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FLEXURAL INVESTIGATION OF FIBROUS CONCRETE SLABS INCORPORATING PET WASTES AS SAND REPLACEMENT

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Abstract

In this paper, the effect of polyethylene terephthalate waste (PET) on the bending behavior of one-way reinforced fibrous concrete slabs was studied. seven different percentages of PET as sand replacement by weight were used: 0%, 5%, 10%, 15%, 20%, 30%, and 50% reinforced by ratio 1.5% of polypropylene fibers of the concrete mixture volume. Seven concrete slab specimens for each replacement ratio of PET with dimensions of 1500 × 500 × 80 mm were tested, in addition to reference slab. The specimens were tested using a four-point load setup, the measurements included failure load, maximum deflection, flexural strain, ductility index, energy absorption, stiffness, first crack load, and crack pattern. Based on maximum load capacity, 10% PET wastes as sand replacement is the optimum proportion in fibrous concrete mixture with 1.5% polypropylene fiber, yielding an ultimate failure load of 51KN. In additional, the values of the ultimate failure load for the mixtures containing PET waste were change by 4.22%, 14.14%, 26.55%, 11.66%, -0.74%, -5.71% and -57.82%, compared to the reference mixture. Other parameters such as maximum deflection, strain, and energy absorption is increase when the percentage of PET increasing in range 5-30% but, the ductility index is increasing in rang 5-50% in concrete slabs. On the other hand, initial stiffness and secant stiffness were found to be lower when the ratio of PET increasing in range 5-30% ,5-50%, respectively.

Keywords:

PET Waste;
Polypropylene fiber PP;
Fibrous concrete;
Reinforced concrete slabs;
Ultimate failure load;
Initial stiffness;
Ductility index.

1 Introduction

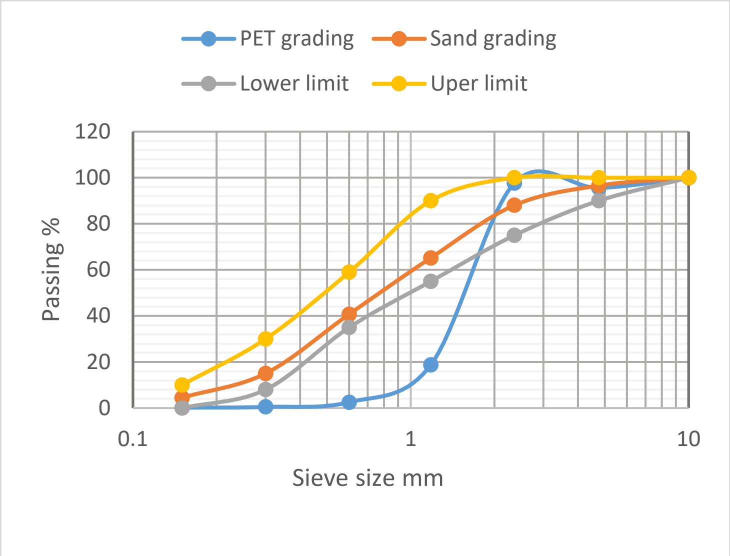
Solid waste is one of many things that hurt the environment. Despite being biodegradable, the yearly quantity of solid waste products from plastics used in homes and businesses is a major contributor to environmental degradation [1-3]. Over the previous half-century, the world's plastic industry has expanded tremendously, increasing from 15 to 322 metric tones. In many countries, plastics are just thrown away in landfills without any kind of treatment, such recycling or repurposing them for environmental benefit [4]. The amount of solid trash that was recycled was just 30%; the rest was either burnt or disposed of in landfills. [5] It was the complexity of plastic waste and the limited quantity of repurposing that set off the problems [6,7]. New studies show that plastic is being investigated more and more for possible usage in concrete Although certain waste materials may be used in concrete, either as fine or coarse aggregates or as added mixes [8,9], it is important to note that not all waste materials are suitable for this use. Recycled crushed glass (RCG), polyethylene terephthalate (PET), and plastic packaging waste (PPW) were used in masonry brick projects in several research [10,11]. An experimental investigation of the effects of polyethylene terephthalate (PET) on concrete was carried out not long ago by a group of researchers who used standard cubes, cylinders, and flexural test beams to measure the material's mechanical characteristics. With the help of contemporary living, they hoped to dispose of these items more efficiently [8,12-14,15]. Some research has studied plastic boxes waste as sand replacement [16]. Other research has studied PVC waste particles as sand replacement [17]. In addition, some research has studied the possibility of recycling PET as reinforcing bars [18,19]. Few studies have investigated Iron filings as a partial substitute for sand [20,21]. Very few studies have investigated the effects of recycled PET fibers on the behaviour of reinforced concrete beams in terms of their structural integrity. Kim et al. [22] examined how three different volumetric percentages of PET fiber 0.5%, 0.75 %, and 1% impacted the structural behaviour of reinforced concrete beams of 2000 × 200 × 300 mm. There was a 400% increase in mid-span deflection compared to the reference specimens, and PET fibers improved tensile resistance, delayed crack figuration, increased ductility, and load capacity. Adnan and Dawood [23] examined the structural behaviour of four 150 × 200 × 1400 mm concrete beam specimens using two kinds of PET fiber waste: uniform hand fibers and uneven machine fibers. Each kind was tested with two volume percentages, 1.5 % and 3%. The beams' secant stiffness and load capacity were found to be somewhat reduced. Nevertheless, there was a noticeable rise in ductility behaviour and an initial stiffness increase. A typical type of reinforced concrete component used as a floor system or deck in buildings and bridges is the one-way reinforced concrete slab. Improving the resilience and longevity of reinforced concrete slabs is a continuously evolving field of study. Since concrete is fragile and has a poor tensile strength, its load-carrying mechanism is severely impaired once cracks start to emerge. Cracks caused by shrinkage have long been an obvious issue with concrete buildings. The slabs under high-speed rails and concrete pavements show these fissures clearly. Controlling the cracks that form as concrete expands and contracts as a result of temperature variations is an ongoing challenge for such structural components. the fibers increase toughness and fracture resistance in hardened concrete by transmitting load at interior micro-cracks [24,25]. Nevertheless, because to developments in composite materials, particularly fibers, several kinds of fibers may be used to increase the durability and endurance of concrete [26-28]. Because PPF reinforced concrete helps to reduce member thickness and, by extension, structural weight, it is much simpler to handle and transport [29]. Adding PPF to concrete decreases its expansion and greatly enhances its strength, keeping the building in a better usable condition [30,31]. The tensile strength of concrete may be increased by adding more fibers [32]. According to Manolis et al. (1997) [33], using 0.5% PPF significantly increased the on-grade slab's resistance to impact loading compared to using 0.1% PPF. Steel fiber reinforced concrete slabs' toughness and ultimate load-carrying capability have been the subject of many previous studies [34,35]. In 2019, a study conducted by Wu et al. [36], the impact of SF on the flexural behaviour of GFRP reinforced beams was examined. The results showed that a 22% improvement in load-carrying capacity was achieved with the addition of 0.6% SF by volume. According to many studies [37,38,39,40,41], fibers play an important role in preventing flexural cracks in slabs. This study stands apart from the others since it investigates the impact on reinforced concrete slabs' structural behaviour of using polyethylene terephthalate waste as a partial substitute for sand. Seven different percentages of PET waste 0%, 5%, 10%, 15%, 20%, 30% and 50% were distributed as partial sand replacement on seven reinforced concrete slabs with dimensions of 1500 x 500 x 80 mm in addition to a reference slab. The specimens were tested using a four-point bending. A set of tests was used to ensure the structural behaviour of each slabs. There are three main advantages to using PET plastic waste in construction projects. Firstly, it helps to reduce the negative effects on the environment. Secondly, it improves the structural behaviour of concrete members. Lastly, it provides a sustainable material that can be used as a partial alternative to aggregates, increasing the longevity of its source.

2 Experimental methodology

In the present study the experimental program is to investigate the effects of using recycled PET bottles as a partial fine aggregate replacement in reinforced fibrous concrete slabs at different percentages.

2.1 Materials

This study makes use of Type I Ordinary Portland Cement. All of these characteristics meet the standards set forth by Iraqi Specification No. 5/1984 [42]. For a fine aggregate, the sand is brought in from the city of Basra in southern Iraq and has a maximum size of 4.75 mm. Coarse aggregate that is no larger than 20 mm was used. Both aggregate kinds are graded according to Iraqi standard Specification No.45/1984 [43]. The grading curve of coarse aggregate as shown in the Fig.1(b) show. This study used PC 260, a polymer derived from modified polycarboxylates, a liquid type superplasticizer that met the requirements of ASTM C494-99 classes A and G [44]. As per the technical standard, the dosage might vary between 0.5L and 4L per 100Kg of binder. For the PET particles were sourced from both large and tiny PET bottles. the PET bottle aggregate is made by crushing and recycling PET bottles of different sizes and colours until they pass through sieve No. 4. Iraqi Specification No.45/1984 [43] was satisfied by the PET particle sieve examination. Fig.1(a) show the grading curve of PET waste and fine aggregate. The shape of PET is shown in Fig.2(a). Polypropylene fibre with a diameter (0.018 mm) and a length of (12 mm) were used to be added to the concrete containing the replacement ratios of PET waste. These fibers have a modulus of elasticity (3700 MPa) and tensile strength (350MPa). Fig.2(b) show the shape of these fibers. Slabs were reinforced longitudinally and laterally with deformed steel bars that had a diameter of 10 mm. the spacing between the steel bars in long direction is 290 mm and 150mm in short direction. The properties of the steel reinforcement were satisfied by ASTM A615/A615M-13[45].



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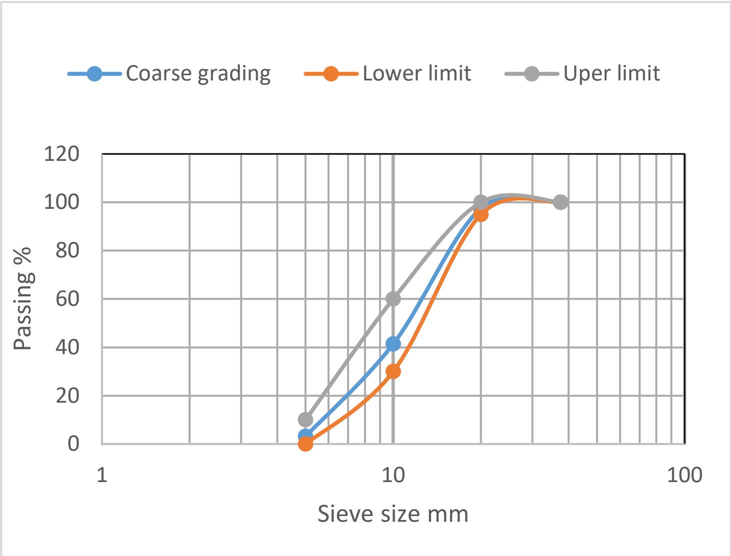

b

Fig.1: a) A grading curve for pet waste and fine aggregate. b) A grading curve for coarse aggregate.

a. the PET waste shape b. the PP fiber's shape

Fig.2: a) the PET waste shape. b) the PP fiber's shape.

2.3 Preparation of the test specimen

Coarse and fine aggregates were both washed and dried before being added to the mixture. Forms were cleaned, oiled, and prepared for casting. Eight forms with dimension of 1500 × 500 × 80 mm were prepared. Every slab used the same reinforcing detail. The variables in this investigation were the percentages of PET waste particles, which were manufactured and combined to partially replace sand in the fibrous concrete slabs. These samples have been named as shown in the Table 1. A mechanical mixer was used to combine each percentage independently. It all started with the addition of fine aggregates, which included PET waste particles. After that, cement and coarse aggregates were combined until the mixture was homogeneous. The next step was the slow addition of superplasticizer and water. Then while the mixing basin is still rotated, the polypropylene fibers are carefully added to the concrete mixture. The mixing operations were halted at least two minutes subsequent to the mixing. After that, the forms were filled with two layers of new concrete, which was then compacted using a vibratory process. Finally, the forms' exteriors were levelled. Forms were unsealed after 48 hours, and specimens were covered with a cotton towel to keep moisture in. Curing for 28 days included continuing to moisten, as shown in Fig.3. After a period of 28 days from the date of casting, all samples were testing.

Fig.3: Casting, curing procedure, and slab specimens.

2.4 Instrumentation and loading setup

Simply supported one-way slabs concrete were cast with dimensions (1500 × 500 × 80) mm and containing different proportions of PET waste. The length to width ratio of these slabs is greater than 2. For each slab, the four-point bending test was used, which involves putting two points to monotonic loads. The shear span to effective depth ratio (a/d) was 7 to ensure flexural failure of slabs and avoiding shear failure. The specimen was placed on two steel roller supports at a distance of 50 mm, measured from the edge of the slab. There were three sections to the 1400 mm specimen's clear span: a 600 mm part spanning mid between the applied forces and two 400 mm sections at each end as shown in the Fig.4. The concentrated load was applied to a distributor slab, which in turn created two concentrated loads on the test slab, using a testing equipment with a capacity of 6,000 KN as shown in the Fig.5. The deflection of the slab specimen was measured by using a device (LVDT) that was positioned at the slab's center from the bottom, an electrical strain gauges measuring 30 mm in length and 120 ohms in resistance are attached at the top slab's mid-point. Thus, in order to collect and preserve the test data, the LVDT and strain gauges was used throughout the test. These data were then sent to a computer for further processing. Data was captured on the slabs' behaviour, as well as cracks and failure methods. The experimental findings of tested slabs were strain, ductility index, energy absorption, maximum deflection, stiffness, and ultimate failure load. Additionally, the reference slab was used to compare the results of the crack study, which included the initial crack load and fracture pattern.

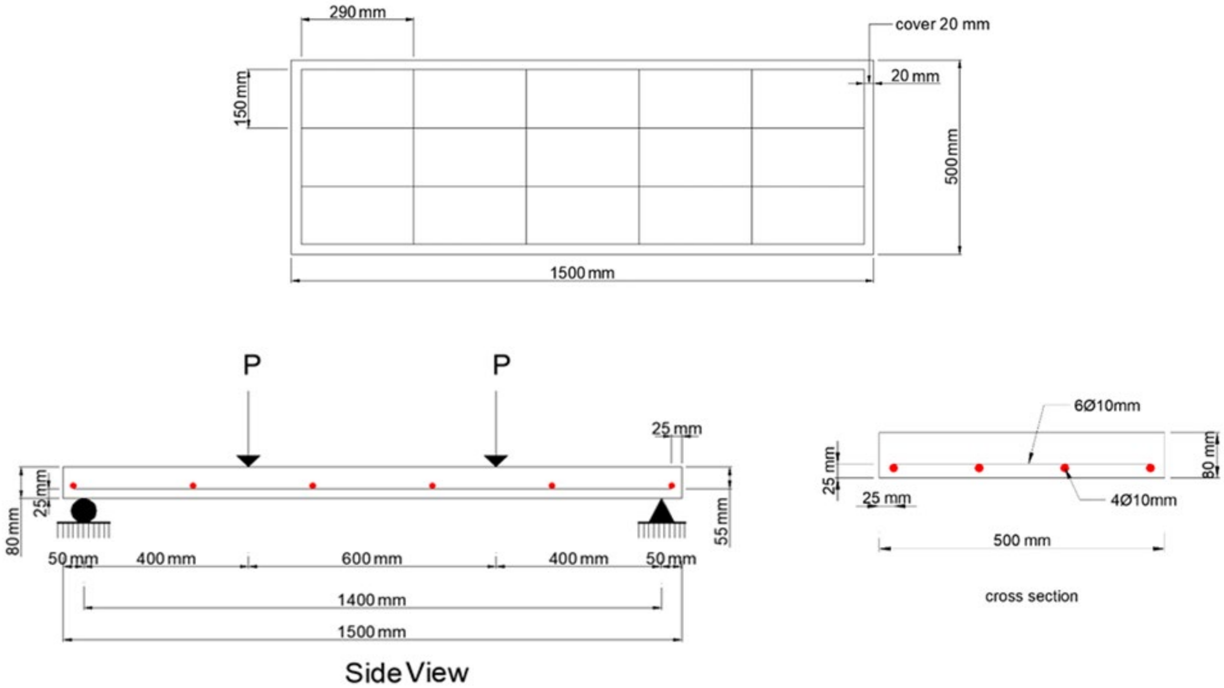

Fig.4: The steel details for all slabs.

Fig.5: Slab Bending Test Machine.

3 Results and discussion
3.1 Slab ultimate load

Fig.6 displays the ultimate failure load values for all reinforced fibrous concrete slabs that the reference slab S0%0%R, which is free of PET and fibers, has an ultimate failure load of 40.3 KN. When compared to the reference slab, slab S0%PF1.5%%R exhibited a 4.22% increase in ultimate failure load, reaching 42KN. A concrete slab with a 5% PET plastic waste to sand ratio (S5%PF1.5%R) achieved an ultimate failure load of 46 KN, which is 14.14% more than the reference slab. The slab concrete that contains 10% PET waste (S10%PF1.5%R) has a greater ultimate load of 51 KN, an increase of 26.55% Compared to the reference slab. Slab S15%PF1.5%R, which replaced 15% of the sand with PET waste, had an ultimate failure load of 45 KN increase by 11.66% when compared to the reference samples. However, specimens S20%PF1.5%R and S30%PF1.5%R showed a decline in ultimate strength when compared to the reference slab; the former had a failure load of 40 KN and the latter of 38 KN, a decline of -0.74% and -5.71%, respectively. Then the slab(S50%PF1.5%R) achieved a severe decline in ultimate failure load 17KNwhich decrease 57.82% when compared to reference slab. The results for all slabs tests shown in the Table 1.

Table 1: Results for all slabs tests.

Slab Designation	PET Ratio %	Ultimate Load Pu [KN]	Maximum deflection Δu [mm]	First crack Fcr [KN]
S0%0%R	0	40.3	15.3	14
S0%PF1.5%R	0	42	17.28	15
S5%PF1.5%R	5	46	19.56	20
S10%PF1.5%R	10	51	21.75	35
S15%PF1.5%R	15	45	23.72	38
S20%PF1.5%R	20	40	25.65	16
S30%PF1.5%R	30	38	27.23	12
S50%PF1.5%R	50	17	16.32	10

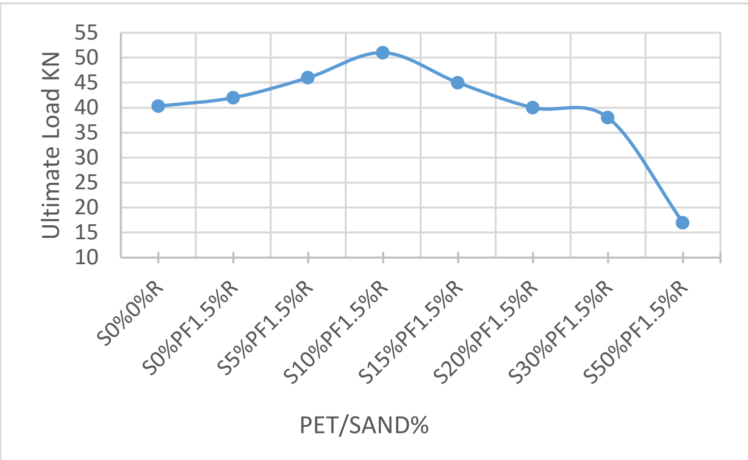

Fig.6: The ultimate failure load to (PET/SAND) relative.

3.2 Load–deflection behavior

Fig.7 displays a mid-span load deflection curve, which shows the maximum deflection of all concrete slabs. As the percentage of PET waste in the concrete slabs rises, the maximum deflection also rises in range 5-30%, according to the data. The lowest maximum deflection measured by the reference slab S0%0%R % was 15.3 mm. In contrast, the concrete slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, and S20%PF1.5%R achieved maximum deflections of 17.28, 19.56, 21.75, 23.72, and 25.65 mm, respectively. These slabs were 12.94%, 27.84%, 42.16%, 55.03%, and 67.65% greater than the reference specimen. With a 77.97% increase over the reference slab, Slab S30%PF1.5%R reached the maximum deflection of 27.23 mm. when the replacement ratio 50% slab

(S50%PF1.5%R) achieved slight increase in maximum deflection 16.32 which increase by 6.67% compared to reference slab. in The presence of PET waste has a favourable influence on the behavior of concrete slabs, as seen in Fig.7, which shifts to another, more flexible behavior in Fig.8, as shown in the maximum deflection path behavior. Based on the relationship between the ultimate failure load and maximum deflection, sample S10%PF1.5%R is considered optimal. As an early warning system before failure, it also shows that the fraction time is becoming longer. A critical property of concrete is its capacity to reduce the effects of dynamic and impulsive stresses in addition to seismic activity.

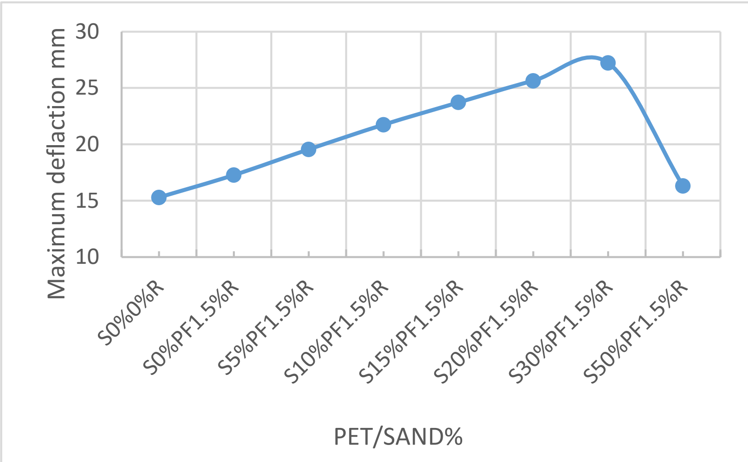

Fig.7: The maximum deflection to (PET/SAND) relative.

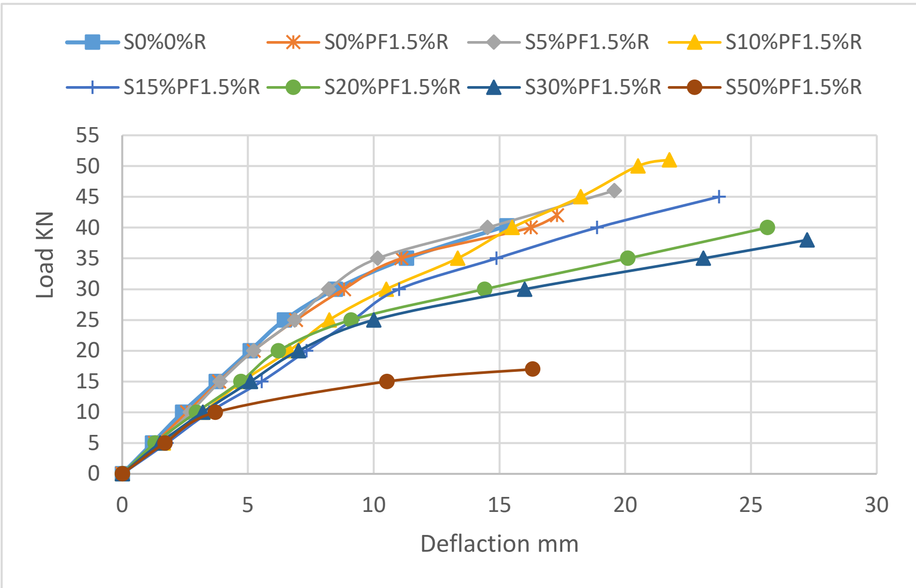

Fig.8: The load to deflection relative for all concrete slabs.

3.3 Ductility index

The ductility index μ may be found through contrasting the load-deflection curve, which is determined by the ratio of the ultimate deflection Δu to the yield deflection Δy. Ductility index results for all Fibrous concrete slabs are shown in Fig.9. In comparison to the control samples, the ductility increases were compatible with the final deflection increase. The ductility index of the concrete slabs increased as the percentage of PET waste increased. Slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, and S30%PF1.5%R had ductility indices of 2.06, 2.08, 2.18, 2.20, 2.91, and 3.17, respectively. Relative to the reference slab, which had the lowest ductility index of 1.99, the corresponding increase ratios were 3.52%, 4.52%, 9.55%, 10.55%, 46.23%, and 59.30%. Then the slab (S50%PF1.5%R) which replacement ratio 50% achieved a rising in ductility 4.08 which increase 105.03% when compared to reference slab.

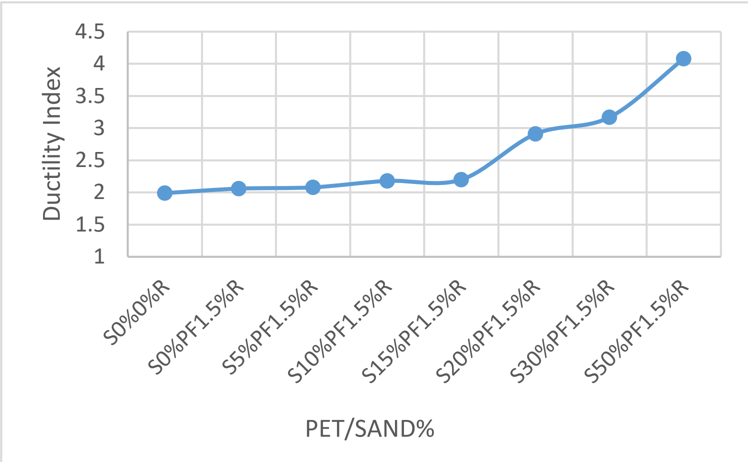

Fig.9: The ductility index to (PET/SAND) relative for all concrete slab.

3.4 Flexural compression strain at failure load

According to the flexural strain measurements, compression strain in reinforced concrete slabs increases as the percentage of PET waste rises in range (5%-30%). Fig.10 shows strain curves, which further demonstrate that reference specimen S0%0%R had compression strains of 0.002639. Slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, and S30%PF1.5%R that record strains of 0.002805, 0.003065, 0.0031, 0.003155, 0.003284, and 0.003305, respectively, with increments of 6.29%, 16.14%, 17.47%, 19.55%, 24.44%, and 25.24, respectively, compared with the reference slab. Then the slab(S50%PF1.5%R) achieved decline in strain 0.0021which decrease 20.42% compared to reference slab. The flexural strain should not go over 0.0035, and all of the strain measurements were within that range. Fig.11 shows a load-strain curve for each specimen, which contrasts the brittleness of the reference concrete slabs with that of the specimens treated with PET particles.

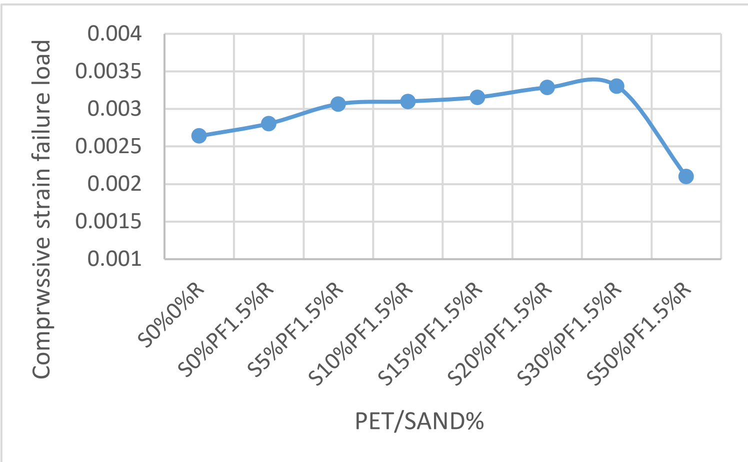

Fig.10: The strain at failure load to (PET/SAND) relative.

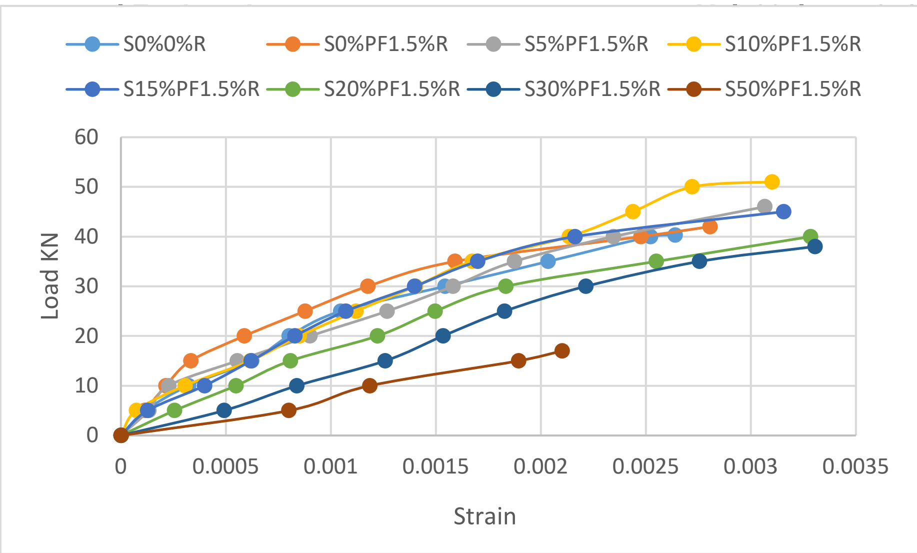

Fig.11: The load to strain for all concrete slabs.

3.5 Stiffness

The initial stiffness and secant stiffness may be obtained from the load-deflection curve. To get the initial stiffness, divide the yield load (PY) by the deflection at yield load (Δy). Additionally, divide the final applied load (Pu) by the ultimate deflection (Δu) to get the secant stiffness. The stiffness is computed in accordance with the work of T. Sullivan et al. [46]. The equations that follow:

Initial stiffness $=\frac{PY}{\Delta y}$ (1)

Secant stiffness $=\frac{Pu}{\Delta u}$ (2)

According to the results, the initial stiffness of the reference concrete slab S0%0%R or slabs with a low PET content S0%PF1.5%R and S5%PF1.5%R were similarly close, measuring 3.90, 3.75, and 3.67 KN/mm, respectively. The initial stiffness of slabs, S10%PF1.5%R, S15%PF1.5%R and S20%PF1.5%R was 3.0, 2.79, and 2.73 KN/mm, respectively, and these slabs showed decreases of 23.08%, 28.46 %, and 30 % when compared to the reference slab. Slab S30%PF1.5%R achieved the lowest initial stiffness of 2.67 KN/mm with a decrease of 31.54% compared to the reference slab. then the slab (S50%PF1.5%R) achieved initial stiffness 3.1KN/mm which less than by 20.51 compared to the reference slab. As can be seen in Fig.12, the initial stiffness reduces as the amount of PET waste increases in rang (5%-30%).

Secant stiffness reduce when the percentage of PET waste in concrete slabs increasing, as shown in Fig.13. The reference slab recorded Secant stiffness of 2.63 KN/mm While concrete slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, S30%PF1.5%R and S50%PF1.5%R had secant stiffness of 2.43, 2.35, 2.34, 1.9, 1.56, 1.40 and 1.04 KN/mm, respectively. This stiffness was 7.60%, 10.65%, 11.03%, 27.76%, 40.68%,46.77% and 60.46% lower than the reference slab. There is an inverse connection between deflection and stiffness in slabs, which is consistent with this result

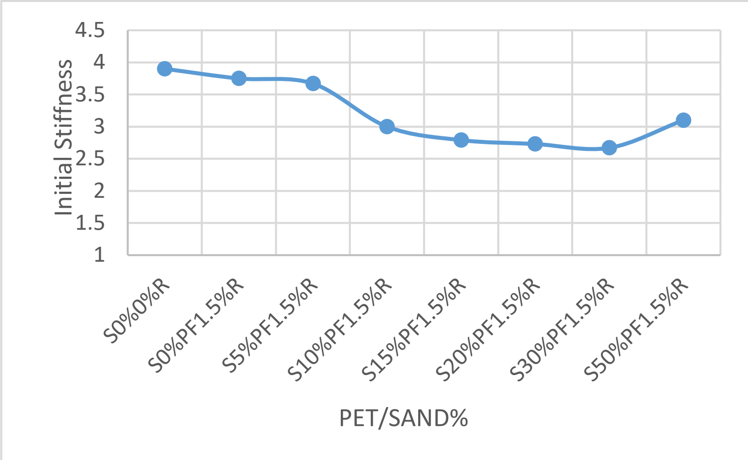

Fig.12: The initial stiffness to (PET/SAND) relative for all concrete slabs

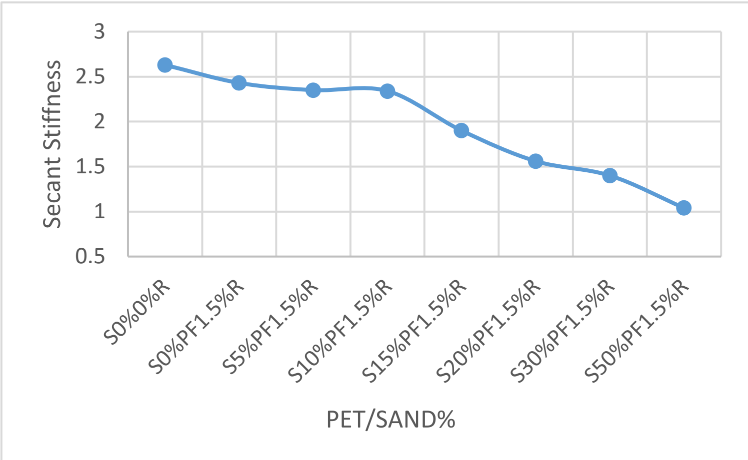

Fig.13: The secant stiffness to (PET/SAND) relative for all concrete slabs.

3.6 Energy absorption

Energy absorption, was determined by finding the area under the load-deflection curve. Fig.14 displays the results of the energy absorption. An increase of PET waste particles in concrete slabs significantly increases energy absorption in range (5%-30%). The reference slab recorded an energy absorption of 381.15 kN.mm. While concrete slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, and S30%PF1.5%R had energy absorptions of 452.79, 571.11, 626.73, 648.0, 665.48, and 687.45 KN.mm, respectively. These absorptions were 18.80%, 49.84%, 64.43%, 70.01%, 74.60%, and 80.36% larger than the reference slab. whereas, the slab(S50%PF1.5%R) achieved severe decline in energy absorption 197.35 KN.mm which decrease 48.22% compared to reference slab. This action exemplifies the fact that recycled PET has a markedly beneficial influence on the ability of reinforced concrete slabs to absorb energy.

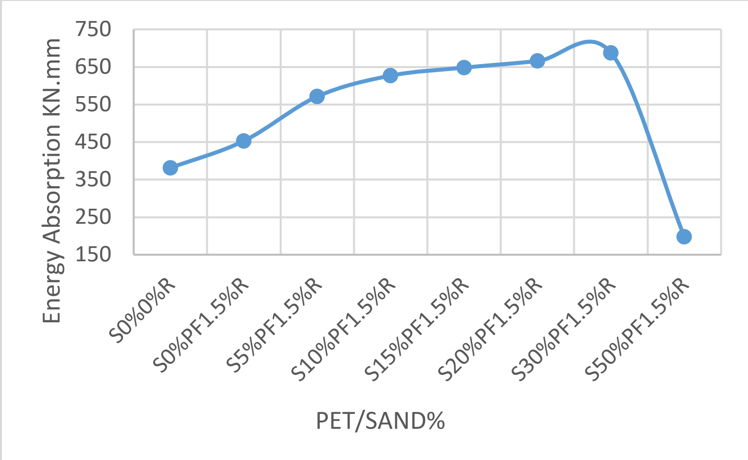

Fig.14: Energy absorption to (PET/SAND) relative for all concrete slabs.

3.7 Crack investigation

Crack investigation was accomplished according to first cracking load and crack pattern.

3.7.1 First cracking load (pcr) for concrete slab

The initial cracking loads for every concrete slab were documented, as shown in Fig.15. As the percentage of PET waste in concrete slabs rises in range (5%-15%), the findings reveal a progressive increase in the load at which the first fracture arises. The reference slab showed the first crack at a load of 14KN, while slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R showed the first crack at loads of 15, 20, 35 and 38 KN, respectively, and these slabs showed increase by 7.14%, 42.86 %,150% and 171.43 % when compared to the reference slab. However, specimens S20%PF1.5%R showed slight increase in first crack at load of 16 KN which more than 14.29% when compared to the reference slab. Then the slabs S30%PF1.5%R and S50%PF1.5%R achieved decline in first crake at load of 12and 10 KN which decrease 14.29% and 28.57% when compared to reference slab.

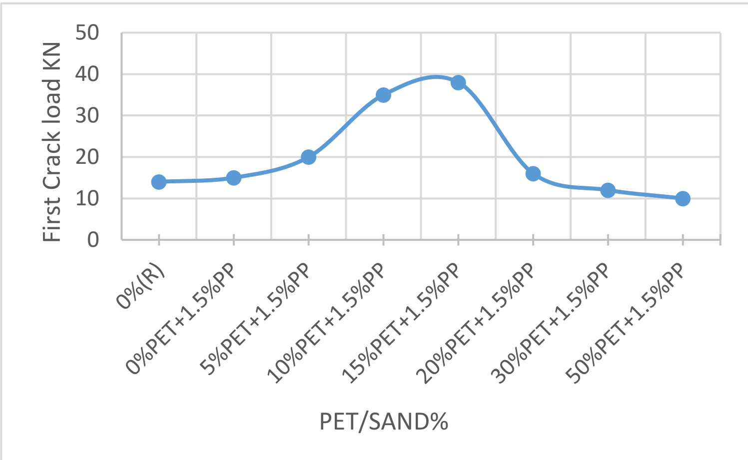

Fig.15: The first crack to (PET/SAND) relative for all concrete slabs.

3.7.2 Crack pattern

Figure 16 shows that the reference slabs exhibited more cracks uniformly distributed along slabs span compared with slabs containing PET waste which showed less cracks at mid-span between load points. For all slabs, the vertical flexural crack began from the bottom slab surface (tension zone), parallel to the loading points and running perpendicular to the beam axis. As the applied load increased, more and more flexural cracks formed, eventually causing the tension side steel bars to give way with negligible concrete crush at compression. The crack patterns in the slabs were different and appeared in different forms. All the slabs containing PET plastic waste in different proportions in the concrete mix showed cracks concentrating mostly in the tension zone at load points and progressed to the compression zone. An increase in the percentage of PET in fibrous concrete slabs resulted in less cracks and greater gaps between them compared to control slabs. As the load intensity grew, more cracks formed and propagated throughout the beam span, resulting in flexural-shear cracks that appear in the area between the support and load point as diagonal cracks.

Fig.16: The crack pattern for all slabs.

4 Conclusions

1) Based on maximum load capacity all reinforced slabs rises as the PET percentage in the slabs increases up to 10%, where the slab S10%PF1.5%R containing ten percentage of PET wastes as sand replacement is the optimum proportion in fibrous concrete mixture with 1.5% polypropylene fiber, yielding an ultimate failure load of 51KN (26.55% compared to the reference slab). For other Slabs S0%PF1.5%R, S5%PF1.5%R and S15%PF1.5%R all had their failure loads raised relative to the reference specimens by 4.22%,14.14% and 11.66%, respectively. In contrast, slabs S20%PF1.5%R, S30%PF1.5%R and S50%PF1.5%R had its failure load reduced by 0.74% and 5.71% and 57.82%.

2) When comparing the findings to the reference specimen, the slab with 30% of PET particles(S30%PF1.5%R) had the greatest deflection index increases of 77.97% and slab with 50% PET (S50%PF1.5%R) had the ductility index increments of 105.03%.

3) Compression strain at failure load rose with increasing percentage of PET particles in concrete slabs, whereas energy absorption increased dramatically, according to the results. The energy absorption and axial strain increments generated by specimen (S30%PF1.5%R) were 80.36% and 25.24% larger, respectively, than those produced by the reference slab.

4) Concrete slabs with a higher PET content have lower secant stiffness and initial stiffness. When compared to the reference slab, the slab (S50%PF1.5%R) had a lower secant stiffness of 60.46 % then, the slab (S30%PF1.5%R) had a lower initial stiffness of 31.54 %.
The first fracture load capacity rose with the percentage of PET in the concrete slab in range (5%-15%), reaching a maximum of 171.43% for slab S15%PF1.5%R compared to the reference slab.

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