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An Investigation on the Properties of the Concrete Containing Waste PET Fibers

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Abstract: Recycling and reusing of the waste materials is an efficient measure in management of the waste materials, which in addition to preventing the pollution, it conserves natural resources. Plastic bottles made of polyethylene terephthalate (PET), constitutes a major fraction of household wastes. They are classified as non-decaying waste materials which are harmful for public health. In this research, the effects of using waste PET as fiber is cement concrete has been investigated. PET fibers at different lengths of 1, 2 and 3cm, have been added to the concrete at 0.5 and 1%, by volume of total mixture, and some engineering properties of the mixtures, including workability, compressive, tensile, flexural and abrasion resistance, and elastic modulus have been investigated. The results show that PET fiber reinforced mixtures have a lower compressive, flexural and tensile strength than the control mixture without fiber. However, the abrasion resistance of fiber reinforced mixtures is higher than the control mixture. In addition, the elastic modulus of the mixtures reinforced by short fibers is lower than that of the control mixture, while the use of longer fibers at certain content, the elastic modulus can be maintained. It is also found that, the PET fiber reinforced mixtures are more energy absorbent. In general, the results of this research show that waste bottles are viable to be used in concrete for some applications.

***Key words**: Concrete, PET fiber, compressive strength, abrasion strength, elastic modulus*

I. INTRODUCTION

Concrete is one of the most extensively used materials in the world, due to its high compressive strength, low cost and long service life. This material is weak in tension, with low ductility and energy absorption. Improving the mechanical properties of the concrete leads to a better performance of the material. One of the effective ways of improving the mechanical properties of the concrete is its reinforcement by the addition of short fibers, which has been increased in last decades. Different types of fibers such as steel, glass, natural cellulose, carbon, nylon, polypropylene etc. have been used in this application. Research studies have shown that the addition of fiber to the concrete can significantly improves some properties of concrete, including tensile strength, toughness and wear resistance, while, at the same time, impair some other properties [1]. The fiber reinforced concrete are usually used in industrial floors, tunneling, mining, security structures, heavy duty pavements, slab types members and runways of airport. As an alternative application for waste materials, with the objective of protection of environment, fibers made of some waste materials have also been used for reinforcing concrete.

Polyethylene terephthalate (PET) is one of the extensively used plastics in the world, 10 million tons of which is annually used for manufacturing 250 billion bottles worldwide. This numbers grows increasingly every year [2]. A large number of the plastic containers are thrown away after single usage, becoming a main cause of environmental pollution. It has been reported that, in 2007, 67% of waste bottles have been sent to landfill in Asia, while 8% of which has been recycled [3]. Recycling of PET waste needs additional expenses for processing. Therefore, the number of returned bottles is very low, making them the most abundant plastic in solid urban waste. Waste plastics, including PET, are considered as non-decaying waste materials, which are not decayed and circulated in the environment and may enter water resources and cause health problems for human and other animals. Thus, finding a low cost application for reusing the PET wastes is an effective measure for protecting the environment. In recent years, a number of research studies have investigated the use of waste PET in Portland cement concrete as fiber and granules [2, 4, 5, 6, 7, 8]. Semiha et al. [8] replaced a fraction of coarse aggregates with waste PET granules and reported some advantages such as reduction of dead weight of the structural members, reduction of the use of natural resources and environmental pollution. Afroz et al. [2], found that the PET fiber reinforced concrete has a higher tensile and shear strength than the plain concrete. Choi et al., [7] found that the strength and modulus of concrete decreases with increasing the volume of PET fiber in concrete. Batayneh et al. [9] reported that the compressive strength of concrete decreases with increasing the fiber content. Ramadevi et al. [10] showed that the addition 1 to 2% of PET fiber causes an increase in the compressive and flexural strength of the concrete, while above 4%, the compressive and flexural strength decreases. Feranternali et al. [6] used fibers of lengths of 10, 20 and 30mm, at contents of 0.05, 0.18 and 0.3% by volume, and found that the strength and Young modulus increase with increasing of PET volume. They also found that the fiber of 30mm length were good in strength than the shorter fibers.

Although, a number of research studies have investigated the properties of PET fiber reinforced concrete; however, the findings are not consistent, and more research is required to be conducted for fully understanding of the properties. This research aims to investigate the effects of PET fiber content and length on some engineering properties of fresh and hardened concrete.

II. MATERIALS

The materials used for making the concrete mixtures in this study were coarse and fine aggregates, cement, water and PET fibers. Cement type II, meeting the requirements of national codes, was used for making all the specimens in this study. Natural sand with a fineness modulus of 2.89, water absorption of 2.5% and dry density of 2.6, and natural gravel with a maximum nominal size of 25mm, moisture absorption of 1.75, dry density of 2.7 both from the same source were used as the aggregates of the mixtures. Fig. 1 shows the gradation of the sand and gravel used in his research for making the mixtures. The gradations were controlled to meet the requirements of ASTM C33 standard.

PET fibers were made from waste bottles of water. The bottle was first placed in a machine which was made for the purpose of making fibers. The machine was comprised of a mold with the same size of the bottles, with 2mm wide grooves on its surface. By rotation of the mold and the bottle connected to the mold, a blade cut the bottle over the grooves and 2mm wide fibers were obtained. Then, the fibers were cut in different lengths of 1, 2 and 3cm, as required in this research.

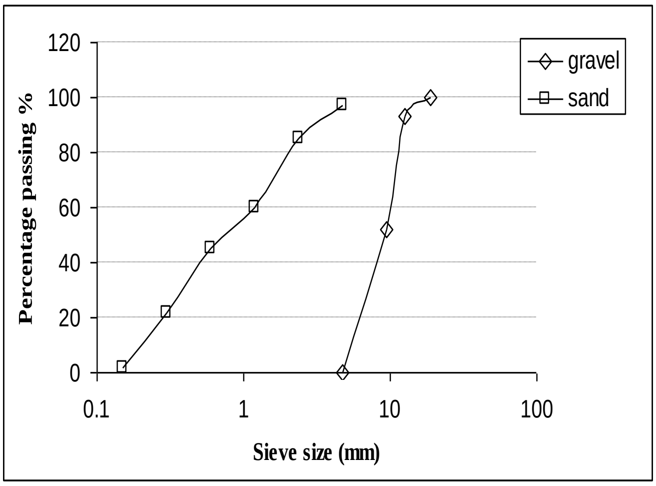

Figure 1. Gradations of fine and coarse aggregates used in this research

III. MIXTURE

Seven different types of concrete mixtures have been used in this study. One as the control mixture, without any PET fiber, the rest containing fiber with 3 different lengths of 1, 2 and 3cm, each at two different contents of 0.5 and 1%, by the volume of mixture. The mixture design was conducted for the control mixture, and the required amount of each component was obtained. The control mixture was made with a water to cement ratio of 0.5 and cement content of 350 kg/m^3. For fiber containing mixtures, the fibers were added to the mixtures as reinforcement without being replaced with any constituents.

IV. EXPERIMENTAL WORK AND RESULTS

A. *Specimen fabrication and preparation*

For making the specimens for the experimental work, depending on the mold volume, the required amount of each constituent was calculated. Coarse and fine aggregates, PET fibers, cement and water were added, respectively, into the mixing pan. A laboratory rotary drum mixer was used in this study. The mixing was continued until a homogenous mixture was obtained. The mixture was then poured in the molds covered by a releasing agent. The mixture was added in three different layers in the molds, and each layer was compacted by a compacting rod in 25 impacts for each layer, after which, the mold was placed on a vibrating table for 20 seconds. The molds were opened after 24 hours and, then, the specimens were placed in a water tank set at 20˚C. The specimens were taken from the tank 1 hour before testing and the surfaces were dried prior to the testing. The following are the shapes, sizes and curing times for the experiments.

1. For the compressive strength tests, cubical specimens 10 cm in each side and cured for 7 and 28 days were used.
2. For the splitting tensile strength and elastic modulus tests, cylindrical specimens, 15cm in diameter and 30cm in height were used and cured for 28 days.
3. For flexural strength tests, beam shape specimens 35cm in length, and 10cm in width and height were used after 28 days of curing.
4. For conducting the abrasion strength tests, block shape specimens, 40cm in width and length, and 8cm in height were used after 42 days of curing.

Two specimens were used for each test condition, and the average was used in the analysis.

B. *Slump Tests*

In order to investigate the effect of the fiber length and content on the workability of the mixtures, slump test was conducted on the fresh concrete of the mixtures containing 0.5 and 1% of 1 and 3cm long PET fiber according to ASTM C143. Fig. 2 shows the results. As can be seen, regardless of the fiber length, the mixtures containing 0.5% of PET fiber have a higher slump than the control mixture, indicating that the mixtures containing 0.5% of PET fiber are more workable than the control mixture. This can be described by the insignificant reinforcing effect of the fibers in 0.5% inclusion, while, they don’t absorb water and cause some abundant water to be left in the mixture which increase the workability. On other hand, the mixtures containing 1% of the fiber has a lower slump than the control mixture, indicating that, the mixtures containing 1% of PET fiber have a lower workability than the control mixture. This can be described by the reinforcing effect of the increase in the fiber content. The results also show that,

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over the range of the lengths investigated in this study, the length of PET fiber does not affect the workability.

C. Compressive Strength Tests

Compressive strength tests were conducted on the 7 types of mixtures using 10×10×10cm cubical specimen cured for 7 or 28 days, according to ASTM-C39 (Fig. 3).

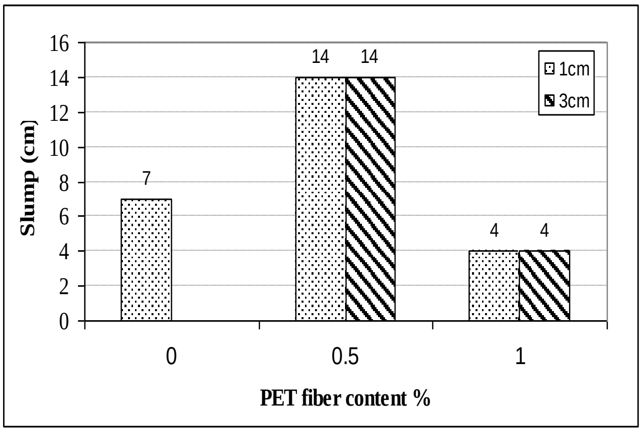

Figure 2. slump tests results

The results of the compressive strength at 7 and 28 days are shown in Figs. 4 and 5, respectively. As can be seen, for both the ages of 7 and 28 days, the compressive strength decreases with increasing the fiber length and content, with the lowest strength for the mixture containing 1% of 3cm fiber. These results confirm the results of Kim et al. [6], Batayneh et al. [9] and Choi et al. [7] which found that the compressive strength decreases with increasing the PET fiber content. This reduction in compressive strength is attributed to the lack of adequate bond between the fibers and cement paste, and more potential to the crack development. Evaluation of the specimens containing fiber showed that they maintained their integrity after failure, indicating that they are capable of absorbing more energy and are useful for applications requiring more resistant against impacts, such as highway barriers. The minimum compressive strength required for structural light weight concrete is 17MPa [11, 12]. As can be seen in Fig. 5, this can be met by all the mixtures containing PET fiber.

Measuring the weight of the cubical specimens before conducting the compressive strength tests and having the volume of the specimens using their dimension, the bulk density of the mixtures was calculated. Fig. 6 shows the

Figure 3. Compressive strength test

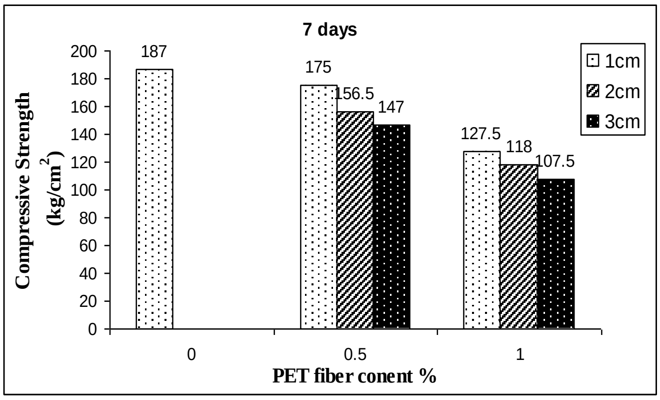

Figure 4. compressive strength of the mixtures after 7 days of curing

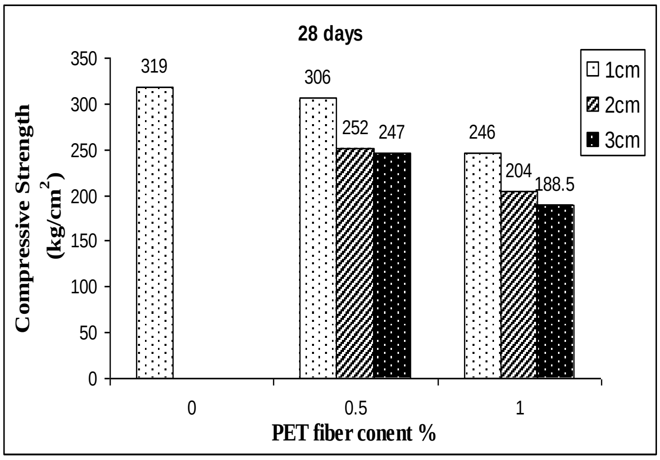

Figure 5. compressive strength of the mixtures after 28 days of curing

Bulk density of the mixtures against the fiber content; it can be seen that the bulk density of the mixtures decreases with increasing the fiber content. This is beneficial in transportation costs and lowering the weight of structural elements.

D. Flexural Strength Test

Flexural strength is a property for the concrete, also known as rupture modulus, which is related to the fatigue life of concrete in rigid pavements. The tests were conducted on beam shape specimens of the mixtures after 28 days of curing, according to ASTM C293. After placing a specimen in the testing frame between two supports, the load was applied at a constant rate through two roller shape arms until the specimen failure, as shown in Fig. 7. The maximum force required for breaking the specimen was used for of strength due to the loss of bond strength, beyond which it is sufficient and the flexural strength decreases. This was also confirmed by visual evaluation of failed specimens. Visual observation of the specimens after failure showed that the fibers of failed specimens did not fail due to fiber rupture, but they had been pulled out of the mixture. Therefore, the flexural strength of the mixtures can be improved by increasing the resistance against pulling out, which can be achieved by using fibers with a rougher surface and or longer fibers. In addition, visual inspection of the failed specimens showed that the specimen made of control mixture did not disintegrate, while the mixtures containing fibers showed a higher integrity, indicating that the mixtures containing fibers are more capable of absorbing energy before failure. The resistance against disintegration increased with increasing fiber content and length.

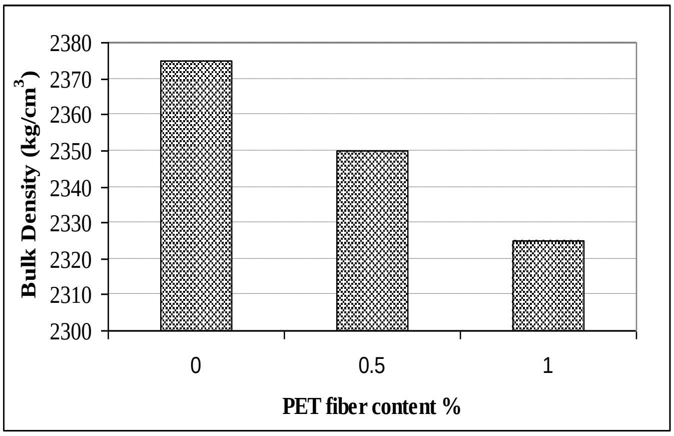

Figure 6. Bulk density of the mixtures

Figure 7. Flexural strength test

Calculating the flexural strength of the mixtures; the flexural strength was calculated using Equation (1).

$$F_b = \frac{PL}{BH^2} \tag{1}$$

In which, F_b is the flexural strength in MPa, P is the load required for breaking the specimen in N, B, H and L are, the width, height and length of specimen in mm.

Fig. 8 shows the summary results of flexural strength tests. As can be seen, for he fiber reinforced mixtures, the flexural strength of the mixtures increases with increasing the length of fibers. This is due to the more reinforcing effect of the fiber with a higher length, where their resistance against pulling out is increased. It can also be seen that, the flexural strength of the mixtures decreases with increasing fiber content. This is attributed to remaining more water in the mixture with a higher fiber content, which results in weakness of concrete. In addition, due to the smooth surface of the fibers, it cause a reduction in the bond between fiber and cement paste and the flexural strength. This is consistent with the results of Sata et al. [13], which states that the bond between PET fiber and cement paste is weak. Up to a certain amount of fiber content, the increase of interlocking by fibers compensate the reduction

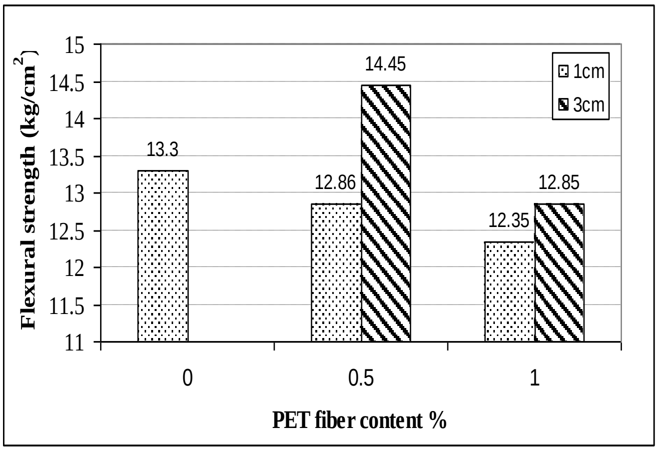

Figure 8. flexural strength of the mixtures

E. Tensile strength tests

Tensile strength tests were conducted on the cylindrical specimens of the mixtures after 28 days of curing, according to ASTM-C496. After placing the specimen between the base plate and loading ram, the load was applied diametrically at a constant rate of 0.02-0.4N/mm^2/s and continued until the specimen failure (Fig. 9). Using the load required for breaking the specimen (P), and Equation (2), the tensile strength (f_{ct}) of the mixtures was calculated.

$$f_{ct} = \frac{2P}{\pi LD} \qquad (2)$$

Where, D is the specimen diameter (15cm) and L is the length of specimen (30cm). Fig. 10 shows the summary results.

Figure 9. Indirect tensile strength test

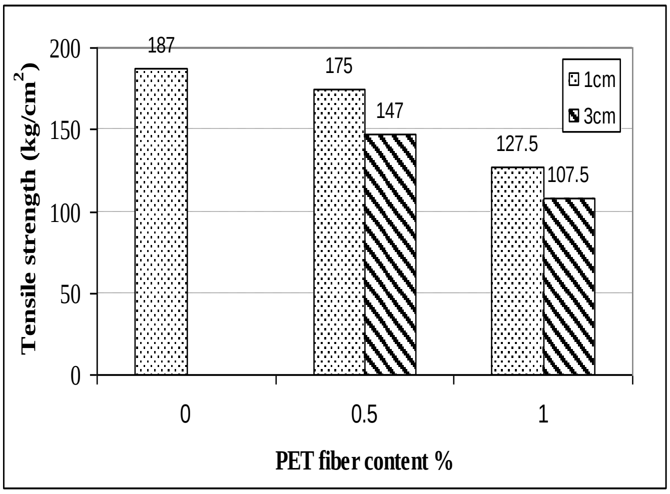

Figure 10. Tensile strength of the mixtures

As can be seen, the tensile strength of the mixtures containing fiber is less than the control mixture, indicating that the PET fiber reinforced concrete will not perform well in the structural elements that the requires high tensile strength, such as pavement slabs. It can also be seen that, at 0.5% of fiber content, the mixtures with 3cm long fiber is higher than that with 1cm long fiber. This is attributed to the more reinforcing effect of longer fibers, which will have more resistance against pulling out of mixture. However, at 1% of fiber content, the tensile strength decreases with increasing the fiber length, which is attributed to more flocculation of fibers in the mixture for higher fiber length which results in reduction of tensile strength. Similar to the specimens under flexural strength testing, the splitting tensile strength tests show that the fiber reinforced concrete specimens maintain their integrity after failure.

F. Abrasion tests

As explained in previous sections, addition of PET fibers to the concrete causes a reduction in its compressive, tensile and flexural strength. Therefore, the use of PET fiber is not efficient in concrete in heavy duty structural members. In order to investigate the applicability of waste PET fibers in concrete for non-structural members and subjected to wear and abrasion, such as floors, sidewalks, canals, culverts etc., abrasion tests were conducted on the mixtures containing different contents of PET fiber. The specimens used for this test were rectangular cubic with a dimension of 40 cm in length and width and 5cm in thickness, cured for 42 days. The specimens were abraded by sand blasting, where the sand with a uniform density was blasted on the specimen from a distance of 7 to 7.5 cm for 1 minute at a pressure of 2 bars. A steel plate with eight 5×5cm holes was placed on the specimen to ensure that the specimen is abraded at predetermined areas. The sand blasting abrades the concrete leaving spaces on the surface of specimens, the volume of which is a measure of resistance to abrasion. The spaces were filled with a clay mud with a known density, and by measuring the mass of the mud filling the spaces, the volume was calculated. By dividing the volume of the spaces to their area the abrasion factor in cm was calculated and used as a criterion for resistance against abrasion. Fig. 11 shows an abraded specimen which has been filled with the mud. This test was only conducted on the control mixture and the mixtures containing 0.5% of 1 and 3cm long fibers. Fig. 12 shows the summary results of abrasion strength for the mixtures. As can be seen, the resistance against abrasion of the mixtures containing fiber is higher than that of the control mixture, and it increases with increasing the length of fiber. This behavior is beneficial for the concrete to be used in sidewalks, floors, canals etc.

Figure 11. Abraded specimens

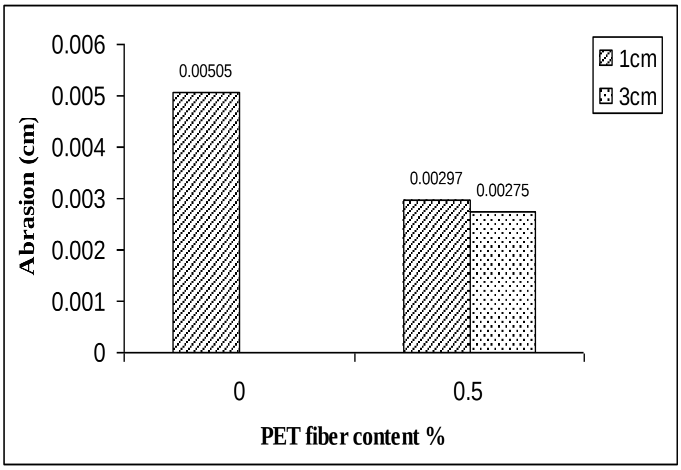

Figure 12. Abrasion test results

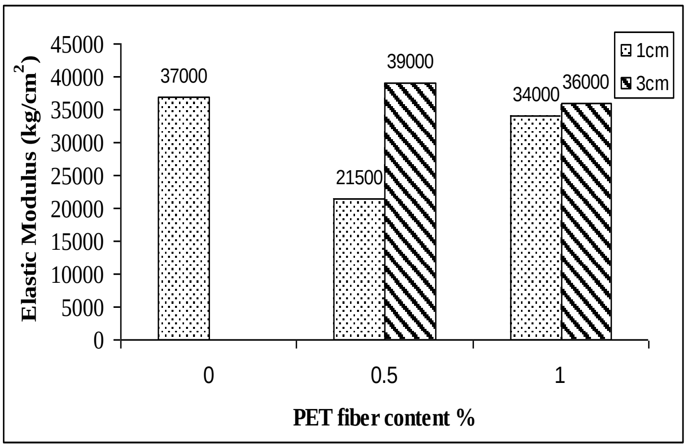

Figure 13. Elastic modulus test results

G. *Elastic Modulus Tests*

The elastic modulus of concrete mixtures was measured using secant method. In this method, the elastic modulus is the slope of a line connecting a point corresponding to a specified strain to the point corresponding to 40% of the ultimate strength of the mixture. The same specimens, as used for indirect tensile strength tests, were used for measuring the elastic modulus, after 28 days of curing. First, using the compressive strength test results, the value of 40% of the ultimate strength was calculated (f_2) for each mixture and used for elastic modulus test. For measuring the deformations, a gauge was placed on a L shape plate suffixed to the specimen surface. Using the stress corresponding to the strain level of 50×10^{-6} (f_1) and the strain corresponding to the stress level of 40% of the ultimate strength (ε_2)of the mixtures, the secant elastic modulus was calculated using Equation (3).

$$E = \frac{\varepsilon_2 - 50\times10^{-6}}{f_2 - f_1} \quad (3)$$

Fig. 13 shows the summary results of the elastic modulus tests. As can be seen, the elastic modulus of the mixtures increases with increasing the fiber length, with the elastic modulus of the mixtures containing 3cm long fiber is not significantly different from that of the control mixture. Even, as can be seen, the elastic modulus of the mixture containing 0.5% of 3cm fibers is higher than that of the control mixture. This is attributed to the stiffening effect of the long fibers. It can also be seen that, the elastic modulus of the mixtures containing 3cm long fibers decreases with increasing fiber content, which can be due to the difficulty of uniformly distribution of the fiber in the mixture, which creates weak spots in the mixture. However, the elastic modulus of the mixtures containing 1cm long fibers increases with increasing fiber content, and, in general, lower than that of the control mixture. Short fibers cannot significantly improve the interlocking of aggregates, especially at low fiber content, and because of their smooth surface, causes a reduction of bond strength. However, the interlocking effect of the fibers increases with increasing the fiber content.

V. CONCLUSIONS

Over the range of fiber content and length utilized in this research, the following results can be drawn in summary:

- Up to a certain amount of fiber content, the workability of concrete increases with increasing fiber content, beyond which it decreases with increasing fiber content. The fiber length does not affect the workability.
- The compressive strength of the mixtures decreases with increasing the fiber content and length.
- The flexural strength of fiber reinforced mixtures increases with increasing the fiber length. However, it decreases with increasing the fiber content.
- The tensile strength of fiber reinforced mixture is lower than that of the control mixture. At lower fiber contents, the tensile strength increases with increasing the length of fiber, while, at higher levels, it decreases with increasing the fiber length.
- The mixtures containing PET fiber are more resistant against abrasion than the control mixture. The resistance against abrasion increases with increasing fiber length.
- The mixtures containing short fiber has lower elastic modulus than the control mixture, with more difference at lower fiber content. By use of long fibers the elastic modulus of the mixture can be maintained and even improved.
- Fiber reinforced mixtures maintain their integrity after failure, indicating that they are more capable of energy absorbent.
- Waste bottles are viable to be used in concrete in applications where more abrasion resistant is required and in light weight structural elements.

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