Journal of Univers https://doi.org/10.26682/sjuod.2022.25.2.45
ity of Duhok., Vol. 25, No.2(Pure and Engineering Sciences), Pp 507-530, 2022

# THE EFFECT OF ADDING WASTE PLASTIC FIBERS ON THE CONCRETE PROPERTIES AND SHEAR STRENGTH OF RC BEAMS: A REVIEW

**A**RI **H**ARBI **R**AFIQ[*] and **Y**AMAN **S**AMI **S**HAREEF **A**L-**K**AMAKi[**]

[*]Faculty of Engineering, Soran University, Erbil, Kurdistan Region-Iraq
[**]Dept. of Civil Engineering, College of Engineering, University of Duhok, Kurdistan Region-Iraq

***(Received: September 22, 2022; Accepted for Publication: November 7, 2022)***

## ABSTRACT

**Plastic waste has been significantly increasing globally. Manufacturing procedures, service sectors, and municipal solid waste all produce a lot of waste plastic items. Concern over the environment and how to dispose of the generated waste has increased due to the rise in plastic waste. Additionally, the use of PET in concrete manufacturing should minimize concerns with plastic waste management and carbon dioxide emissions re-cycling plastic waste, thus replacing the need to dispose of it in a landfill, which has a limited capacity. One alternative is to develop "green concrete" by using plastic waste as a recycled ingredient in concrete buildings. However, before any structure is constructed out of concrete that contains plastic, it is important to know how the use of PET in concrete affects the concrete properties and structural behavior. Especially the shear strength of concrete beams, which is one of the fundamental problems in civil engineering. Therefore, this study serves as an overview of experiments that substituted polyethylene terephthalate (PET) for concrete as a volume ratio additive. It provides information on the mix design and behavior of concrete when PET is utilized.**

***KEYWORDS:*** Plastic Waste; Polyethylene Terephthalate (PET); Green Concrete; Mechanical Properties; Shear; RC Beams.

## 1. INTRODUCTION

Concrete is one of the world's utmost prevalent and widely used construction materials [1]. Per year, around 10 billion tons of concrete are produced worldwide [2]. Such production of concrete is likely to grow to 18 billion tons by 2050 [3]. The concrete industry has a big impact on the environment and is a key consumer of natural resources around the world [4]. However, while the use of concrete cannot be strictly limited, there are several ways to minimize its environmental impact. Whatever type of concrete is used, whether low, normal, or high strength, the freshly mixed concrete must be plastic or semi-fluid in nature to be molded by hand or mechanically. Concrete with a predetermined compressive strength for a plan of (55 MPa) or more is considered high-strength concrete (HSC) [5].

In past years, high-rise structures were required to utilize high-strength concrete to limit the size of members and the weight on lower stories. Furthermore, due to its low permeability, HSC performs well in hazardous conditions, allowing it to be used safely in marine projects while lowering maintenance costs. However, the main disadvantage of HSC is that it is likely to be brittle when compared to normal-strength concrete (NSC), which limits its application. This means that concrete samples including beams could be very brittle if not adequately reinforced. Furthermore, silica fume is a basic ingredient for producing HSC due to its high pozzolanic activity, yet, it makes the sample more brittle [6]. As a result, researchers could address the goal of improving ductility in the field investigation, as some research revealed that employing different lengths and types of fiber increased HSC ductility [7, 8]. Some investigations revealed to improve HSC ductility by reinforcing the matrix with small discrete fibers and randomly oriented fibers to prevent brittleness [9]. When concrete begins to crack, fibers carry stress from one side of the crack to the other, resulting in prolonged crack development or improved ductility under shear loads [10].

Waste products have been generated as a result of new technologies and human lifestyles.



ahr460h@cive.soran.edu.iq

Plastics are in high demand around the world due to their benefits, such as their appropriateness for usage and cheaper cost. In recent years, it has been observed that overstocked large quantities of waste plastic all over the world [11].

Several years ago, the world produced 348 million tons of plastics, out of which 64.4 million tons were generated in Europe. Only around 25% of plastic waste worldwide is recycled. Thus recovering and recycling plastics is still unproductive, and millions of tons end up every year in landfills and oceans [12]. Thus, plastic waste has become a source of threat to the environment of modern civilization as the plastic materials are non-biodegradable and comprise toxic compounds, especially cadmium and lead, that mix with the rainwater and pollute the rivers, seas, oceans, and the soil in the case of burial it, also, to restore to the natural cycle, it will take hundreds of years [13].

The bulk of such solid waste was deposited in waste dump sites. The disposal of it requires effort and cost, as well as environmental pollution by poisonous gases, including dioxins as a result of burning various types of plastic. This signifies that this waste handling is unfavorable because it is a harmful activity to the environment. As a result, a new approach to sustainable development is required, something that can maximize solid waste removal, reuse, and recycling [14, 15]. Therefore, numerous investigations have been undertaken to reuse each kind of waste.

The study aims to examine the fresh concrete properties in addition to the hardened properties of HSC comprising PET waste fiber. In addition, the effect of different ratios of PET waste fiber added to concrete on the concrete material properties will be investigated. Furthermore, the performance of HS RC beams containing fiber derived from PET plastic waste will be addressed.

## 2. SIGNIFICANCE OF STUDY

Reusing plastic with other components is a better solution to minimize the effect of plastic on the environment to create products with more advanced features than their original form. One of these products is concrete [16]. The statistics of the U.S. Environmental Protection Agency (EPA) for 52 years displayed that the level of recycling plastic is inconsistent with the rate of its production, where plastic manufacture in the year 2012 reached approximately 31.75 million tons, in contrast, only 2.8 million tons were treated, which means 9.1% from the entire production of plastic as presented in F.g.(1. [17]. Thus, recovering and recycling plastics is still inefficient. Plastic waste is generated every year in regions shown in Fig. **(2** [18].

The utilization of renewable materials has recently been detected in many sectors because of economic and environmental reasons, in which the utilization of recycled plastic is a significant step toward sustainability. Fiber-reinforced concrete has a higher tensile strength than non-reinforced concrete. It improves the concrete's long-term durability. It improves impact strength and slows the spread of cracks. The viability of various concrete mix design alternatives for restoring the shear strength capabilities of RC beams comprising PET waste inclusions is examined in this research. A follow-up study presents a comprehensive study of the effects of adding PET fiber on concrete properties and the shear strength of RC beams. Such information could be useful in promoting the usage of post-consumer plastics in structural concrete grades with medium-to-high strength.

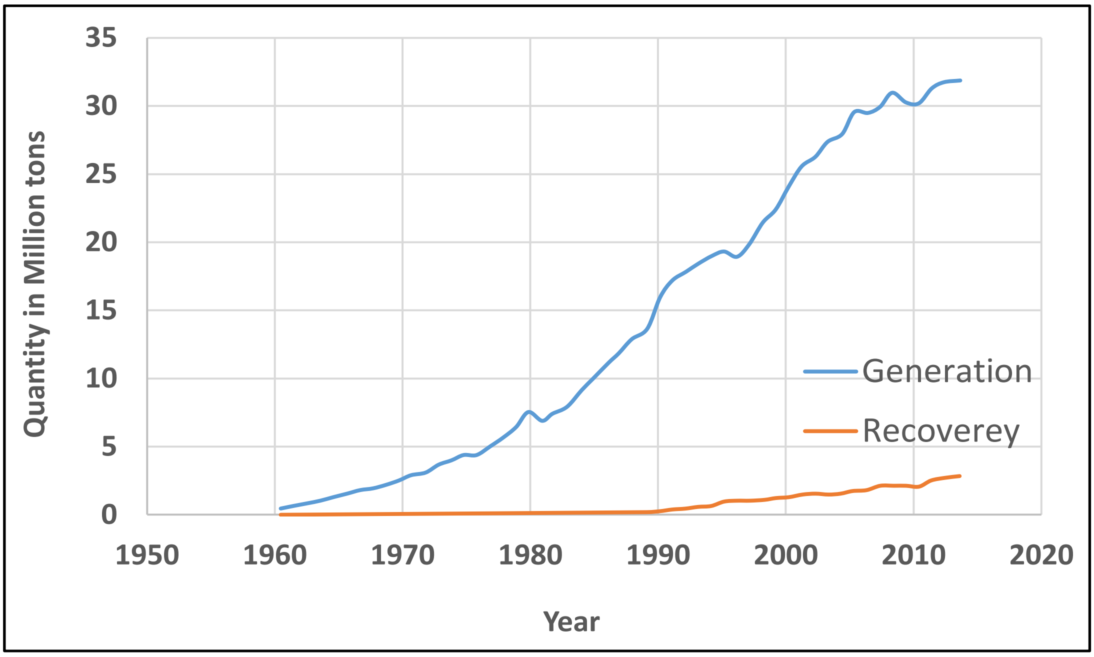


**Fig. (1):** Plastics generation and recovery in the United States (from 1960 to 2012) [17]

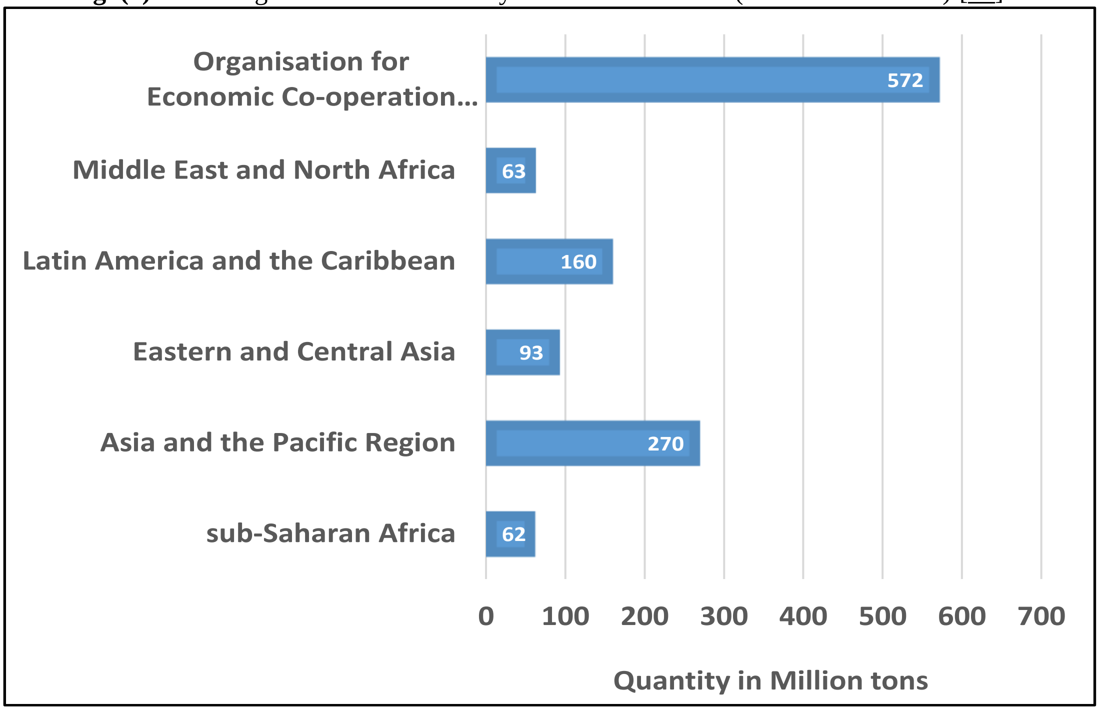


**Fig. (2):** Waste generation by region [18]

## 3. POLYETHYLENE TEREPHTHALATE (PET)

Plastics are primarily divided into two groups: thermoplastic and thermosetting. With cooling and heating, thermoplastic plastics such as polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polystyrene (PS), and high-density polyethylene (HDPE) can harden and melt. Thermosetting plastics, for instance, polyurethane, phenolic, unsaturated polyester, melamine, silicone, and epoxy, on the other hand, cannot be dissolved by heat [19, 20].

PET waste from plastic bottles is one of the common plastic wastes at both the local and global levels, owing to its widespread utilization in the manufacture of soft drinks and drinking water bottles, both of which are essential components of daily human consumption [21]. Water and soft drink bottle demand and consumption are straight relative to population density, which also entails a growth in the amount of PET bottles thrown, which will grow dramatically in the future as the population grows. The yearly usage of plastic drink bottles is anticipated to be 10 million tons or 250 billion bottles and is growing at a rate of 15% per year [22]. Therefore, in some countries like the United States of America (USA), which first began utilizing PET bottles, efforts are made to recycle used PET bottles to address environmental matters.

One of the ideas is to employ recycled PET bottles as a polyester resin in polymer concrete; another idea is to produce lightweight concrete using recycled PET as a filling material or as a partial substitute for the concrete components. In addition, some investigators tried to utilize PET fibers as reinforcing concrete materials [23, 24]. The inclusion of distributed synthetic fibers, natural, or steel in a cement-based mix can generally be quite efficient in preventing plastic shrinkage cracking [25-27]. Therefore, fiber-reinforced mortar and concrete show outstanding responses in tensile and crack resistance. Primarily, fibers control the spread of cracks and limit their width. Fibers can stop the enlargement of cracks at both macro and micro levels in fiber-reinforced concrete (FRC) [28]. Also, recycled PET fibers are believed to advance the mechanical properties of concrete as they have outstanding physical properties when utilized for concrete reinforcement. For instance, one of the problems associated with HSC is poor toughness, which can be resolved by reinforcing the concrete with discontinuous short fibers.

Factors such as easy availability, easy recycling, inexpensive, high strength-to-weight ratio, chemical resistance, highly transparent and shatterproof properties, and low cost to produce PET an accessible solution for consumable product packaging. Fibers really do not increase the strength, but they make the concrete ductile and improve tensile strength by utilizing the unique advantages of these properties, designers can create economic sections [29]. Their viscoelastic nature, low density, and non-corrosive materials are the key attractive properties [30]. The main benefit of employing waste PET bottles as aggregates is that they reduce the concrete's self-weight due to their low unit weight [31]. Furthermore, the most prominent benefits of adding recycled fibers to concrete include significant improvements in impact resistance, energy absorption, ductility, and load-deflection behavior [32].

PET, on the other hand, is made up primarily of crude oils and is not biodegradable [33]. Lower heat resistance PET resins are susceptible to oxidation [34]. Micro-defects such as honeycombs and voids may emerge during the placement due to inappropriate consolidation at low workability levels and worsening of mechanical performance due to the high stiffness of fibers [35]. Because of its low melting point, it cannot be utilized in ovens since it melts when exposed to high temperatures [36].

## 4. UTILIZING PET PLASTIC FIBERS IN CONCRETE

Plastic waste recycling has become one of the key difficulties in current years, as the global annual consumption of plastics has increased dramatically. PET bottles are often used for liquid packaging products such as water, carbonated soft drinks, beverages, household sauces, and other liquids but have damaged our ecosystem [37]. Recycled PET fiber from bottles offers a way to minimize global waste while also improving the mechanical performance of concrete [38]. PET has been used in several investigations to determine its potential usage as a concrete additive and has been pulverized so that it could be mixed with concrete. Many studies have been carried out over the last three decades to address the consequence of plastic waste on concrete [39]. In the following sections, this study will review some of these properties, in detail, such as workability, density, compressive strength, and splitting tensile strength, see Table (**1**

**Table (1)**: A summary of some typical details of past studies related to the workability, density, compressive strength, splitting tensile strength, and flexure strength characteristics of concrete containing plastic PET fiber.

| No | References and Year | Type of Composite | Type of Plastic Waste | Particle Size in mm | W/C | Fiber Volume Fraction % | Characteristics that Reviewed | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | **Workability** | **Density** | **Compressive Strength** | **splitting Tensile strength** | **Flexure Strength** |
| 1 | Silva, Betioli [40] | Mortar | PET-bottles | D = 0.026 and L = 20 | 0.61 | 0, 0.4 and 0.8 vol.% | | | ✓ | ✓ | ✓ |
| 2 | Ochi, Okubo [41] | Concrete | PET-bottles | D = 0.7 and L = 30 and 40 | 0.55, 0.60 & 0.65 | 0, 0.5, 1 and 1.5 vol.% | ✓ | | ✓ | | ✓ |
| 3 | Won, Jang [23] | Concrete | Embossed PET | L = 50 | 0.5 | 0 and 1.0 vol.% | | | ✓ | | |
| 4 | Kim, Yi [42] | Concrete | PET- bottles + PP | t = 0.2, W = 1.3 and L = 50 | 0.45 | 0.5, 0.75, and 1.0 vol.% | | | ✓ | | |
| 5 | Foti [43] | Concrete | PET-bottles | t = 0.1, W = 5 and L = 35 for lamellar and D = 6 and t = 5 for circular fiber | | 0, 0.5, and 0.75, vol.% | | | ✓ | | ✓ |
| 6 | Fraternali, Ciancia [44] | Concrete | PET-bottles + PP | D = 0.7 and 1.1 and L = 40 and 52 | 0.53 | 0 and 1 vol.% | | | ✓ | | ✓ |
| 7 | Pereira de Oliveira and Castro-Gomes [45] | Mortar | PET-bottles | t = 0.5, W = 2 and L = 35 | | 0, 0.5, 1.0, and 1.5 vol.% | | ✓ | ✓ | | ✓ |
| 8 | Pelisser, Montedo [46] | Concrete | PET-bottles | D = 0.25 - 0.3 and L = 10, 15, and 20 | 0.62 | 0, 0.05, 0.18, and 0.3 vol.% | ✓ | | ✓ | | ✓ |
| 9 | Ramadevi and Manju [47] | concrete | PET-bottles | | 0.45 | 0, 0.5, 1, 2, 4, and 6 vol.% | | | ✓ | ✓ | ✓ |
| **No** | **References and Year** | **Type of** | **Type of** | **Particle Size in** | **W/C** | **Fiber Volume** | **Characteristics that reviewed** | | | | |

(Continued next page)

ahr460h@cive.soran.edu.iq

| No | References and Year | Type of Composite | Type of Plastic Waste | Particle Size in mm | W/C | Fiber Volume Fraction % | Characteristics that Reviewed: Workability | Density | Compressive Strength | splitting Tensile strength | Flexure Strength |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | Nibudey, Nagarnaik [48] | Concrete | PET-bottles | W = 1 and 2 and L = 25 | 0.48 | 0, 0.5, 1, 1.5, 2, 2.5 and 3 vol.% | ✓ | ✓ | ✓ | ✓ | ✓ |
| 11 | Maruthachalam and Muthukumar [49] | Concrete | PET | D = 0.02 and L = 38 | 0.45 | 0, 0.1, 0.2, 0.3, 0.4 and 0.5 vol.% | | | ✓ | ✓ | ✓ |
| 12 | Prahallada and Parkash [50] | Concrete | Waste plastic | | 0.48 | 0 and 0.5 vol.% | ✓ | ✓ | ✓ | ✓ | ✓ |
| 13 | Irwan, Asyraf [51] | Concrete | PET-bottles | W = 6 - 10 | 0.65 | 0, 0.5, 1, and 1.5 vol% | | | ✓ | ✓ | |
| 14 | Spadea, Farina [52] | Concrete | PP + PET | D = 0.7 and 1.1 and L = 40 and 52 | 0.38 | 0 and 1 vol.% | | | ✓ | | ✓ |
| 15 | Taherkhani [53] | Concrete | PET-bottles | W = 2 and L = 10, 20, & 30 | 0.5 | 0, 0.5, and 1 vol.% | ✓ | ✓ | ✓ | ✓ | ✓ |
| 16 | Marthong [54] | Concrete | PET-bottles | t = 0.5, W = 0.5, 1 and 2 and L = 4, 5, 8 and 10 | 0.5 | 0, 0.5 and 1.0 vol.% | ✓ | | ✓ | ✓ | ✓ |
| 17 | Marthong and Sarma [55] | Concrete | PET-bottles | t = 0.5, W = 0.9, 1.2 and 1.5 and L = 8 | 0.5 | 0 and 0.5 vol.% | ✓ | | ✓ | ✓ | ✓ |
| 18 | Marthong and Marthong [56] | Concrete | PET-bottles | t = 0.5, W = 2 and L = 50 | 0.5 | 0, 0.5 and 1.0 vol.% | | | ✓ | ✓ | ✓ |
| 19 | Wiliński, Łukowski [57] | Mortar & Concrete | PET-bottles | t = 0.2 – 0.25, W = 2 - 3 and L = 50 - 70 | 0.45 and 0.5 | 0, 0.1 and 0.3 vol.% | ✓ | | ✓ | ✓ | ✓ |

| | | Composite | Plastic Waste | | | Fraction % | Workability | Density | Compressive Strength | Splitting Tensile strength | Flexure Strength |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | Boiny, Alshkane [58] | mortar | PET-bottles | L =8 and 16 | 0.47 | 0, 0.5, 1, , 1.5, 2 and 3 vol.% | | ✓ | ✓ | ✓ | |
| 21 | Guendouz, Debieb [59] | Sand Concrete | PET-bottles | t = 0.5 and L = 40 | 0.86 | 0, 0.5, 1, 1.5, and 2 vol.% | ✓ | ✓ | ✓ | | ✓ |
| 22 | Ananthi, Eniyan [60] | Concrete | PET- bottles | t = 0.08 & 0.48, W = 2.8 and L = 12.7 | | 0, 0.3, 0.6, 0.9 and 1.2 vol.% | | | ✓ | ✓ | |
| 23 | Khalid, Irwan [61] | Concrete | PET-bottles | D = 60, W = 5 & 10 and L = 55 | 0.55 | 0, 0.25, 0.5, 1, 1.25, and 1.5 vol.% | | | ✓ | ✓ | |
| 24 | Shahidan [62] | concrete | PET-bottles | t = 5, and L = 50 | 0.45 | 0, 0.5, 1, 1.5 and 2 vol.% | ✓ | | ✓ | ✓ | |
| 25 | Al-Hadithi, Noaman [63] | Self-compacting concrete | PET-bottles | t = 0.3, W = 4, and L = 35 | 0.33 | 0, 0.25, 0.5, 1, 1.25, 1.5 and 2 vol.% | | | ✓ | | ✓ |
| 26 | Mohammed and Rahim [64] | Concrete | PET-bottles | t = 0.4, W = 1.2, and L = 20 & 40 | | 0, 0.75, and 1 vol.% | | | ✓ | ✓ | |
| 27 | Thomas and Moosvi [65] | Concrete | PET-bottles | W = 2 – 2.3 and L = 50 | 0.36 | 0, 0.2, 0.4, 0.6 and 0.8 vol.% | ✓ | | ✓ | ✓ | ✓ |
| 28 | Huang and Zhou [66] | Coal Gangue Fine Aggregate Concrete | PET-bottles | w = 3 - 5 and L = 14 - 16 | 0.54 | 0, 0.1, 0.3, and 0.5 vol.% | | | ✓ | ✓ | ✓ |

PET: polyethylene terephthalate; W/C: water to cement ratio; t: fiber thickness; L: fiber length; W: fiber width; D: fiber diameter;

**4.1 Workability/Slump**

Workability is the consistency of fresh concrete mixtures that identifies how simply it can be homogeneously mixed, set, unified, and finished. The slump test is the most frequently approached strategy to find concrete workability, which could be done either in the laboratory or on the site. The consequence of the addition of PET fiber on the workability of concrete in literature is reviewed and discussed below.

Fig (3 also displays the relationship and variation between the percentage of PET fiber incorporated in concrete or mortar and slump values based on data from previous studies, as shown in Table (**1**.

Ochi, Okubo [41], Nibudey et al. [48], Guendouz et al. [59], Shahidan [62], and Thomas and Moosvi [65] reported that the workability of concrete would decrease by adding fiber content. Pelisser, Montedo [46] indicated that the workability of concrete would increase by adding very low fiber volume content (0.05 vol. %). However, by further increasing fiber content, the workability of PET-reinforced concrete will decrease. Taherkhani [53] reported that the workability of concrete would increase by adding fiber content to 0.5%. However, increasing the fiber content of concrete will reduce its workability. Marthong [54], Marthong and Sarma [55] reported that the slump of the mixture drops with the rise of fiber contents. Furthermore, the shape of fibers was determined to have only a minor impact on concrete workability. Fiber dimensions, on the other hand, are crucial in achieving optimal concrete workability. Wiliński, Łukowski [57] revealed that the presence of fibers in the concrete mix over 0.3% by volume causes major problems with homogeneity and workability.

Shahidan [62] attributed the slump decreasing to the existence of PET fibers in concrete, which generates increased friction between the particles, resulting in poorer workability in the mixtures. Furthermore, the fibers' high concentration and huge surface area allow the cement paste to absorb quickly, increasing the viscosity of the concrete mixture. Thomas and Moosvi [65] indicated that the decreased slump value could be due to the fibers that create a barrier to the flow of concrete.

In summary, the addition of plastic fibers to concrete will result in a reduction in the slump of the concrete because the fibers induce an increase in the friction that exists between the particles of the concrete and act as a barrier to the flow of the concrete.

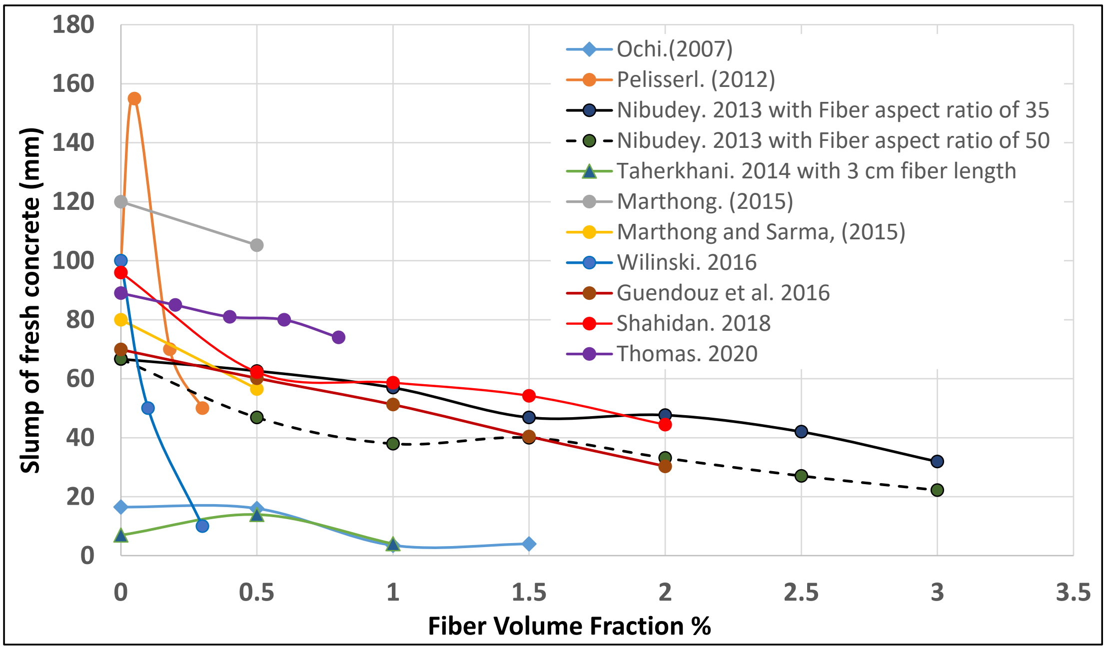


**Fig. (3):** The variation of slump value of concrete by adding PET-Fiber [41, 46, 48, 53-55, 57, 59, 62, 65]

**4.2 Unit Weight**

The density of a material is the measurement of its quantity or mass per unit of volume. The effect of the PET fiber addition on the density of concrete in the literature is reviewed and discussed below. In addition, Fig. (**4** displays the



ahr460h@cive.soran.edu.iq

relationship and variation between the percentage of the PET fiber added in mortar or concrete. Table (**1** shows the bulk density values based on data from previous studies.

Pereira de Oliveira and Castro-Gomes [45] and Boiny, Alshkane [58] reported that the density of mortar is slightly reduced with the addition of PET fibers in hardened mortar. Nibudey, Nagarnaik [48], and Taherkhani [53] reported that the concrete density is slightly reduced when PET fiber is added to concrete. Guendouz, Debieb [59] reported that the sand concrete density is reduced with the addition of fiber to sand concrete.

In summary, because the addition of fiber creates more pores in the concrete, the density of the concrete will be slightly lowered when the plastic fiber is added to concrete.

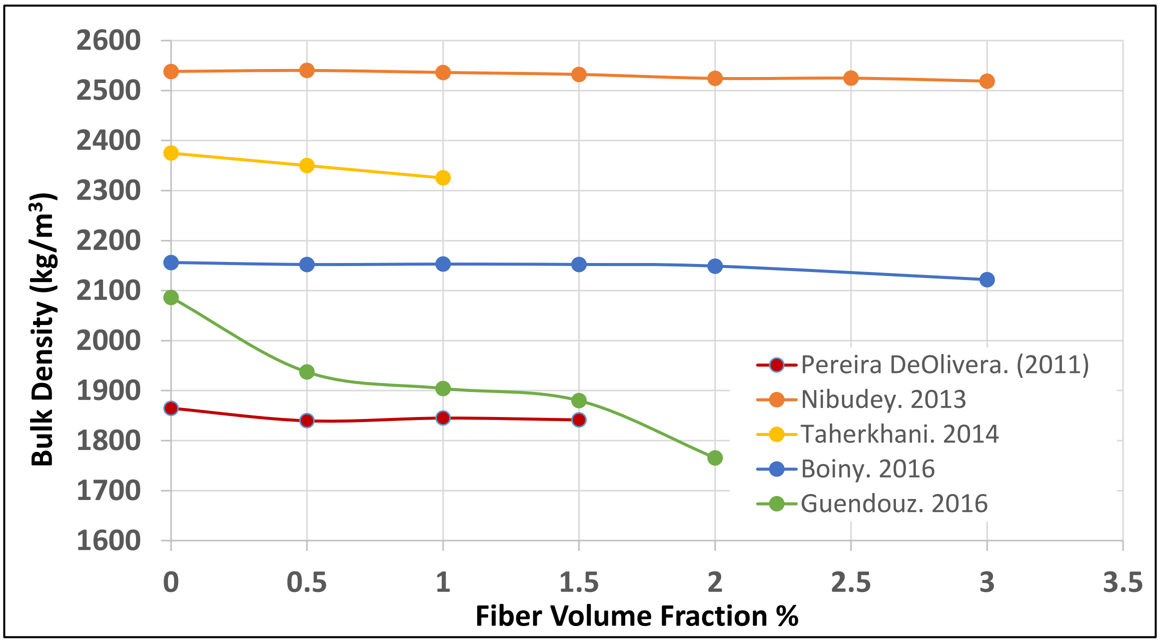


**Fig. (4):** The variation of density value of concrete by adding PET-Fiber [45, 48, 53, 58, 59]

### 4.3 Compressive Strength

Compressive strength signifies the capacity of the material to resist pressure applied by the compression machine, as the sample is fractured when it passes the limits of compressive stress. To understand the influence of adding waste PET fiber on the concrete compressive strength, several studies have been performed in the past and are summarized in this section. Fig. (**5** also represents the relationship and variability between the percentage of PET fiber added to concrete or mortar and compressive strength values, as established by data in Table (**1** from a previous study.

Silva, Betioli [40] and Pereira de Oliveira and Castro-Gomes [45] reported that adding fiber to mortar does not influence the compressive strength of mortars. Ochi, Okubo [41], and Shahidan [62] appealed that increasing the fiber content of concrete by 1% will increase its compressive strength. Nevertheless, increasing the fiber content of PET-reinforced concrete will reduce its compressive strength. Kim, Yi [42], and Foti [43] stated that adding PET fiber to concrete showed a slight reduction in compressive strength. Fraternali, Ciancia [44] documented that the concrete compressive strength will increase by adding fiber to concrete. Pelisser, Montedo [46], Maruthachalam and Muthukumar [49], and Spadea, Farina [52] stated that increasing PET fiber content in concrete has a minimum impact on the concrete compressive strength. Ramadevi and Manju [47] reported that raising the fiber percentage of concrete by 2% enhances its compressive strength, whereas increasing the PET fiber proportion reduces the concrete's compressive strength. Nibudey, Nagarnaik [48], and Guendouz, Debieb [59] investigated the compression behavior of concrete with various fiber content and different fiber aspect ratios. The outcomes showed that increasing the fiber content of concrete to 1.5% increased the compressive strength somewhat. However, increasing the fiber content of PET-reinforced concrete will reduce its compressive strength. Furthermore, it was stated that the aspect ratio is ineffective. Marthong [54] performed that adding PET sheet fiber to 0.5% in concrete enhanced the concrete compressive strength. However, increasing the fiber content in concrete reduces the compressive strength. In addition, it was indicated that the dimensions and geometry of fibers directly affect the enhancement rate in the compressive strength. Flattened-end sheet fibers resulted in an improvement in the compressive strength because of their exceptional bonding with the concrete matrix and its fine dispersion. Fibers with smaller dimensions resulted in concrete with higher compressive strengths.

Marthong and Sarma [55] tested four different geometries of PET sheet fibers. Test results indicated that adding 0.5% PET sheet fiber to concrete improved the compressive strength of samples which varied with the geometry of the fibers. Also, it has been reported that plain cylindrical samples are crushed without showing any resistance to the compressive load. Marthong and Marthong [56] stated that the inclusion of recycled PET fiber in normal strength concrete (NSC) adversely affected the compressive strength property of the concrete. The additions of PET fiber in concrete slightly lower concrete compressive strength of the samples. Boiny, Alshkane [58] reported that the compressive strength of the mortar drops with increasing the fiber content or increasing fiber length. Wiliński, Łukowski [57] used ethylene vinyl acetate (EVA) copolymer modified with silica powder to enhance the bond strength of recycled PET fiber and resistance against hydrolysis. The results indicated that the concrete compressive strength would increase by adding 0.1% fiber content, and by further increasing fiber content, the PET concrete compressive strength will decrease.

Ananthi, Eniyan [60] specified that the concrete compressive strength will increase by adding 0.9% fiber content. However, by further increasing fiber content, the compressive strength of PET- reinforced concrete will decrease. Khalid, Irwan [61] stated that the compressive strength of fiber reinforced concrete (FRC) was not influenced by the volume of the added fibers and the geometry of the fiber. Al-Hadithi, Noaman [63] described that the self-compacting concrete (SCC) compressive strength will increase by adding 1.5% fiber content. The distribution of PET fibers inside the microstructure of concrete is responsible for the increase in compressive strength after 28 days. This state causes the hardened concrete to become more homogeneous and reduces the number of voids, making it more cohesive. However, by further increasing fiber content the compressive strength of SCC will decrease. Taherkhani [53] and Mohammed and Rahim [64] revealed that the concrete compressive strength decreases with increasing the fiber content or increasing fiber length. Thomas and Moosvi [65] illustrated that the concrete compressive strength would increase by adding 0.4% fiber content. However, by further adding fiber content the compressive strength of PET-reinforced concrete will decrease. Huang and Zhou [66] showed that the concrete compressive strength would increase by adding 0.1% fiber content. However, by further increasing fiber content the compressive strength of PET-reinforced concrete will decrease.

Mohammed and Rahim [64] detailed that a high concrete mass is dense and compact with a low ratio of pores, and flaws may be the main reason for the loss of compressive strength. The presence of PET fiber is frequently accompanied by flaws between the concrete and the plastic surface. This will produce a weak zone within the dense HSC mass, allowing cracks to propagate. Huang and Zhou [67] detailed that air infiltration can cause larger pores in the concrete matrix during the fibers and concrete mixing process. This indicates that the FRC's bonds are weakened by the weak arrangement around the fibers.

In summary, the addition of 0.5% fiber content to concrete will result in an increase in the compressive strength of the concrete. The increase in compressive strength is due to the dispersion of PET fibers throughout the microstructure of concrete. This causes the hardened concrete to become more homogenous and reduces the amount of voids, which leads it to be more cohesive. However, when the fiber content is increased further, the compressive strength of concrete will decrease. This is due to the fact that fiber creates more pores in concrete.

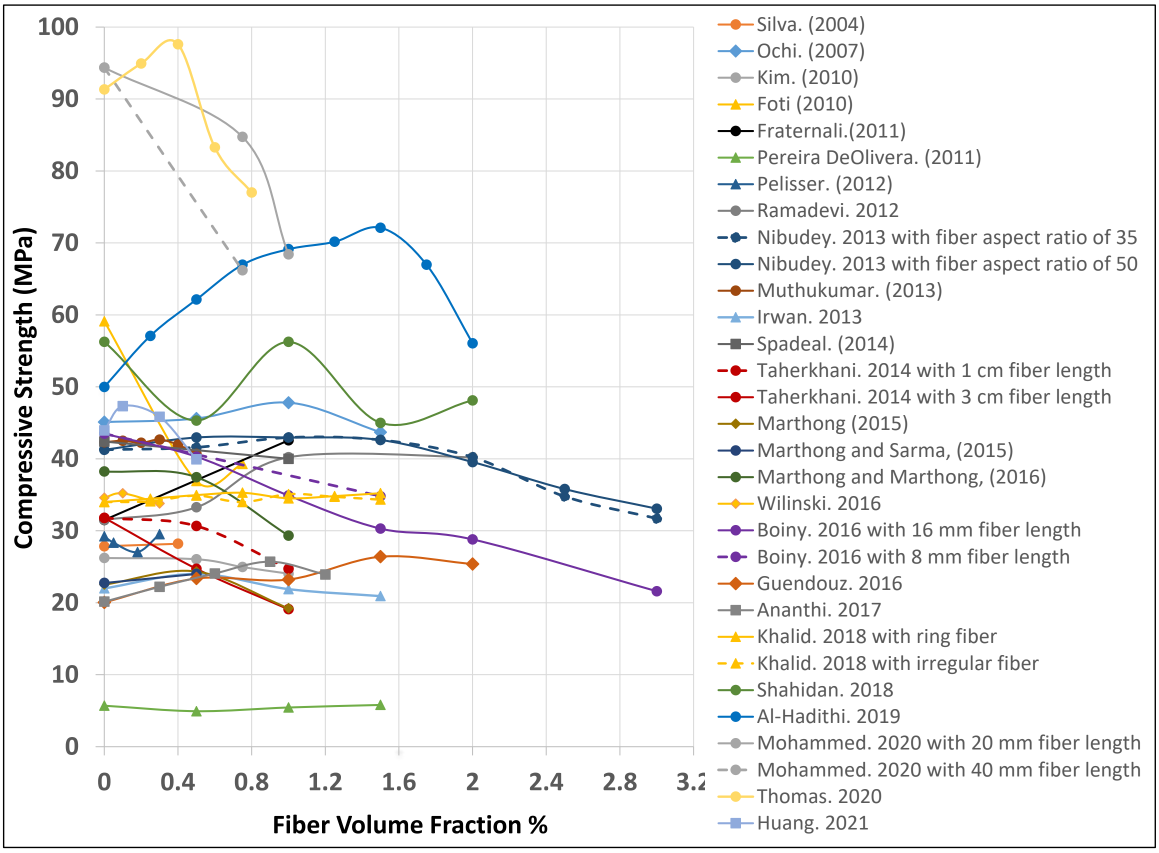


**Fig. (5):** The variation of compressive strength value of concrete by adding PET-fiber [40-49, 51-66]

### 4.4 Splitting Tensile Strength

Tensile strength is the capability of a material to withstand a tensile (pulling) force. The impact of the addition of PET fiber on the concrete splitting tensile strength in literature is reviewed and discussed below. In addition, Fig. (**6** displays the relationship and variation between the percentage of the PET fiber added in concrete or mortar and splitting tensile strength values according to the data of past- research mentioned in Table (**1**.

Silva, Betioli [40] claimed that the tensile strength of concrete would decrease by adding fiber content. Ramadevi and Manju [47] reported that increasing the fiber content of concrete to 2% will increase the split tensile strength. However, increasing the fiber content further reduces the split tensile strength of PET-reinforced concrete. Nibudey, Nagarnaik [48] investigated the split tensile strength of concrete with different fiber content and different fiber aspect ratios. The outcomes showed that the concrete split tensile strength will increase by adding fiber content to 1%. The split tensile strength of PET-reinforced concrete will, however, decrease as the fiber percentage is increased further. In addition, it was indicated that the concrete split tensile strength will increase by increasing the fiber aspect ratio. Maruthachalam and Muthukumar [49] illustrated that the concrete split tensile strength will increase by adding fiber content to 0.3%. However, as the fiber content is increased, the split tensile strength of PET-reinforced concrete would decrease.

Taherkhani [53] described that the split tensile strength of the mixtures decreases with increasing the fiber content and length. Marthong and Sarma [55] reported that the inclusion of 0.5% PET fiber enhanced the tensile strength. The addition of PET fiber increased the specimen's tensile properties and demonstrated its potential to absorb energy in the post-cracking stage. In addition, for the same fiber content, the geometry of sheet fiber plays a major role in the tensile strength of normal strength PETFRC. Marthong [54] and Marthong and Marthong [56] stated that smaller fiber dimensions improved tensile strength due to better dispersions of short fibers, which led to greater bridging action in the concrete matrix. However, the split tensile strength decreases with an increase in fiber contents of more than 0.5%. Furthermore, when the concrete fractured, the fiberless concrete split out. The PET fibers concrete, on the other hand, cracked but did not totally separate. The findings also show that adding PET fibers improves the ability to withstand additional tensile stress, particularly during the post-cracking stage. Boiny, Alshkane [58] claimed that the split tensile strength of mortar would increase by adding fiber content to 0.5%. However, by further increasing fiber content, the split tensile strength of PET-mortar will decrease. In addition, it was indicated that by decreasing fiber length, the split tensile strength of PET-mortar will decrease. Ananthi, Eniyan [60] presented that the concrete split tensile strength will increase by adding 0.9% fiber content. The split tensile strength of PET-reinforced concrete would, however, drop when the fiber content was increased.

Khalid, Irwan [61] outlined that the concrete split tensile strength was influenced by the shape of the fiber effect. When ring PET-fiber wad is added to concrete, the concrete split tensile strength increases until 1.25% PET-fiber is added to concrete, but by further increasing PET-ring fiber, the concrete split tensile strength will decrease. Shahidan [62] reported that the splitting tensile strength increased only with the addition of fibers up to about 1.0%, after which the splitting tensile strength decreased. Mohammed and Rahim [64] reported that the split tensile strength of the mixtures decreases with increasing the fiber content, but this reduction will be smaller when using a bigger fiber length. Thomas and Moosvi [65] detailed that increasing the fiber content in concrete to 0.4% will improve the splitting tensile strength. Increased fiber content, on the other hand, lowers the splitting tensile strength of PET-reinforced concrete. Huang and Zhou [66] reported that adding 0.1% fiber to concrete improves the splitting tensile strength. Increased fiber content, on the other hand, reduces the splitting tensile strength of PET-reinforced concrete.

In summary, the key to achieving tensile strength appears to be important for two reasons: fiber distribution in the mix must be homogeneous, and fiber percentage must be carefully determined. The tensile strength of polypropylene fibers is increased by a bridging mechanism, and after a typical percentage of volume fraction, the extra fiber in the concrete leads to a reduction in the bond strength between concrete ingredients, resulting in rapid failure when compared to concrete with fewer volumes of fibers.

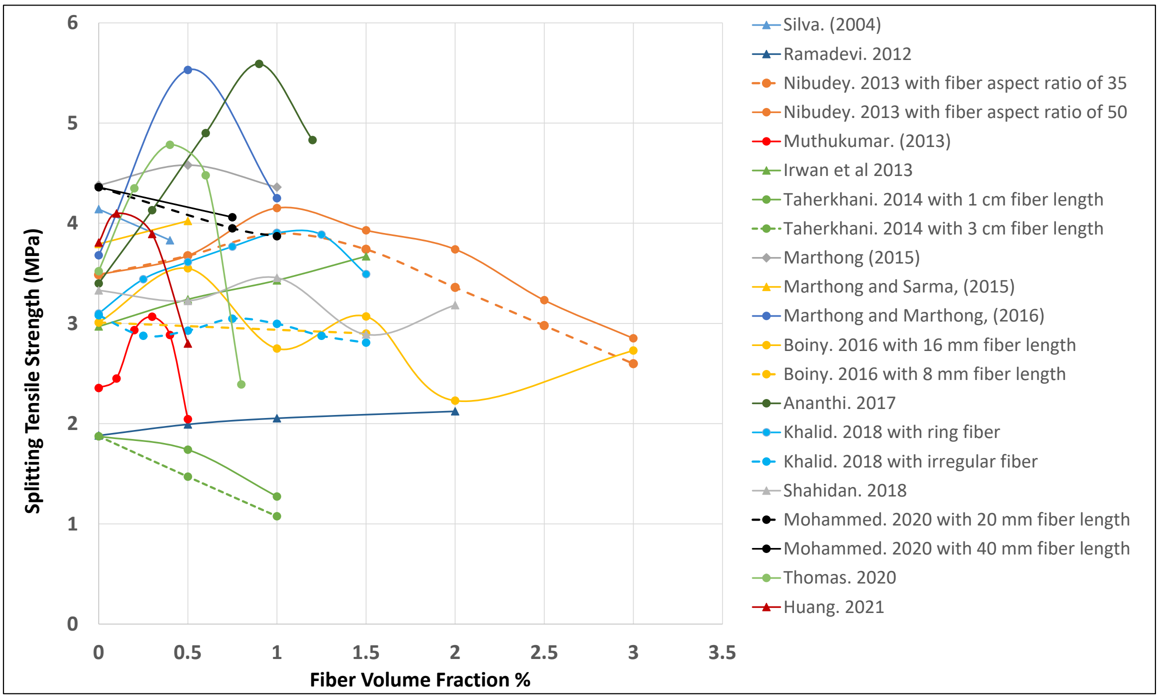


**Fig. (6):** The variation of splitting tensile strength value of concrete by adding PET-Fiber [40, 47-49, 51-56, 58, 60-66]

#### 4.5 Flexure Strength

The resisting ability to fail in bending a structural member is termed flexural strength, which is usually calculated by a three-point or four-point loading test. Previous studies recorded that PET fiber affects the concrete flexural strength, as discussed below. In addition, based on the results in Table **(1** from the previous studies, Fig.(**7** represents the relationship and fluctuation between the proportion of PET-Fiber incorporated in concrete or mortar and flexure strength values. Silva, Betioli [40], and Spadea, Farina [52] stated that adding fiber to the mortar does not impact the flexure strength of mortars. Ochi, Okubo [41] reported that the flexure strength of concrete would increase by adding fiber to concrete. Foti [43] reported that adding 0.5% fiber content to concrete reduces flexure strength. If the fiber content of PET-reinforced concrete is increased further, the flexure strength will improve. Pereira de Oliveira and Castro-Gomes [45] reported that the flexure strength of concrete would increase by adding fiber to concrete. in addition, from their investigation, it can be summarized that increasing fiber content from 0.5% to 1.5% improves the ability of the concrete to support more loads, especially after cracking, because fiber improves tensile strength compatibility at post cracking state depending on fiber dispersion and orientation in the tensile zone but first crack strength was nearly the same in both cases. Fraternali, Ciancia [44] observed that high-strength PET fiber increased flexural strength significantly compared to polypropylene fiber. As for shapes, they concluded that crimped fibers help more ductility improvement compared to straight-shaped fibers in terms of successive bonding between fiber and paste. Pelisser, Montedo [46] found that recycled-bottle-PET fibers improved the flexural and impact toughness of 28-day-old conventional concrete. Ramadevi and Manju [47] stated that increasing the fiber content of concrete to 4% will gradually improve its flexural strength. If the fiber content of PET-reinforced concrete is increased further, the flexural strength will not change. Maruthachalam and Muthukumar [49] reported that the flexure strength of concrete would decrease by adding fiber content. Nibudey, Nagarnaik [48] investigated the flexure strength of concrete with different fiber content and different fiber aspect ratios. The outcomes specified that the concrete flexure strength would increase by adding fiber content to 1%. Increasing the fiber content of PET-reinforced concrete, on the other hand, lowers its flexural strength. Furthermore, it was claimed that increasing the fiber aspect ratio would improve concrete's flexural strength. Taherkhani [53] reported that the flexural strength of fiber-reinforced mixtures increases with increasing fiber length. However, the flexural strength decreases with increasing the fiber content. Marthong [54] and Marthong and Sarma [55] observed that adding PET sheet fiber to 0.5% in concrete improved the flexural strength which varied with the geometry of the fibers. However, the addition of more than 0.5% of large-sized (sheet) PET fiber in concrete reduces the flexural strength. Furthermore, the shape and size of PET fibers have an impact on the flexural strength of concrete that contains them. Flattened-end slit sheet fiber outperforms straight slit sheet fiber greatly in terms of load-carrying capacity and energy dispersing capabilities. Similarly, regardless of geometry, short scattered fibers may withstand greater deformation, indicating a higher energy dissipation capability. Wiliński, Łukowski [57] tested NSC containing recycled PET fiber and flexural strength results showed unimportant changes in the outcome data. Marthong and Marthong [56] confirmed that PET fiber concrete has a substantial load-carrying capacity and energy dissipation capability when compared to samples without fiber. Furthermore, by transferring internal force, the interfacial interaction between the fiber and the matrix permits the fiber to bear the load and prevent crack progression. The flexural toughness was improved as a result of this process. However, the flexural strength declines beyond 0.5% fiber contents. Guendouz, Debieb [59] labeled that adding 1% fiber content to sand concrete advances its flexural strength. Conversely, increasing the fiber content further in PET-sand concrete reduces its flexural strength. Al-Hadithi, Noaman [63] claimed that increasing 1.5% fiber to sand concrete improves its flexural strength. The inclusion of PET fibers increased inhomogeneity and reduced voids in SCC, resulting in improved flexural strength. Additionally, the bond strength between the concrete and PET fibers improved, as did PET fibers' ability to bridge tensile stress fractures. Thomas and Moosvi [65] found that increasing the fiber content of concrete to 0.4% improves its flexure strength. Conversely, increasing the fiber content of PET concrete reduces its flexural



ahr460h@cive.soran.edu.iq

strength. Huang and Zhou [66] described that increasing the fiber content of concrete to 0.1% increases flexure strength. On the other hand, increasing the fiber content decreases its flexural strength. Fiber addition and fiber type have a direct impact on the flexural strength of FRC.

In summary, by incorporating fiber content of up to 1%, the flexure strength of concrete will increase. However, the flexure strength of PET-reinforced concrete will decrease as the fiber percentage increases further. PET fiber concrete has a substantial load-carrying capacity and energy dissipation capability when compared to samples without fiber. Furthermore, by transferring internal force, the interfacial interaction between the fiber and the matrix permits the fiber to bear the load and prevent crack progression. The flexural strength was improved as a result of this process.

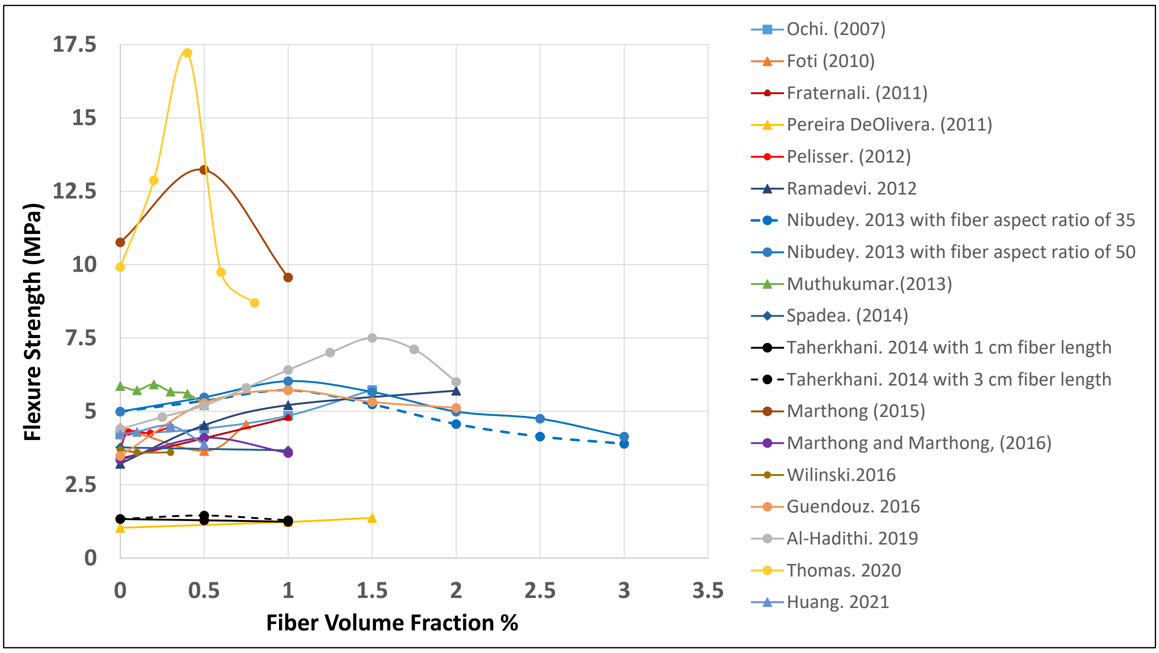


**Fig.(7):** The variation of flexure strength value of concrete by adding PET-Fiber [40, 41, 43-49, 51-57, 59, 62, 63, 65, 66]

## 5.UTILIZING PET PLASTIC FIBERS IN RC BEAMS

Many studies have been carried out over the last decade to address the effect of plastic waste on structural concrete. In the following sections, this study will review some of the structural properties, such as ultimate load, load at First crack and deflection. In addition, Figure 8, Figure 9, and Figure 10 display the relationship and variation between the level of the PET-Fiber added in concrete and load at the first crack or ultimate load or maximum deflection values.

Kim, Yi [42] showed that when compared to samples without fibers, PET fiber in RC beams improved tensile resistance, fracture resistance, strain–hardening capabilities, delayed macro-crack formation, and elevated the maximum mid-span deflection to around 400%. RC beams made from recycled PET fiber showed increased ductility and ultimate strength. Both concrete tensile and compression reinforcement yielding caused the recycled PET fiber RC beams to fail. The relative ductility indices of the recycled PET fiber RC specimens were roughly 7-10 times higher than those of the samples without fiber content. When the cross-sectional area capable of withstanding the load is roughly equivalent to the cross-sectional area before the load was applied, the bond between the rebar and concrete is strong enough to produce uniformity, and the cracks created during the initial stages of loading are crossed by short fibers dispersed randomly within the member. The ductility index and energy capacity both decrease as the fiber volume percentage rises by roughly 0.5%. Foti [28] used three arrangements of simple cutting PET bottle fibers as discrete reinforcement of samples in substitution of steel bars. The first is a circular fiber with a diameter of 5 mm. Long PET strips (half bottle) are put in the same position as steel bars in beams in the second form. The third shape is a strip of bottles with dimensions of (45 × 0.2 × 300) mm. Their findings claimed that increasing the ductile behavior of circular PET waste fibers by 1% is the optimal percentage. Additionally, both short strips of fibers and circular fibers have shown a positive stitching effect in the post-cracking phase of concrete.

Prabha and George [68] reported that raising PET fiber in the concrete mix increases the concrete's compressive, shear, and flexural strengths over the reference concrete. Furthermore, during the early stages of loading, very few flexural cracks were seen in the mid-span. Additional flexural cracks were seen in each shear span as the load increased. Due to a combination of shear and flexural stress, these cracks were beginning to shift toward the loading point. Further loading caused preliminary shear cracks to emerge in the shear span, and it is in this load that the concrete's shear strength is defined. The experiment found that traditional concrete examples break abruptly at ultimate strength, but FRC specimens do not. According to the findings of the study, FRC with a pet fiber aspect ratio of 4 and a volume of 2% in M25 grade concrete can be used in infrastructure applications such as concrete structures.

Ahmadi, Farzin [69] showed that the ultimate load of the concrete beam increased with rising PET fiber. In addition, it is conducted that the deflection of the concrete beam decreased with increasing PET fiber. Mohammed [15] stated that When PET waste concrete is utilized for the beam instead of normal concrete, the stiffness and mode of failure do not change. However, the maximum load capacity was reduced slightly. When PET waste was mixed with concrete, the peak load deflection and load-deflection response were marginally altered. Furthermore, it has been determined that RC beams can be securely produced with concrete containing up to 15% PET waste if a tensile mode of failure occurs. There is a considerable area in the cross-section of concrete beams subjected to a flexure that can be filled with concrete containing PET waste between the tensile steel rebar and the compression zone, which is the zone of inactive cracked concrete. Accordingly, employing PET waste in these zones aids in the production of recycled concrete of this sort. As a result, there's a probability that a considerable amount of PET waste might be used to make flexural concrete elements like beams and slabs.

Al-Hadithi and Abbas [17] showed that the absorbed energy and shear strength of RC beams were improved by mixing plastic fibers into the concrete until the fiber percentage reached 1%. A slight rise in the first fracture load has been seen with an increase in PET fiber level of up to 1%. In comparison to samples without waste plastic fibers, the value of deflection at the same load level was reduced with the existence of waste plastic fibers that acted to bridge the cracks. Furthermore, the presence of waste plastic fibers decreased the deflection of the beam at the initial crack by a small amount because the plastic fibers' resistance to tensile stresses began at the same time as the crack's propagation. Jaisri and Kanimozhi [70] observed that increasing PET fiber to 1% enhanced the ultimate load of the concrete beam. The ultimate load, on the other hand, was reduced as PET fiber was increased further. Furthermore, it was discovered that increasing PET fiber to 1% reduced the deflection of the concrete beam. The deflection, on the other hand, increased as the PET fiber increased.

Al-Hadithi and Abbas [71] explained that the reduction in beam deflection at the initial fracture with the presence of waste plastic fibers was minimal. This was due to the plastic fibers' resistance to tensile strains, which began soon after crack propagation. When steel fibers were utilized, nevertheless, the resistance to tensile loads began prior to the first crack appearing, which increased the load of the first crack and reduced the deflection of the beams significantly. Generally, all categories of fibers can bridge cracks and redistribute stresses in the beam to handle the increased load with only a slight deflection at the same load level because the rate of rise in the load is slower than the rate of increase in the deflection value, the behavior of the load-deflection curve shifts from elastic linear to plastic nonlinear. The beam's shear strength reaches its maximum, and inclined cracks are disseminated towards the support or focused load. Furthermore, it was discovered that as the fiber % raised, the width of the greater diagonal crack in the beams decreased. After failure, this behavior showed an increase in the connections and attraction points between the individual sections of concrete. By adding waste plastic fibers of 1%, the shear strength and absorbed energy of RC beams were increased. For beams with steel stirrups, an increase in PET fiber level leads to a small rise in the first fracture load. The rise in the first crack load was larger in the CFRP stirrup beams, reaching fiber content of 1.5%, the shear ductility of beams was enhanced by incorporating waste plastic fibers into concrete.

Mohammed Ali [72] reported that the impact of PET fiber on direct shear is greater than that of concrete beam shear strength. The presence of PET fiber in concrete leads to a drop in the number of cracks and their spacing, as well as a shift in the failure mode from shear to flexure. As a result, PET fiber has a greater effect on shear than flexure. Adnan and Dawood [73] claimed that except in the shear zone, the cracks were concentrated in the mid-span of the beams, and they were practically evenly distributed along the beam span. Final failure loads expand cracks that start in the bottom section of the specimens and propagate up to the upper section of the specimen. PET fiber samples reveal a flexural failure mode, proving the validity of the earlier design that the beams fail in flexure. When compared to the reference beam, all RC beams with PET fibers demonstrated a small reduction in ultimate load. Despite a minor reduction in ultimate load, the existence of PET fibers in the beams had a positive influence on their overall ductility behavior. The ductility of this effect can be about 2-5 times that of the reference beam. The hybrid beam exhibits a lot of this behavior. The secant stiffness of all PET fiber-containing beams was lower than that of the reference beam. Simultaneously, the initial stiffness of the beam increases as the content of PET fibers in the concrete mixture increases.

Ullah Khan and Ayub [74] reported that the loading capacity for the PET-fibered beams in the beams described for the flexural mode of failure had increased by a moderate amount. In the beams specified for the shear mode of failure using PET fibers, however, there was a less substantial improvement in loading capacity. The deflection corresponding to load capacity, on the other hand, was shown to be significantly enhanced and at failure. PET fibers worked admirably, contributing significantly to the response of the beams specified for shear and 23.51% at a fiber content of 1.25%. Except at a flexural failure modes. After reaching full loading capacity and failure in the constant bending moment zone, concrete crushing in the compression zone was detected. Similar to the control beam, the PET-fiber beam had full loading capability and concrete crushing in the flexure zone. Furthermore, when beams were detailed for a shear mode of failure in the control beam, flexural cracks appeared in the constant flexure zone at first. As the load increased, shear cracks formed in the constant shear zone and spread diagonally in the line of the loading point. The failure occurred due to diagonal stress. Hairline cracks began to form in the PET fiber beam at lower loads, and a diagonal tension crack caused an abrupt collapse. Because of the PET fibers, the crack spacing was less than the control beam. Even though the beam failed in a shear mode, the loading capacity was shown to increase when fibers were present.

Al-Hadithi, Abdulrahman [75] reported that for all steel reinforcement ratios, the addition of PET fiber provides a decrease in both ultimate deflection and first crack deflection when compared to reference beams. The lowest deflections were found in all beams with varying reinforcing areas when waste plastic fibers (WPFs) with a volumetric ratio of 1% were used. Furthermore, it has been demonstrated that adding PET fibers to concrete beams increases the ductility value of the beams. The WPFs are often dispersed inside the concrete mixture, which leads to increased homogeneity and a decrease in the amount of void inside the concrete, making it more cohesive and tougher. When micro-cracks appear inside the matrix, PET fibers attempt to stop the spread of these types of cracks in the nearby region and limit their spread. Therefore, the crack propagation path becomes elongated, necessitating more energy for fracture propagation to continue. As a result, this operation must reach high stress for failures to occur. That is, by adding PET fibers to the RC beam, the beams can tolerate a wide range of stress caused by the external load.

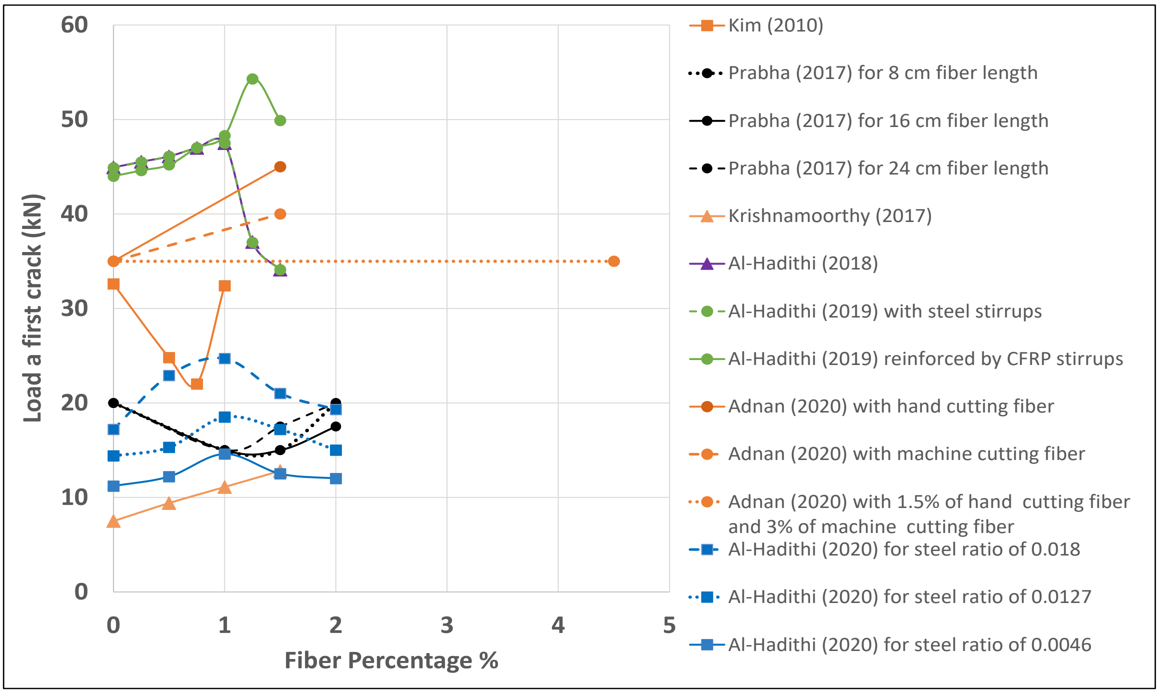


**Fig. (8):** The variation of load at the first crack value of concrete beam by adding PET-Fiber

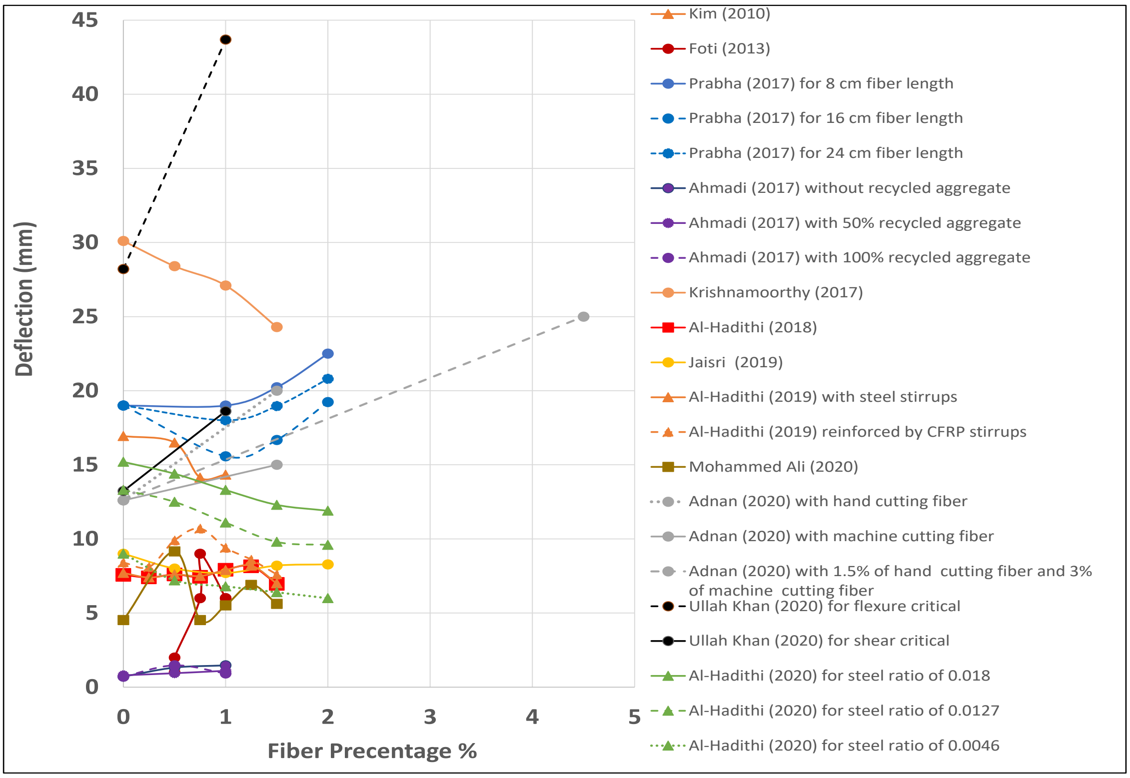


**Fig. (9)**: The variation of the ultimate load value of concrete beam by adding PET-Fiber

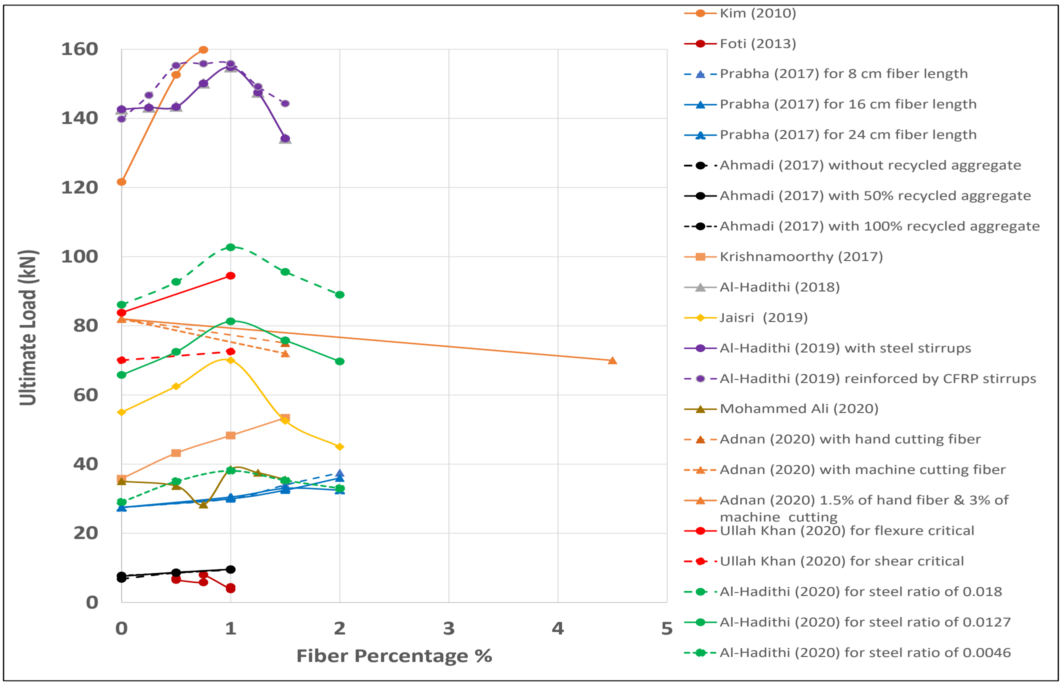


**Fig. (10):** The variation of the deflection value of concrete beam by adding PET-Fiber

Khalid, Irwan [61] examined the behavior of RC beams containing synthetic fibers. The results showed that adding ring-shaped PET (RPET-5) or (RPET-10) fibers to RC beams did not affect the deflection behavior of the control RC beams. Concrete beams containing RPET-10 during the cracking phase increased the initial crack by 32.3 percent more than control concrete beams. Except for the reinforced synthetic FC beams, the outcomes of the relative ductility (ultimate load) of the RC beams with RPET fibers were insignificant when associated to those of conventional RC beams. Adding RPET fibers to the RC beams, on the other hand, had a considerable impact, especially in the linear elastic zone. The results are shown in Fig. (11, Fig. (12, Fig. (13).

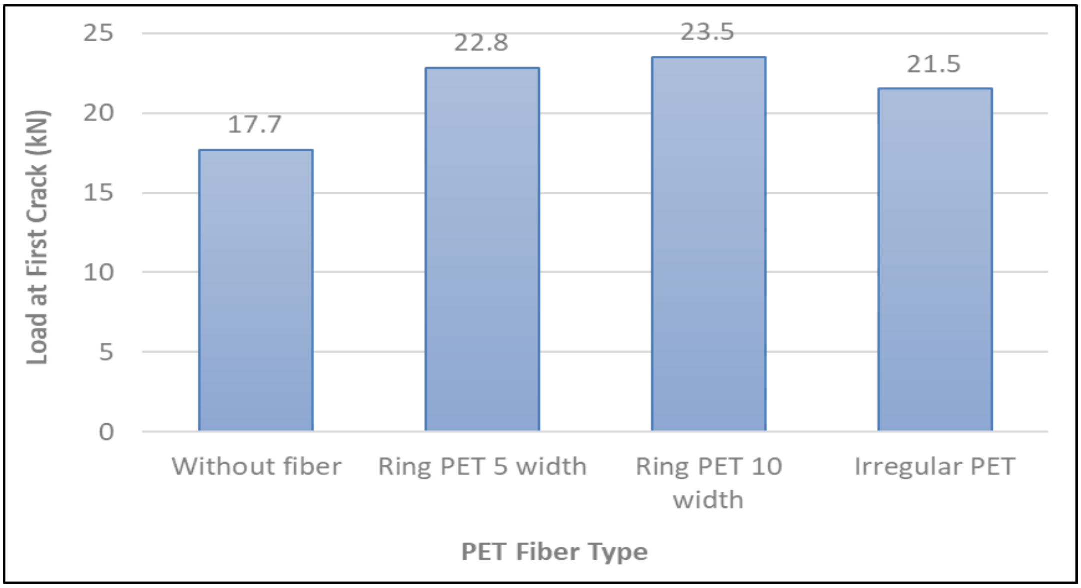


**Fig. (11)**: The variation of load at the first crack value of concrete beam with PET-Fiber types

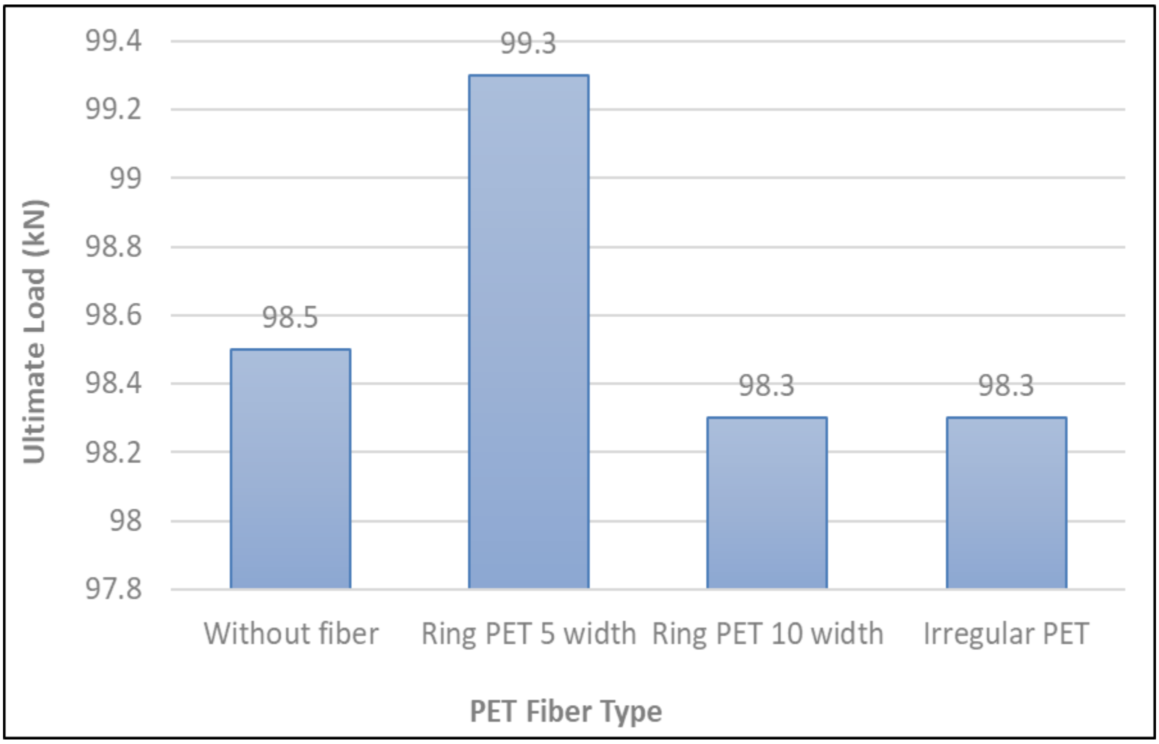


**Fig. (12):** The variation of ultimate load value of concrete beam with PET-Fiber type

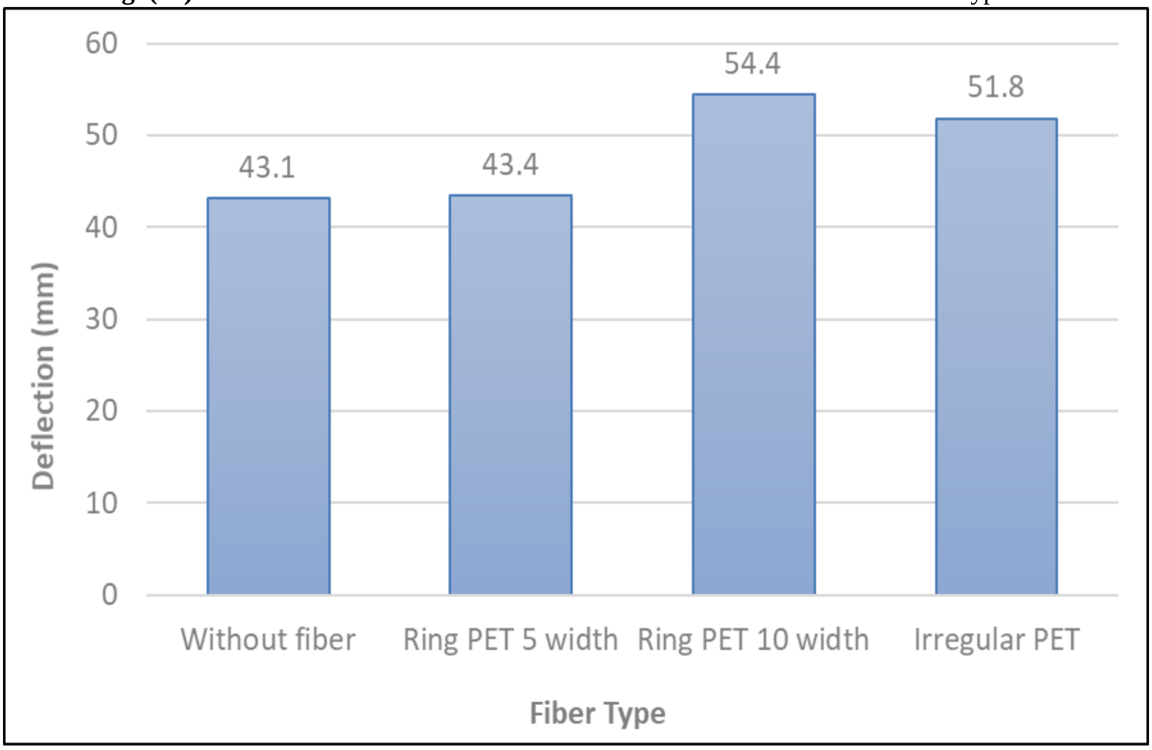


**Fig. (13):** The variation of the deflection value of concrete beam with PET-Fiber type

Mohammed and Rahim [76] reported that when PET fiber is added to concrete under flexural loading, the cracking of a load of HSC beams improves, attributable to the capacity to regulate cracks in the elastic region. The beam's ultimate load capacity was found to be considerably reduced. This can be explained by the degradation of compressive strength.

Furthermore, the presence of PET fiber does not impact the failure mode of a beam designed for flexure. Because the flexural reinforcement given in the tension zone controls the moment capacity of beams, HSC beams constructed of concrete with PET waste fiber have a good probability of being manufactured. Short PET fibers or a mix of short and long fibers with an ideal dosage of 0.75% by volume are recommended for this purpose. The results are illustrated in

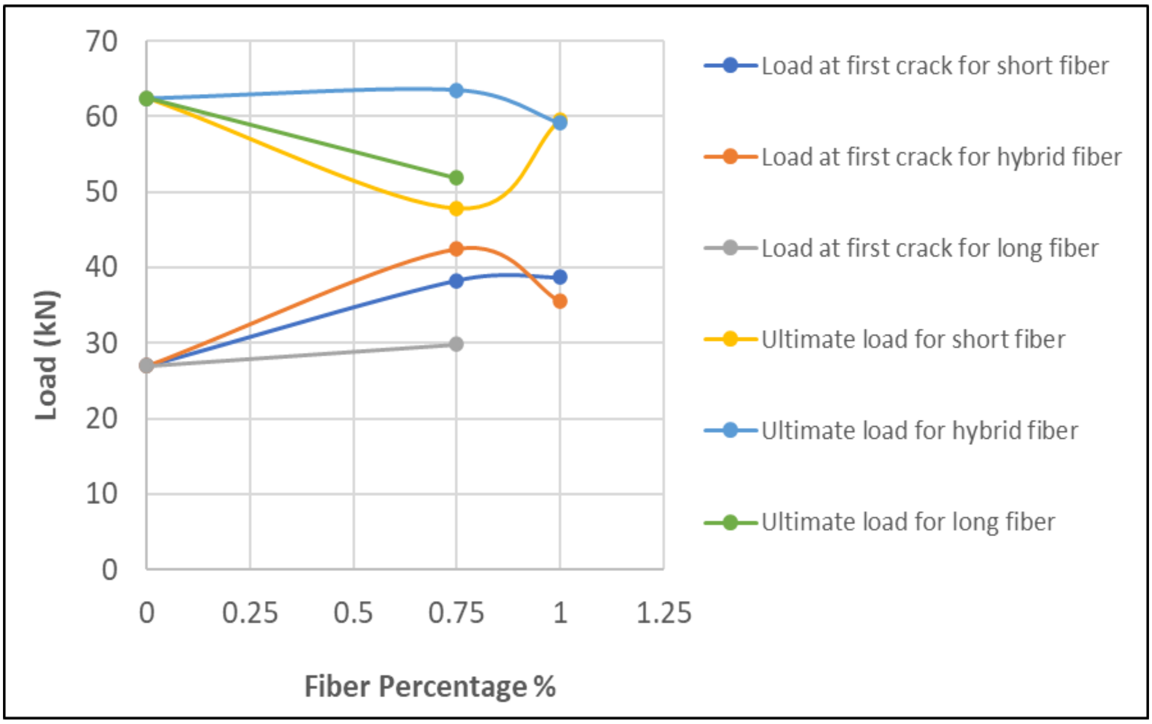


**Fig (14):** The variation of load value of concrete beam by adding PET-Fiber

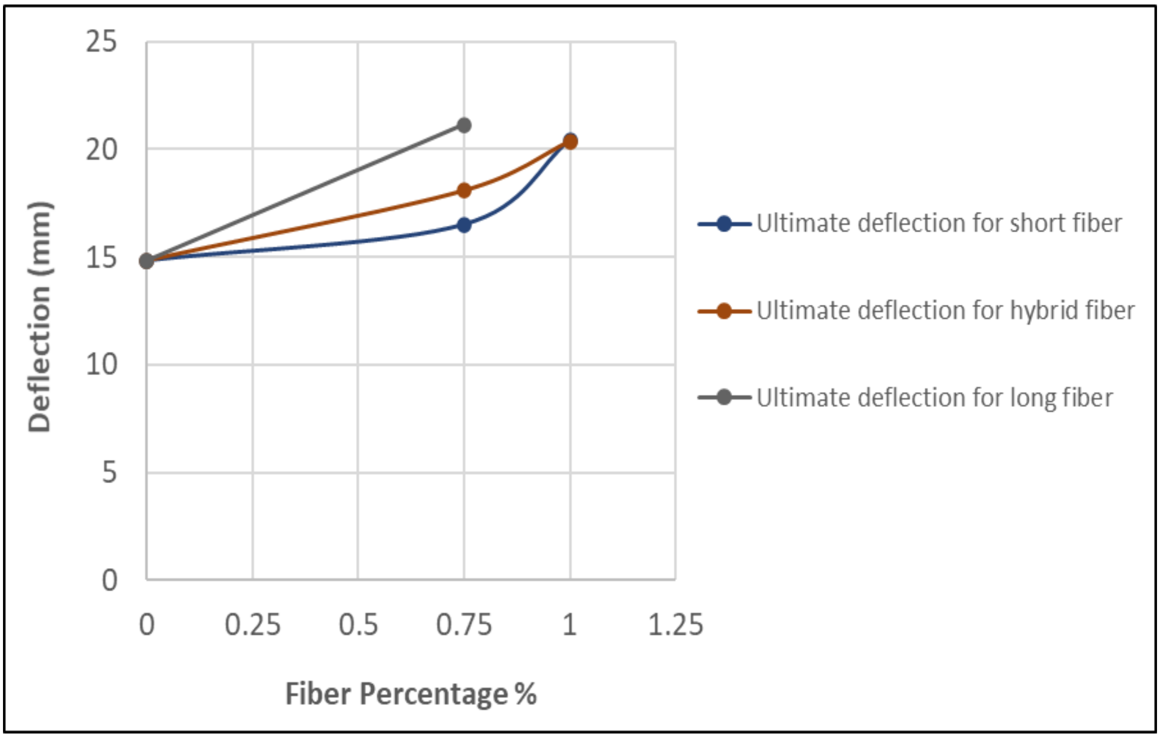


**Fig. (15):** The variation of the deflection value of concrete beam by adding PET-Fiber

## 5. CONCLUSION SUMMARY AND FUTURE STUDY DIRECTION

This study has presented first an in-depth literature review on the fresh and mechanical characteristics of concrete made of recycled PET waste from plastic bottles as green concrete. Second, it also presents a comprehensive review on the behavior of RC beams made of recycled PET waste from plastic bottles. An examination of the literature reveals a host of concerns that need to be investigated further:

1. The presence of PET fibers in concrete causes higher friction between the particles, resulting in decreased workability in the mixtures. In addition, the high concentration of fibers and large surface area of the fibers allow the cement paste to absorb quickly, increasing the viscosity of the concrete mixture.
2. The review claimed that the concrete density is slightly reduced with the addition of fiber to concrete.
3. There are typically flaws between the plastic surface and the concrete when PET fiber is present. Within the dense HSC mass, this will create a weak zone, allowing cracks to propagate and may be the key cause for the loss of compressive strength.
4. The strategy to improve tensile strength appears to be due to two factors: the fiber distribution in the mix must be homogeneous, and the fiber proportion must be properly calculated. When compared to concrete with lower volumes of fibers, a bridging mechanism increases the tensile strength of polypropylene fibers, and after a typical percentage of volume fraction, the extra fiber in the concrete reduces the binding strength between concrete ingredients, resulting in rapid failure.
5. In general, increasing the PET fiber content of concrete by 1% improves its flexural strength. Further increasing the fiber addition level in PET concrete, on the other hand, reduces its flexural strength.
6. Samples with plastic fiber underwent less deflection at the same load level than samples without waste plastic fiber because the fibers acted to bridge cracks. In addition, the presence of PET fiber in concrete leads to a drop in the number of cracks and their spacing. Furthermore, the absorbed energy and shear strength of RC beams were improved by mixing plastic fibers into the concrete until the fiber percentage reached 1%.
7. Based on a literature review of concrete material properties and RC beams that contains PET fiber, the shear behavior of high-strength RC beams, including PET fiber, has not been explored till now, including HSC material properties. This has been identified as a gap in the literature that needs further investigation.

The goal of encasing PET in concrete is important for two reasons: (i) to avoid its disposal in landfills, which would result in a loss of total material; and (ii) to inspire citizens to selectively recycle PET by demonstrating that the effort to segregate waste has good environmental consequences. PET can be used to partially substitute fine aggregates in concrete, with the triple benefit of (i) encouraging citizens to choose waste, (ii) avoiding waste from going to landfills, and (iii) reducing natural resource exploitation. As a result, the impact of recycled waste plastics as fine and coarse particles, as well as fiber, on the fresh, mechanical, and durability characteristics of concrete has been investigated.

Green concrete expands the range of waste materials that can be managed and used in practice. Incorporating waste materials that may leak toxic substances (waste plastics, some demolition waste, and some chemicals, for example) causes secondary pollution that can endanger human health and ecosystems. So far, in the sustainable building sector, the last item should be the most significant, and it should be addressed. Green concrete production reduces energy consumption by combining waste materials with mortar, yet, some methods are far from green when considering the release of dangerous chemicals into the environment as a result of their use in concrete. It's possible that the reduced strength is due to the larger air content and poor bonding capacity of plastic particles in concrete. Future study is needed in this area to enhance these factors. Changing the form, size, and surface of plastic particles can also help to improve the characteristics of concrete.

Recycled plastic aggregates could be used in civil engineering applications such as pavement and infrastructure instead of being disposed of in landfills. Façade elements, non-structural concrete panels, blocks (for river bank protection), concrete bricks (for general uses), and temporary shelters can all be made with recycled plastic aggregates. A specific level of plastic aggregates may be utilized in concrete for constructions with lower imposed loads, structural applications, and constructions where durability is less crucial. Instead of employing expensive synthetic or steel fibers, plastic fibers could be utilized in concrete to control fractures, shrinkage, and creep. Not only would this lessen reliance on natural aggregates, but it may also lower the concrete cost.

### 6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this review paper.

## REFERENCES


1.Meyer, C., *The greening of the concrete industry.* Cement and Concrete Composites, 2009. **31**(8): p. 601-605.
2.Hache, E., et al., *The impact of future power generation on cement demand: An international and regional assessment based on climate scenarios.* International Economics, 2020. **163**: p. 114-133.
3.Mehta, P.K., *Greening of the concrete industry for sustainable development.* Concrete international, 2002. **24**(7): p. 23-28.
4.Etxeberria, M., *13 - The suitability of concrete using recycled aggregates (RAs) for high-performance concrete*, in *Advances in Construction and Demolition Waste Recycling*, F. Pacheco-Torgal, et al., Editors. 2020, Woodhead Publishing. p. 253-284.
5.363R-10, A., *Report on high strength concrete*, in *American Concrete Institute*. 2010: Farmington Hills, MI.
6.Shah, A.A. and Y. Ribakov, *Recent trends in steel fibered high-strength concrete.* Materials & Design, 2011. **32**(8): p. 4122-4151.
7.Bencardino, F., et al., *Experimental evaluation of fiber reinforced concrete fracture properties.* Composites Part B: Engineering, 2010. **41**(1): p. 17-24.
8.Nili, M. and V. Afroughsabet, *Combined effect of silica fume and steel fibers on the impact resistance and mechanical properties of concrete.* International Journal of Impact Engineering, 2010. **37**(8): p. 879-886.
9.Ali, B., et al., *Development of Ductile and Durable High Strength Concrete (HSC) through Interactive Incorporation of Coir Waste and Silica Fume.* Materials, 2022. **15**(7): p. 2616.
10.Lakavath, C., et al., *Effectiveness of Hybrid Fibers on the Fracture and Shear Behavior of Prestressed Concrete Beams.* Fibers, 2022. **10**(3): p. 26.
11.Rahmani, E., et al., *On the mechanical properties of concrete containing waste PET particles.* Construction and Building Materials, 2013. **47**: p. 1302-1308.
12.Gourmelon, G., *Global plastic production rises, recycling lags. New Worldwatch Institute analysis explores trends in global plastic consumption and recycling. Retrieved 10 December 2017*. 2015.
13.Saikia, N. and J. de Brito, *Use of plastic waste as aggregate in cement mortar and concrete preparation: A review.* Construction and Building Materials, 2012. **34**: p. 385-401.
14.Oyenuga, A.A. and R. Bhamidimarri, *Reduce, Reuse and Recycle: Grand Challenges in Construction Recovery Process.* International Journal of Social Behavioral Educational, Economic, Business and Industry Engineering, 2015. **9**: p. 1131-1137.
15.Mohammed, A.A., *Flexural behavior and analysis of reinforced concrete beams made of recycled PET waste concrete.* Construction and Building Materials, 2017. **155**: p. 593-604.
16.Ferdous, W., et al., *Recycling of landfill wastes (tyres, plastics and glass) in construction–A review on global waste generation, performance, application and future opportunities.* Resources, Conservation and Recycling, 2021. **173**: p. 105745.
17.Al-Hadithi, A.I. and M.A. Abbas, *The effects of adding waste plastic fibers on the mechanical properties and shear strength of reinforced concrete beams.* Iraqi J. Civ. Eng, 2018. **12**: p. 110-124.
18.Hoornweg, D. and P. Bhada-Tata, *What a waste: a global review of solid waste management.* 2012.
19.Panyakapo, P. and M. Panyakapo, *Reuse of thermosetting plastic waste for lightweight concrete.* Waste Manag, 2008. **28**(9): p. 1581-8.
20.Siddique, R., J. Khatib, and I. Kaur, *Use of recycled plastic in concrete: a review.* Waste Manag, 2008. **28**(10): p. 1835-52.
21.Evode, N., et al., *Plastic waste and its management strategies for environmental sustainability.* Case Studies in Chemical and Environmental Engineering, 2021. **4**: p. 100142.
22.Afroz, M., M. Jobaer, and M. Mahmudul Hasan, *Performance of plain PET fibers to enhance the mechanical behavior of concrete under tension and shear.* International Journal of Science, Engineering and Technology Research, 2013. **2**(9): p. 1668-1672.
23.Won, J.-P., et al., *Long-term performance of recycled PET fibre-reinforced cement composites.* Construction and Building Materials, 2010. **24**(5): p. 660-665.
24.Singh, S., et al., *Sustainable utilization of granite cutting waste in high strength concrete.* Journal of Cleaner Production, 2016. **116**: p. 223-235.
25.Najm, H. and P. Balaguru, *Effect of large-diameter polymeric fibers on shrinkage cracking of cement composites.* Materials Journal, 2002. **99**(4): p. 345-351.
26.Qi, C., J. Weiss, and J. Olek, *Characterization of plastic shrinkage cracking in fiber reinforced concrete using image analysis and a modified Weibull function.* Materials and Structures, 2003. **36**(6): p. 386-395.
27.Kim, J.-H.J., et al., *Effects of the geometry of recycled PET fiber reinforcement on shrinkage cracking of cement-based*

*composites.* Composites Part B: Engineering, 2008. **39**(3): p. 442-450.
28.Foti, D., *Use of recycled waste pet bottles fibers for the reinforcement of concrete.* Composite Structures, 2013. **96**: p. 396-404.
29.Yoo, D.-Y. and N. Banthia, *Mechanical properties of ultra-high-performance fiber-reinforced concrete: A review.* Cement and Concrete Composites, 2016. **73**: p. 267-280.
30.Meddah, M.S. and M. Bencheikh, *Properties of concrete reinforced with different kinds of industrial waste fibre materials.* Construction and Building Materials, 2009. **23**(10): p. 3196-3205.
31.Khalil, W. and H. Mahdi. *Some properties of sustainable concrete with mixed plastic waste aggregate*. in *IOP Conference Series: Materials Science and Engineering*. 2020. IOP Publishing.
32.Ahmed, H.U., et al., *Use of recycled fibers in concrete composites: A systematic comprehensive review.* Composites Part B: Engineering, 2021. **215**.
33.Fangueiro, R., *Fibrous and composite materials for civil engineering applications*. 2011: Elsevier.
34.Panowicz, R., et al., *Properties of Polyethylene Terephthalate (PET) after Thermo-Oxidative Aging.* Materials, 2021. **14**(14): p. 3833.
35.Shan, L. and L. Zhang. *Strength and fiber synergy effect of steel-polypropylene hybrid fibre-reinforced concrete*. in *IOP Conference Series: Earth and Environmental Science*. 2019. IOP Publishing.
36.Meza, A., et al., *Mechanical Optimization of Concrete with Recycled PET Fibres Based on a Statistical-Experimental Study.* Materials (Basel), 2021. **14**(2).
37.Ajamu, S., J. Ige, and T. Oyinkanola, *Effect of waste (PET) bottle fibers on the properties of concrete.* International Journal of Research in Engineering & Technology, 2018. **6**(9).
38.Meza, A., et al., *Mechanical Optimization of Concrete with Recycled PET Fibres Based on a Statistical-Experimental Study.* Materials (Basel, Switzerland), 2021. **14**(2): p. 240.
39.Umasabor, R.I. and S.C. Daniel, *The effect of using polyethylene terephthalate as an additive on the flexural and compressive strength of concrete.* Heliyon, 2020. **6**(8): p. e04700-e04700.
40.Silva, D.A., et al., *Degradation of recycled PET fibers in Portland cement-based materials.* Cement and Concrete Research, 2005. **35**(9): p. 1741-1746.
41.Ochi, T., S. Okubo, and K. Fukui, *Development of recycled PET fiber and its application as concrete-reinforcing fiber.* Cement and Concrete Composites, 2007. **29**(6): p. 448-455.
42.Kim, S.B., et al., *Material and structural performance evaluation of recycled PET fiber reinforced concrete.* Cement and Concrete Composites, 2010. **32**(3): p. 232-240.
43.Foti, D., *Preliminary analysis of concrete reinforced with waste bottles PET fibers.* Construction and Building Materials, 2011. **25**(4): p. 1906-1915.
44.Fraternali, F., et al., *Experimental study of the thermo-mechanical properties of recycled PET fiber-reinforced concrete.* Composite Structures, 2011. **93**(9): p. 2368-2374.
45.Pereira de Oliveira, L.A. and J.P. Castro-Gomes, *Physical and mechanical behaviour of recycled PET fibre reinforced mortar.* Construction and Building Materials, 2011. **25**(4): p. 1712-1717.
46.Pelisser, F., et al., *Mechanical properties of recycled PET fibers in concrete.* Materials Research, 2012. **15**(4): p. 679-686.
47.Ramadevi, K. and R. Manju, *Experimental investigation on the properties of concrete with plastic PET (bottle) fibres as fine aggregates.* International journal of emerging technology and advanced engineering, 2012. **2**(6): p. 42-46.
48.Nibudey, R., et al., *Strength and fracture properties of post consumed waste plastic fiber reinforced concrete.* International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD), 2013. **3**(2): p. 9-16.
49.Maruthachalam, D. and J. Muthukumar, *Mechanical Performance of Recycled Pet Fiber Reinforced Concrete with Low Volume Fraction.* International Journal of Structural and Civil Engineering Research, 2013. **2**: p. 101-108.
50.Prahallada, M. and K. Parkash, *Effect of different aspect ratio of waste plastic fibers on the properties of fiber reinforced concrete e an experimental investigation.* International Journal of Advanced Engineering Research and Technology, 2013. **2**: p. 1-13.
51.Irwan, J.M., et al., *The Mechanical Properties of PET Fiber Reinforced Concrete from Recycled Bottle Wastes.* Advanced Materials Research, 2013. **795**: p. 347-351.
52.Spadea, S., et al., *Energy dissipation capacity of concretes reinforced with recycled PET fibers.* Ing. Sismica, 2014. **31**(2): p. 61-70.
53.Taherkhani, H., *An investigation on the properties of the concrete containing waste PET fibers.* International Journal of Science and Engineering Investigations, 2014. **3**(27): p. 37-43.
54.Marthong, C., *Effects of PET fiber arrangement and dimensions on mechanical properties of concrete.* The IES Journal Part A: Civil & Structural Engineering, 2015. **8**(2): p. 111-120.
55.Marthong, C. and D.K. Sarma, *Mechanical Behavior of Recycled Pet Fiber Reinforced Concrete Matrix.* International Journal of Civil and Environmental Engineering, 2015. **9**(7): p. 879-883.
56.Marthong, C. and S. Marthong, *An experimental study on the effect of PET fibers on the behavior of exterior RC beam-column connection subjected to reversed cyclic loading.* Structures, 2016. **5**: p. 175-185.

57. Wiliński, D., P. Łukowski, and G. Rokicki, *Application of fibres from recycled PET bottles for concrete reinforcement.* Journal of Building Chemistry, 2016. **1**(1): p. 1-9.
58. Boiny, H.U., Y.M. Alshkane, and S.K. Rafiq. *Mechanical properties of cement mortar by using polyethylene terephthalate fibers*. in *5th National and 1st International Conference on Modern Materials and Structures in Civil Engineering, Iran (Islamic Republic of Iran)*. 2016.
59. Guendouz, M., et al., *Use of plastic waste in sand concrete.* J. Mater. Environ. Sci, 2016. **7**(2): p. 382-389.
60. Ananthi, A., A.J.T. Eniyan, and S. Venkatesh, *Utilization of Waste Plastics as a Fiber in Concrete.* International Journal of Concrete Technology, 2017. **3**(1): p. 56-60.
61. Khalid, F., et al., *Performance of plastic wastes in fiber-reinforced concrete beams.* Construction and Building Materials, 2018. **183**: p. 451-464.
62. Shahidan, S., *Concrete incorporated with optimum percentages of recycled polyethylene terephthalate (PET) bottle fiber.* International Journal of Integrated Engineering, 2018. **10**(1).
63. Al-Hadithi, A.I., A.T. Noaman, and W.K. Mosleh, *Mechanical properties and impact behavior of PET fiber reinforced self-compacting concrete (SCC).* Composite Structures, 2019. **224**: p. 111021.
64. Mohammed, A.A. and A.A.F. Rahim, *Experimental behavior and analysis of high strength concrete beams reinforced with PET waste fiber.* Construction and Building Materials, 2020. **244**: p. 118350.
65. Thomas, L.M. and S.A. Moosvi, *Hardened properties of binary cement concrete with recycled PET bottle fiber: an experimental study.* Materials Today: Proceedings, 2020. **32**: p. 632-637.
66. Huang, Y. and A. Zhou, *Study on Mechanical Properties of PET Fiber-Reinforced Coal Gangue Fine Aggregate Concrete.* Geofluids, 2021. **2021**.
67. Huang, H., et al., *Property Assessment of High-Performance Concrete Containing Three Types of Fibers.* International Journal of Concrete Structures and Materials, 2021. **15**(1).
68. Prabha, D. and S. George, *Shear Behaviour of Reinforced Concrete Using PET Bottle Fibre.* International Journal of New Technology and Research, 2017. **3**(5): p. 263288.
69. Ahmadi, M., et al., *Mechanical properties of the concrete containing recycled fibers and aggregates.* Construction and Building Materials, 2017. **144**: p. 392-398.
70. Jaisri, M.P. and M.M. Kanimozhi, *Flexural Strength of Concrete Using Polyethylene Terephthalate (PET) Fibres.* 2019.
71. Al-Hadithi, A.I. and M.A. Abbas, *Innovative technique of using carbon fibre reinforced polymer strips for shear reinforcement of reinforced concrete beams with waste plastic fibres.* European Journal of Environmental and Civil Engineering, 2019. **25**(3): p. 516-537.
72. Mohammed Ali, T.K., *Shear strength of a reinforced concrete beam by PET fiber.* Environment, Development and Sustainability, 2020. **23**(6): p. 8433-8450.
73. Adnan, H.M. and A.O. Dawood, *Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers.* Case Studies in Construction Materials, 2020. **13**: p. e00367.
74. Ullah Khan, S. and T. Ayub, *Flexure and shear behaviour of self-compacting reinforced concrete beams with polyethylene terephthalate fibres and strips.* Structures, 2020. **25**: p. 200-211.
75. Al-Hadithi, A., M. Abdulrahman, and M. Al-Rawi. *Flexural behaviour of reinforced concrete beams containing waste plastic fibers*. in *IOP Conference Series: Materials Science and Engineering*. 2020. IOP Publishing.
76. Mohammed, A.A. and A.A.F. Rahim, *Experimental behavior and analysis of high strength concrete beams reinforced with PET waste fiber.* Construction and Building Materials, 2020. **244**.