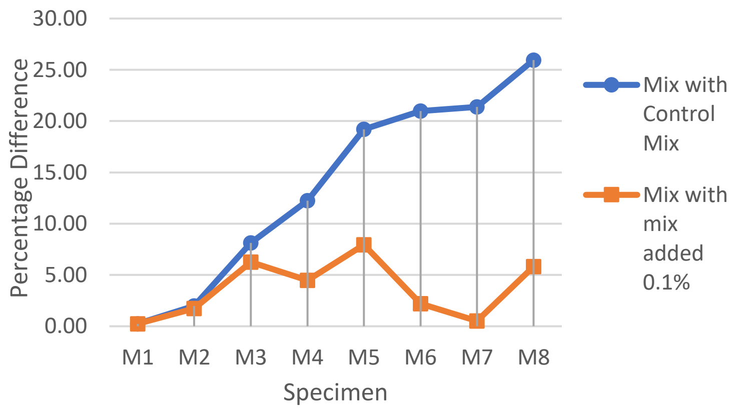


Fig. 8 The percentage difference of the water absorption between each mix with the control mix and between each mix with the mix added 0.1% of fibre

4.5 Compression Strength Test for Hardened Fibre-reinforced Concrete

The ultimate load and compression strength of the FRC at an early and mature age is decreased when the fibre content is increased. This is because the waste PET fibre with high content has affected the bonding between the fibre and other concrete ingredients. Furthermore, the high water absorption has also influenced the compression strength of the FRC. Figure 9 shows the compression strength of the control mix and others mix for 7 days and 28 days. M5 and M8 represented the highest and lowest value, respectively of the compression strength at an early age. The compression strength of the FRC for all mixes at an early stage is stated to obtain less than the control mix and a mix of 0.5% of fibre (M5) is illustrated as the highest value amongst the mix with the percentage difference of 1.86%.

Whilst, the highest value of the percentage difference between the control mix which is more than 10% is reported as 10.30% for M1, 11.66% for M6, 25.23% for M7 and lastly 26.68% for M8. All mixes had not achieved 75% of the design grade. This is because the superplasticiser is excluded in the mixing and the waste PET fibre is kept too long which influenced the problem of clotted fibres.

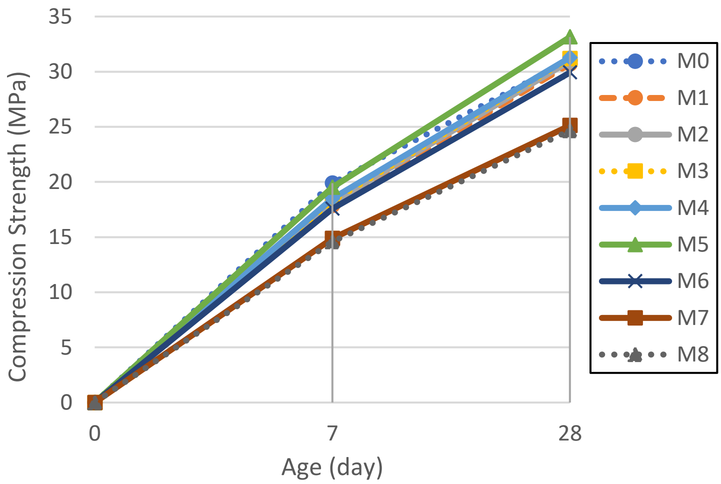


Fig. 9 The compression strength versus curing age relationship

For 28 days duration, the highest value is noted for M5 and the lowest value is reported for M8. All mixes moved slowly to achieve the compression strength at 28 days with more than the design grade except for M6, M7 and M8. Mix with the added fibre of 0.1% and 0.2% at 28 days is reported to have a reduction of compression strength but the compression strength has grown for mix M3 of 0.3% until mix M5 of 0.5%. After the fibre is added more than 0.5%, the compression strength value is decreased as shown in Figure 6. The percentage difference between control mix with M1, M2, M3, M4, M5, M6, M7 and M8 is reported to obtain 1.10%, 0.26%, 0.46%, 0.76%, 6.33%, 3.62%, 19.09% and 20.57%, respectively. Thomas and Moosvi [25] mentioned the fibre added which could improve the compression strength with the maximum fibre of 0.4%. The statement is classified as conservative because 0.5% also produced an increment of the compression strength. Figure 10 illustrates the compression strength with the proportion of waste PET fibre for 7 days and 28 days. The graph pattern of the 7 days and 28 days showed the same pattern and the result of compression strength is in good condition.

5. Comparison Study

The compression study is discussed to verify the result with other previous study results. The comparison study of the compression strength of the FRC with the previous study such as Shinde et al. [31]. The prediction of the compression strength formula by referring to Ojeda [32]. All the compression results of the previous studies are compared by using percentage differences with the result of the experimental. Bui et al. [14] mentioned about the concrete with using waste PET fibre in the proportion of 0.25%, 0.5% and 0.75% and combined with the recycled coarse aggregate and silica fume still produced a reduction in compressive strength. Table 3 tabulates the result of the previous study. The new prediction formula for compression strength at 28 days (f_c), as stated in Eq. (1) by the study of Ojeda [32], is used in the study.

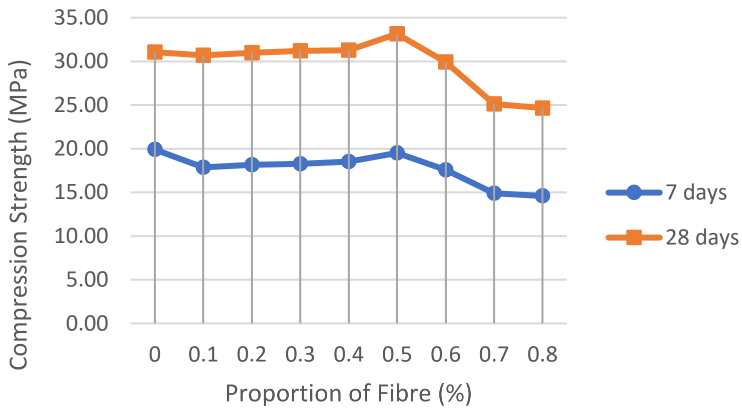


Fig. 10 The compression strength of FRC with waste PET fibre at 7 and 28 days

$$f_c = -31.433w/c - 0.645P + 0.031C + 38.140 \quad (1)$$

where, w/c = water cement ratio, P = plastic content by volume in %, C = cement content (kg/m^3).

Table 3. Description of the previous study on the result of the compression strength

Authors	Description	Proportion of fibre (%)	Compression Strength (MPa)	Percentage Difference (%)	Remarks
Shinde et al. [31]	The FRC with grade 30 and the plasticiser of 0.20% of cement weight is used. The proportion of the fibre with 0.5%, 1.0%, 1.5% and 2.0% of the cement weight is investigated. The length and breadth of the fibre are 50 mm and 2 mm, respectively.	0.5%	25.12 MPa for 7 days and 39.86 MPa for 28 days	22.25% for 7 days and 16.86% for 28 days	The study used a plasticiser in the mixing and the compression strength of the FRC is increased when the fibre is in the percentage of 0.5% and 1.0%. However, the compression strength of the FRC goes down after 1.0%. The percentage difference between 7 days and 28 days is 36.98%. The result showed that more than 0.5% or 1.0% is reported to have a better result compared with other specimens is considered conservative.
Ojeda [32]	The Eq. (1) is used.	0.1%, 0.2%, 0.3%, 0.4% and 0.5%	33.50 MPa, 33.43 MPa, 33.37 MPa, 33.30 MPa and 33.24 MPa	8.35%, 7.40%, 6.52%, 6.07% and 0.30%	The study is compared with the new prediction formula for compression strength at 28 days for 0.1% to 0.5% only. The prediction result of compression strength is calculated and determined the percentage difference. The percentage difference is around 0.3% to 8.35%.

6. Compression and Flexural Strength Relationship

The strength of compression and flexural are often linked. Depending on the particular concrete mix, flexural strength ranges from 10% to 15% of compression strength.

According to standards and previous studies which discussed on the relationship between compression and flexural strength such as the Australian Standard (AS 3600), American Concrete Institute (ACI 363-92) and Smaoui et al. [30], respectively used to determine the prediction of the flexural strength of the concrete. The prediction of the flexural strength of the concrete by referring to Eq. 2 based on AS 3600, Eq. 3 based on ACI 363-92 and Eq. 4 based on a study by Smaoui et al. [30] is used. These equations are important to predict the flexural strength of the concrete without any testing activity or usage of the experiment tool.

$$f_f = 0.6\sqrt{(f_c)} \tag{2}$$

$$f_f = 0.94\sqrt{(f_c)} \tag{3}$$

$$f_f = 5\text{x}10^{-6}(f_c)^{4.0323} \tag{4}$$

where, f_f = flexural strength (MPa).

Figure 11 is shown the result of the prediction of flexural strength by using Eq. 2, Eq. 3 and Eq. 4 from the experimental result of the compression strength of concrete. Eq. 4 is more reliable when compared with other standards.

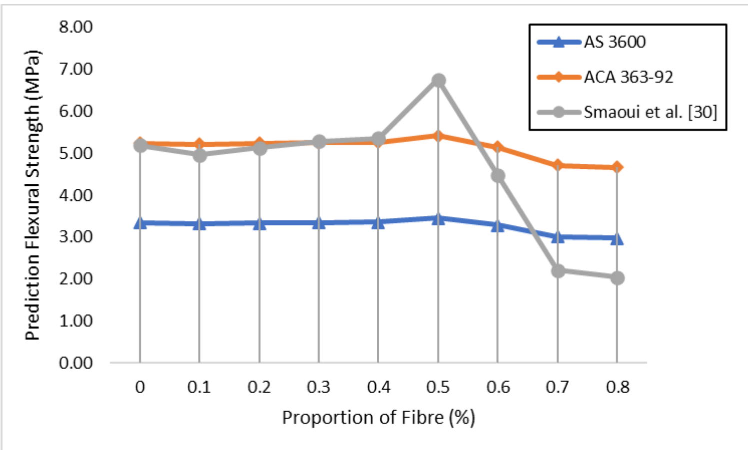


Fig. 11 The prediction flexural strength of all mixes

7. Conclusion

From the observation and analysis of the experimental activity, the following conclusions are drawn and analysed. The ultimate load of the mechanical properties of the fibre in a single shape and hoop-shaped is reported to obtain 91.773 kN and 236.195 kN, respectively. The percentage difference of the ultimate stress between the single shape and hoop-shaped is 22.29%. Furthermore, the strain of the ultimate load and elastic modulus of the hoop-shaped is 0.0397 mm/mm and 4.66 GPa, respectively. The waste PET fibre in hoop-shaped is chosen for adding in the FRC and tightening the bonding between the fibre and other concrete ingredients.

In fresh concrete conditions, the workability of the FRC is reduced when the proportion of the waste PET fibre is increased. All mixes with additional of fibre content are considered as a degree of workability in low conditions and M1 has shown the highest value of the height of slump. The percentage difference between the control mix and M1 is 8.0% and the range from 8% to 65% represents the difference in percentage between the control mix and other mixes. The water absorption of the FRC is decreased by increasing the waste PET fibre content. M1 and M8 have shown the lowest and highest value of water absorption in FRC, respectively.

The compression strength of FRC is determined as less than 75% of the design grade for all mixes and more than 30 MPa for all mixes except for M6, M7 and M8 at 28 days. The compression strength of FRC is reduced when the amount of the waste PET fibre is more than 0.5%. The percentage difference between the control mix with the highest value of the compression strength for 7 days is 1.86% and for 28 days is 6.33%. The excessive water absorption has also had an impact on the compression strength of the FRC. The compression strength data and information are important for further study and to form the structural elements such as beams, columns or slabs.

For further study, the workability, water absorption and compression strength of the FRC will be able to be resolved if using the superplasticiser or nanomaterial as a replacement or additional material. Thus, adding PET fibre to FRC without any modification, alterations or adjustments is not acceptable. The experimental activity especially the mechanical properties could be extended for tensile and flexural strength, and could be investigated the length and width of waste PET fibre in increasing the strength of the FRC.

Acknowledgement

The authors warmly thank the Universiti Teknologi MARA (UiTM) Cawangan Pahang for the facility support. Sincerest gratitude is extended to the staff and faculty members for providing technical advice and to the College of Engineering of Universiti Teknologi MARA (UiTM) Cawangan Pahang, Kampus Jengka for allowing the use of laboratory machines and equipment.

References

[1] Yong ZJ, Bashir MJK, Hassan MS. Biogass and Biofertilizer Production from Organic Fraction Municipal Solid Waste for Sustainable Circular Economy and Environmental Protection in Malaysia. Science of the Total Environment, 2021; 776: 145961. https://doi.org/10.1016/j.scitotenv.2021.145961

[2] Awoyera PO, Olalusi OB, Iweriebo N. Physical, Strength and Microscale Properties of Plastic Fiber-reinforced Concrete Containing Fine Ceramics Particles. Materialia, 2021; 15: 100970. https://doi.org/10.1016/j.mtla.2020.100970

[3] Liang Y, Tan Q, Song Q, Li J. An Analysis of the Plastic Waste Trade and Management in Asia. Waste Management, 2021; 119: 242-253. https://doi.org/10.1016/j.wasman.2020.09.049

[4] Khoo KS, Ho LY, Lim HR, Leong HY, Chew KW. Plastic Waste Associated with the COVID-19 Pandemic: Crisis or Opportunity? Journal of Hazardous Materials, 2021; 417: 126108. https://doi.org/10.1016/j.jhazmat.2021.126108

[5] Khatab HR, Mohammed SJ, Hameed LA. Mechanical Properties of Concrete Contain Waste Fibers of Plastic Straps. IOP Conference Series: Materials Science and Engineering, 2019; 557: 012059. https://doi.org/10.1088/1757-899X/557/1/012059

[6] Ullah Khan S, Ayub T. Flexure and Shear Behaviour of Self-compacting Reinforced Concrete Beams with Polyethylene Terephthalate Fibres and Strips. Structures, 2020; 25: 200-211. https://doi.org/10.1016/j.istruc.2020.02.023

[7] Borg RP, Baldacchino O, Ferrara L. Early Age Performance and Mechanical Characteristics of Recycled PET Fibre Reinforced Concrete. Construction and Building Materials, 2016; 108: 29-47. https://doi.org/10.1016/j.conbuildmat.2016.01.029

[8] Pereira EL, de Oliveira Junior AL, Fineza AG. Optimization of Mechanical Properties in Concrete Reinforced with Fibers from Solid Urban Wastes (PET Bottles) for the Production of Ecological Concrete. Construction and Building Materials, 2017; 149: 837-848. https://doi.org/10.1016/j.conbuildmat.2017.05.148
[9] Chen HL, Nath TK, Chong S, Foo V, Gibbins C, Lechner AM. The Plastic Waste Problem in Malaysia: Management, Recycling and Disposal of Local and Global Plastic Waste. SN Applied Sciences, 2021; 3(437). https://doi.org/10.1007/s42452-021-04234-y
[10] Ncube LK, Ude AU, Ogunmuyiwa EN, Zulkifli R, Beas IN. An Overview of Plastic Waste Generation and Management in Food Packaging Industries. Recycling, 2021; 6(12): 2-25. https://doi.org/10.3390/recycling6010012
[11] Alsadey S. Utilization of Plastic Bottle Waste in Concrete. Journal of Biological and Environmental Engineering, 2016; 1(1): 1-5.
[12] Mohammed AA, Faqe Rahim AA. Experimental Behavior and Analysis of High Strength Concrete Beams Reinforced with PET Waste Fiber. Construction and Building Materials, 2020; 244: 118350. https://doi.org/10.1016/j.conbuildmat.2020.118350
[13] Al-hadithi AI, Noaman AT, Mosleh WK. Mechanical Properties and Impact Behavior of PET Fiber Reinforced Self-compacting Concrete (SCC). Composite Structures, 2019; 224: 111021. https://doi.org/10.1016/j.compstruct.2019.111021
[14] Bui NK, Satomi T, Takahashi H. Recycling Woven Plastic Sack Waste and PET Bottle Waste as Fiber in Recycled Aggregate Concrete: An Experimental Study. Waste Management, 2018; 78: 79-93. https://doi.org/10.1016/j.wasman.2018.05.035
[15] Alani AH, Bunnori NM, Noaman AT, Majid TA. Durability Performance of a Novel Ultra-high-performance PET Green Concrete (UHPPGC). Construction and Building Materials, 2019; 209: 395-405. https://doi.org/10.1016/j.conbuildmat.2019.03.088
[16] Fakoor M, Nematzadeh M. Evaluation of Post-fire Pull-out Behavior of Steel Rebars in High-strength Concrete Containing Waste PET and Steel Fibers: Experimental and Theoretical Study. Construction and Building Materials, 2021; 299: 123917. https://doi.org/10.1016/j.conbuildmat.2021.123917
[17] Nematzadeh M, Shahmansouri AA, Fakoor M. Post-fire Compressive Strength of Recycled PET Aggregate Concrete Reinforced with Steel Fibers: Optimization and Prediction via RSM and GEP. Construction and Building Materials, 2020; 252: 119057. https://doi.org/10.1016/j.conbuildmat.2020.119057
[18] Noroozi R, Shafabakhsh G, Kheyroddin A, Moghaddam AM. Investigating the Effects of Recycled PET Particles, Shredded Recycled Steel Fibers and Metakaolin Powder on the Properties of RCCP. Construction and Building Materials, 2019; 224: 173-187. https://doi.org/10.1016/j.conbuildmat.2019.07.012
[19] Colak AB, Akcaozoglu K, Akcaozoglu S, Beller G. Artificial Intelligence Approach in Predicting the Effect of Elevated Temperature on the Mechanical Properties of PET Aggregate Mortars: An Experimental Study. Arabian Journal for Science and Engineering, 2021; 46 (5): 4867-4881. https://doi.org/10.1007/s13369-020-05280-1
[20] Ganesh Prabhu P, Arun Kumar C, Pandiyaraj R, Rajesh P, Sasi Kumar L. Study on Utilization of Waste Pet Bottle Fiber in Concrete. International Journal of Research in Engineering & Technology, 2014; 2 (5): 233-240.
[21] Faisal SK, Irwan JM, Othman N, Wan Ibrahim MH. Flexural Toughness of Ring-shaped Waste Bottle Fiber Concrete. MATEC Web of Conferences, 2016; 47: 01002. https://doi.org/10.1051/matecconf/20164701002
[22] Usmani MU, Abdul Awal ASM. Physical, Mechanical and Durable Characteristics of Concrete Incorporating Polyethylene Terephthalate Fiber from Bottle Waste. Journal of Critical Review, 2020; 7 (5): 908-916. https://doi.org/10.31838/jcr.07.05.187
[23] Aditya Krishna Reddy K, Arun Kumar C. Study of Mechanical Properties of Concrete using Waste Pet Bottle Fibres for the Reinforcement. International Journal of Engineering and Management Research, 2014; 4 (2): 232-240.

[24] De Luna AM, Ahmed Shaikh FU. Anisotropy and Bond Behaviour of Recycled Polyethylene Terephthalate (PET) Fibre as Concrete Reinforcement. Construction and Building Materials, 2020; 265: 120331. https://doi.org/10.1016/j.conbuildmat.2020.120331
[25] Thomas LM, Moosvi SA. Hardened Properties of Binary Cement Concrete with Recycled PET Bottle Fiber: An Experimental Study. Materials Today: Proceedings, 2020; 32: 632-637. https://doi.org/10.1016/j.matpr.2020.03.025
[26] Khalid FS, Irwan JM, Wan Ibrahim MH, Othman N, Shahidan S. Splitting Tensile and Pullout Behavior of Synthetic Wastes as Fiber-Reinforced Concrete. Construction and Building Materials, 2018; 171: 54-64. https://doi.org/10.1016/j.conbuildmat.2018.03.122
[27] Adnan HM, Dawood AO. Strength Behavior of Reinforced Concrete Beam using Re-cycle of PET Wastes as Synthetic Fibers. Case Studies in Construction Materials, 2020; 13: e00367. https://doi.org/10.1016/j.cscm.2020.e00367
[28] Cui X, Liu G, Wang C, Qi Y. Effects of PET Fibers on Pumpability, Shootability and Mechanical Properties of Wet-mix Shotcrete. Advances in Civil Engineering, 2019: 1-14. https://doi.org/10.1155/2019/2756489
[29] Nibudey RN, Nagarnaik PB, Parbat DK, Pande AM. Compressive Strength and Sorptivity Properties of PET Fiber Reinforced Concrete. International Journal of Advances in Engineering and Technology, 2014; 7 (4): 1206-1216.
[30] Smaoui H, Trabelsi A, Kammoun Z, Aouicha B. Mechanical, Physical, Blast Waves and Ballistic Impact Resistance Properties of a Concrete Incorporating Thermally Treated PET Inclusions. Construction and Building Materials, 2023; 365: 130088. https://doi.org/10.1016/j.conbuildmat.2022.130088
[31] Shinde TR, Kumar VA, Jadhav RM. Comparative Study of Waste Pet Bottle Fibers and Polypropylene Fiber Reinforced Concrete. International Journal for Research in Engineering Application & Management, 2018; Special Issue - ICRTET2018: 854-858.
[32] Ojeda JP. A Meta-analysis on the Use of Plastic Waste as Fibers and Aggregates in Concrete Composites. Construction and Building Materials, 2021; 295: 123420. https://doi.org/10.1016/j.conbuildmat.2021.123420