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Properties of Sustainable Self- compacting Concrete Containing Treated and Modified Waste Plastic Fibers

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ABSTRACT

This study aims to improve different properties of sustainable self-compacting concrete SCC containing treated and modified polyethylene terephthalate PET fibers. For this purpose, gamma ray surface treatment and geometric modification were utilized for the used PET fibers. Concrete fresh properties include slump flow, T_{500}mm, L-box and sieve segregation while mechanical properties include compressive, split tensile strength, flexural strength, static modulus of elasticity and impact strength. Further, physical properties and related durability properties comprise dry density, ultrasonic pulse velocity, porosity and water absorption. The results obtained demonstrated that the treatment and the modification used for the PET fibers slightly reduced the fresh properties of produced sustainable SCC (slump flow, T_{500} mm, L-Box and sieve segregation). However, they were within the limits of the SCC specification as reported in EFNERC guidelines. Further, concrete hardened properties in terms of compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, impact strength, ultrasonic pulse velocity, decrease in the dry density, decrease in porosity and water absorption increased significantly.

1. Introduction

Developments in concrete technology have led to the production of new types of concrete such as self-compacting concrete (SCC) [1], which is a modified version of High Performance Concrete HPC. It was developed in Japan in the late 1980s in order to produce highly durable concrete [2]. Self-compacting concrete is easy to spread under its own weight without any external vibrations. Due to its high flowability, this type of concrete is more suitable for use in difficult casting conditions or in sections with heavy rebar without the need for the use of vibrators, thus reducing the noise emitted and improving productivity [3]. Self-compacting concrete consists of the same materials used in normal concrete NC (cement, sand, gravel, water, mineral and chemical additives). However, large amounts of binder and chemical admixtures with less amount of coarse aggregate should be adopted in self-compacting concrete as compared to normal concrete. This is in order to improve the fresh properties. The higher amount of cement in SCC will increase the cost of production as well as will cause high carbon dioxide emissions from cement manufacturing. Accordingly, the world needs environmentally friendly building materials to reduce CO_2 emissions and provide a beautiful and healthy environment while reducing wastes at the same time [4]. Therefore, part of cement can be replaced by a certain part of mineral additives and fillers such as (silica fume, fly ash, and limestone) in SCC to achieve that. In addition, chemical additives such as superplasticizer can be used to obtain high strength by reducing the ratio of water

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to powder (w/p) and improve the workability and durability properties of the SCC[5]. Further, different types of natural and industrial byproducts have been used to produce environmentally friendly concrete at low cost instead of traditional building materials [6]. Over the recent years, the amount of various products from plastics is increasing, which has resulted in the production of larger quantities of household polymeric waste that causes serious environmental pollution [7]. Plastic takes a long time to degrade, possibly hundreds of years. The most common plastic wastes on earth are polyethylene terephthalate (PET) which is mostly affect water, soil and air. It is used only once and then disposed as waste such as soft drink bottles and food containers [8]. Therefore, recycling plastic wastes and using them as a fiber to reinforce concrete is one of the best solutions for the disposal of these wastes and the sustainable management of solid waste. Previous studies showed that the use of recycled plastic fibers in normal concrete and self-compacting concrete increased mechanical properties, durability, flexural toughness and impact strength [7]. The high amount of fine materials in SCC might increase the formation of shrinkage cracks. Therefore, these wastes can be used as fibers within SCC mixtures to enhance tensile strength and to improve overall performance [3]. Many authors have studied the efficiency of plastic fiber as strengthening substances for concrete [9]. Frhaan et. al said that the addition a different volume fraction ratio of the fibers improved the mechanical properties , and the results showed that the optimum tensile strength was achieved at a fiber content of 1.5% [5], but Vijaya et.al claimed that the average splitting tensile strength increased by increasing the percentage of fibers up to 1.0% [10]. PET is known to be chemically inert and stable due to its hydrophobic nature. The researchers counted some shortcomings in using these fibers, including the low surface energy of PET, which leads to poor adhesion to the cement matrix. Therefore, the PET surface may need different types of treatments to improve the adhesion of the fibers to the cement matrix [11]. Surface modification and treatment may increase the interfacial strength between the fibers and the cement matrix compared to untreated PET fibers. In this paper, treated and modified PET fibers were used in sustainable SCC and they were compared to the same concrete containing un-treated and modified fibers. This is in an optimized sustainable SCC containing 30% fly ash as a partial replacement of cement. The reference SCC mixture in this study was selected by making nine different mixtures designed using three different volume fractions of PET V_f (0.5, 0.75, 1) and three different aspect ratios A_r (15, 30, 45)%. These nine mixes were optimized using a multi-objective optimization which indicated that the V_f and A_r of the PET fibers, for optimum performance in terms of the main fresh and hardened properties and partitioning aspects of sustainability (CO_2 emission and cost reduction), were 0.7% and 24.4, respectively. This is in order to select the optimum reference mix for this study which can be very useful for reducing the number of experimental mixes required for the PET treatment phase as well as saving the time taken to produce this mixture. Various studies were conducted on the surface modification of the plastic before using it in the concrete mixes. For example, Martínez-Barrera et al., 2019 [12] applied the treatment process to polyester slurry using gamma rays at doses of (100 and 200) KGy. They claimed that the effect of radiation on the polymer helped to improve its mechanical properties[12]. As for the geometries shapes, an experimental investigation has been carried out by Kumar et al., 2019 [13] to examine the effect of five PET fiber geometries on M30 regular concrete with 0.5% V_f. Several tests were performed to evaluate the physical and mechanical performance of concrete. The results indicated that the addition of circular fibers cut from one side showed the best results when added to the concrete mix. The authors claimed that this geometry of PET fibers can efficiently seal concrete cracks and increase concrete ductility [13]. Erwan et al., 2014 [14] studied the effect of adding irregular polyethylene terephthalate fibers (IPET) on the deflection of reinforced concrete beams. PET fibers were added with a fraction volume ranging from 0.5% to 1.5%. The reinforced concrete beams were tested using four point loads. It was found that the addition of these PET fibers improves the first crack and final strength as well as the ductility of reinforced concrete beams as compared to regular shape of PET and these properties increased with the increased Vf of the PET fibers. The main aim of the current work is to study the possibility of improving the properties of a special type of sustainable SCC that includes PET fibers with optimized characteristics in terms of V_f and A_r (0.7, 24.4). This is by applying gamma ray surface treatment on PET fibers and by generating a modification of these fibers in different geometrical shapes. This can be achieved by examining a wide range of properties of the produced SCC in the fresh and hardened states and determining the best process of treatment and modification.

2. Experimental program

2.1. Materials

Ordinary Portland cement (OPC) type I with specific gravity and fineness of 3.15 and 325m^2/kg respectively was used to cast all the SCC mixes in the present investigation. This cement confirms the limitation of the Iraqi specification (IQS No. 5/1984) [15]. Class F fly ash (FA) type was used as a secondary binder with a replacement level of 30% by weight of cement. The Blaine fineness of this type was 380 m^2/kg whereas the specific gravity was 2.15 ASTM C618-12 [16]. Table 1 shows the chemical properties of the used cement and fly ash.

A coarse aggregate with a maximum size of 10 mm was used confirming the specifications. The specific gravity and water absorption of this type were 2.62 and 0.53%, respectively, which confirms the limitations of the Iraqi specifications (IQS.No45 1984) and ASTM C33 [17][18]. Locally available natural fine sand was also used as fine aggregate with a maximum particle size of 4.75 mm. The water absorption ratio of this sand is 0.70% with a specific gravity of 2.60. Sieve analysis was shown in Fig. 1 for the two types of aggregate.

Table1. Chemical properties of the used cement and fly ash

Item %	Cement	Fly ash
CaO	61.95	18.1
SiO_2	20.9	38.8
Al_2O_3	5.31	14.7
Fe_2O_3	3.33	19.48
SO_3	2.5	1.5
MgO	2.35	3.3
K_2O	0.92	1.79
Na_2	0.17	0.38
L.O.I	2.38	1.32

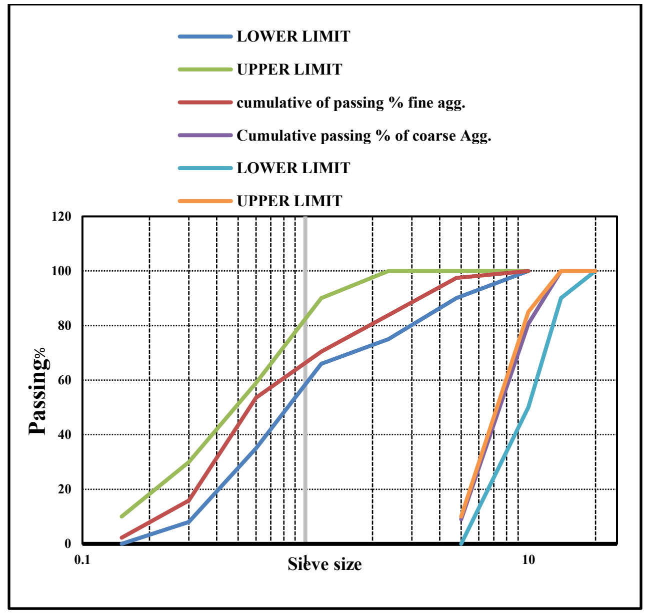

Figure1. Grading results of fine and coarse aggregates

In the current study, plastic fibers from discarded PET soft drink bottles were used, which were first collected and then cleaned with water to remove dust. Soft drink bottles were cut by hand into sheets after the neck and bottom of the bottle were removed. Next, the plastic sheets were cut by a paper shredder into 4 mm wide strips and then the fibers were cut with modified scissors to control the required length of the PET strips. Fig. 2 shows the process used to prepare PET fibers (PET bottle, PET paper produced, and the machine used to cut the fibers). The modulus of elasticity and tensile strength of this type of recycled fiber is 0.57 and 105 MPa. The physical properties of the used PET fibers are shown in Table 2

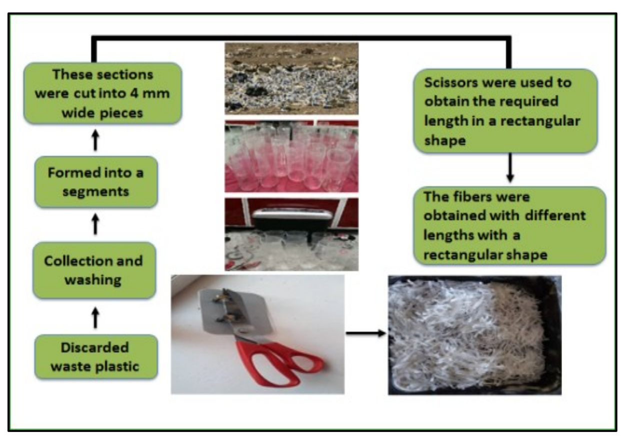

Figure 2. The process used to prepare PET fibers

Table 2. Physical properties of used PET

Physical property of PET	Result
Specific gravity	1.375
Water absorption (24 h)	Nil
Shape of particles	Flaky or flat particles
Bulk density	417.87 Kg/m3
Thickness	0.35 mm
Tensile strength	105 MPa
Melting temperature	230-250 ºC
Tensile modulus	4.0 GPa

The samples were made of polyethylene terephthalate (PET) in special shapes and tested using a special micro-device (maximum load 5 kN) , as shown in Fig. 3. This device is used to determine the compressive, tensile and flexural strength of various materials, such as rubber, polymer ceramics and composites [19] [20]. This test was carried out according to (ASTM- AD 1708-02). The tensile stress results for PET fibers are shown in Fig. 3.

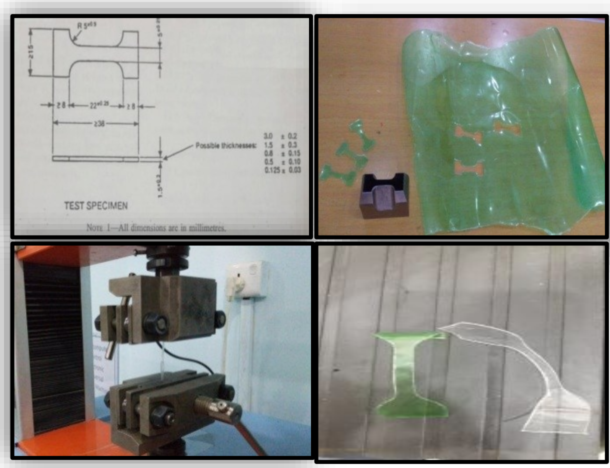

Figure 3. Tension test of PET fibers of form [19] [20]

High range water reducing admixture SP solution of poly carboxylic (sika viscocrete- 5930) type F was used as super plasticizer, which meets the ASTM C 494 limitation [21].

2.2.Mix proportioning, samples preparation and testing programs

2.2.1. Mix proportioning

In this study, several experimental mixtures were made in the laboratory to design the final proportions of the reference mixture (without adding fibers), which were designed by trial and error method to obtain the best rheological and mechanical properties of SCC without segregation and bleeding. The EFNARC guidelines were used as a reference for the design of the control mixture [22]. The best rheological and mechanical properties of SCC were achieved when the replacement level of fly ash as a supplemental cementing material was 30% by weight of cement [23]. A total binder content of 530 kg/m^3 was used while the content of fine aggregate, course aggregate, water and superplastizer (857, 770, 175 and 6%) were respectively in all SCC mixtures of this study.The research was carried out after the reference mixture of PET fibers was obtained in the previous stage and included three SCC mixtures (an optimized mixture in terms of the best V_f and A_r without treatment, physical gamma treatment and geometric cut-off). M refers to the mix, OP refes to optimized refernce mix, GS refers to geometric shape, GR refers to gamma rays.

2.2.2. PET fibers treatments

In this research, the PET fibers were treated in two ways, which are physical treatment (exposure to gamma ray) and modification of fibers in geometric shapes (looks like the E-section and one-sided cut circular fibers).

2.2.2.1. Physical treatment

The surface of the PET fibers was modified by a physical method (gamma rays). The goal of using gamma rays is to enhance the mechanical properties of plastics in order to recycle them into products as good as they were before recycling. In general, polymer products are immiscible, which leads to poor adhesion with the cement matrix [12]. The most common gamma ray is Co 60, which emits a monocular energy of 1.17,1.33 MeV, and has a half-life of 5.3 years. It is important to irradiate the sample with radiation at a dose of 16Gr/hr [24]. In this work 3 doses (2,5,7) KGy of gamma rays were performed. The radioactive fibers were introduced into the reference SCC mixture MOP and their properties were confirmed by examining some of the main fresh and mechanical properties. The gamma radiation best dose was adopted depending on the test presented in a Table 4. This treatment was conducted at the University of Baghdad- Iraq / College of Science / Department of Physics depending on the bases of Fig. 4.

Table 4. Trials of treatment by gamma ray with different doses

Radiation dose	Slump flow mm	T_{500} mm sec	Comp. strength MPa	Tensile strength MPa
2 KGy	650	5.0	57.9	3.3
5 KGy	690	13	59.8	3.9
7 KGy	**770**	**4.1**	**53.6**	**4.2**

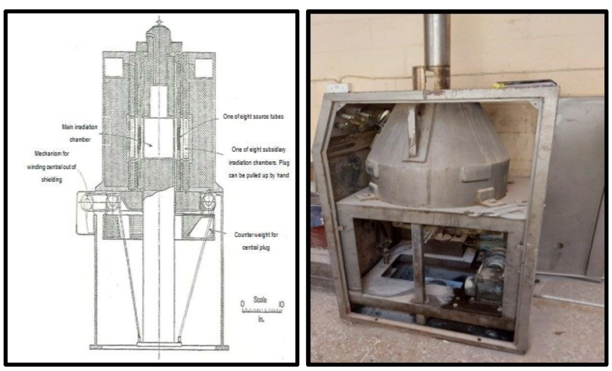

Figure 4. Gamma cell Co60 irradiation unit [24]

2.2.2.2.Modification of fibers in geometric shapes

The geometry of the PET fibers used in this study was of a shape similar to that of steel fibers (ACI Committee 544, 1996). The two best shapes from literature were selected based on previous research (a) deformed sheet fibers (looks like the E-section), and (b) one-sided circular fibers [25][13], as shown in Fig. 5.

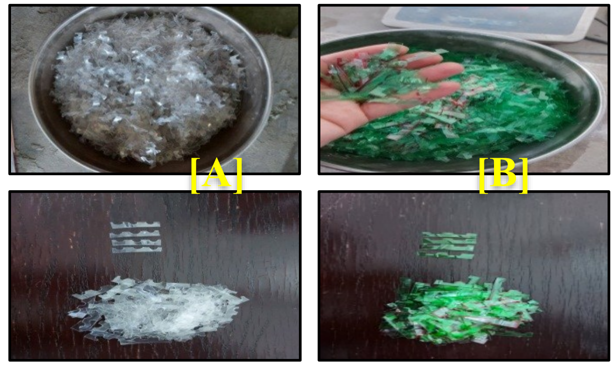

Figure 5. PET fiber geometry obtained by hand cutting [A] one-sided cut circular fibers,[B] deformed sheet fibers (looks like the E-section)

The fibers were produced by hand cutting after washing and drying. However, manual production of short fibers of variable cross-section is a difficult task. The lengths of the fibers were chosen after obtaining the optimum proportion of the fibers. The best type of engineering shapes of PET fibers was selected based on the tests shown in the Table 5.

Table 5 Trials of geometric modifications of engineering shaped PET fibers

Type PET fiber geometry	Slump flow mm	T_{500} mm sec	Comp. strength MPa	Tensile strength MPa
One-sided cut circular	800	3.2	50.9	3.9
Deformed sheet E-section	**800**	**2.4**	**58.3**	**4.4**

According to the preliminary experimental results treatment with gamma rays gave the dose of 7 KGy the best dose. While the geometric shapes gave the best shape looks like the E-section. These modifications gave the best experimental results of the mixture for the rheological and mechanical properties of the sustainable produced SCC before starting the second stage of this research.

2.2.3. Samples preparation

To prepare the fresh SCC mixes, the required quantities of coarse aggregate and fine aggregate were first mixed for 1 min. by means of a 25 kg pan mixer. Cement C and fly ash FA were pre-mixed for 2 min by hand to ensure dispersion of FA granules into the cement. Then, cement and fly ash were added to the mixer. During mixing, a small amount of water was added to prevent the fly ash granules from volatilizing. After that, PET fibers were added and the mixing continued for 3 minutes. Finally, the remaining water and SP were added to the mixture, and the wet mixing was continued for 2 minutes. Finally, the concrete is left for one minute to rest, and then it is mixed again for one minute to obtain a homogeneous mixture as shown in Fig. 6.

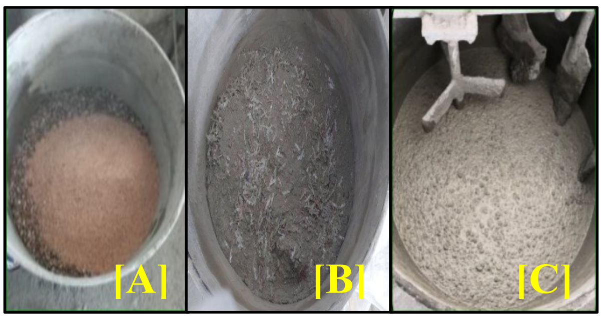

Figure 6. Mixing process

2.2.4. Testing program

The test program was conducted for the current study included all required new fresh properties of SCC (slump flow, T_{500}mm, L-box, sieve segregation tests) and hardened properties (compressive tensile strength and flexural strength, static modulus of elasticity, flexural toughness, impact strength, dry density, ultrasounic puls velocity, porosity and water absorption).A slump flow test was performed to evaluate the flow ablity of fresh concrete using a slump flow diameter and time T_{500} mm. Visual inspection during the test. As well as the T_{500}mm arrival time gauge to give additional indications about the separation resistance of the SCC. The L-box test is performed to estimate the ability to pass the SCC mixture using the h2/h1 blocking ratio through a confined area and a narrow aperture while the areas are crowded with reinforcement steel. The index of the L-box value is measured as the ratio between the height of the concrete in the horizontal dimension h2 to the residual height of the concrete in the vertical dimension h1. As for the sieve segregation test, a test was conducted to determine the segregation resistance for fresh SCC mix. The segregation index is determined by dividing the concrete mass passing through the sieve opening by the total cast concrete block. All fresh concrete tests were performed as mentioned in the EFNARC Guideline[22].

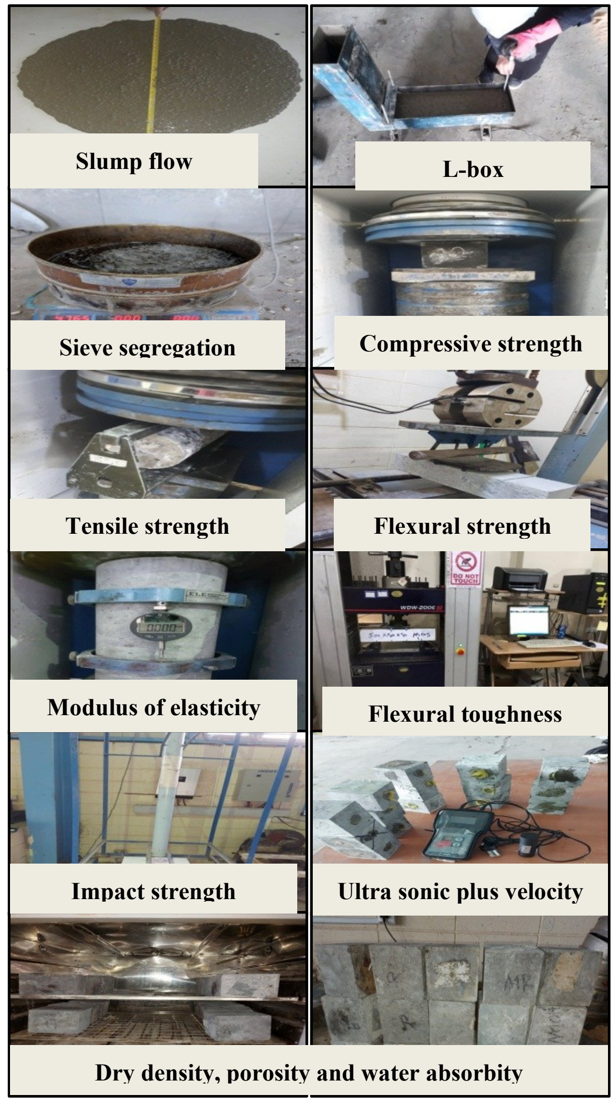

Figure 7. Fresh and hardened tests

As for the mechanical properties of self-compacting concrete, it was carried out under the same conditions. The recorded results were obtained by taking an average of three samples at each age. The compressive strength test was carried out according to **BS EN 12390-3: 2002** [26] using nine cubes. 100 mm at 7,28,56 days. Three cylinders (100 x 200 mm) were made to calculate the splitting tensile strength is in 28 days in relation to **ASTMC496** [27]. Concrete prisms with dimensions of (500×100×100mm) mm were cast in order to calculate the flexural strength flexural toughness according to **ASTMC78 and ASTM C 78** [28] [29]. Three cylinders with dimensions (150×300 mm) were also cast to calculate the modulus of elasticity according to the specification. Also, to calculate the impact strength, number of two concrete slabs with a dimensions of (500x500x50mm) were used **ACI 544.2 R-88** [30]. As for the physical and durability properties, three cubes of dimensions (100 x 100) were cast to calculate the dry density, ultrasonic pules velocity, porosity and water absorption according to the specifications mentioned C138/C138M–14, ASTM C597 and ASTM C 642 [31][32][33] respectively. Fig.7 shows photographs for all the tests performed in this study.

3. Results and Discussion

3.1. Effect of surface treatment of PET fibers on fresh properties performance

In this study, the slump flow diameter results for fresh SCC with modifications for PET fibers are shown in Fig. (8A). In the mixture containing fibers exposed to MGR, there was no change between this mixture and the reference mixture with respect to the flow of the mixture. As for the MGS (fiber engineering PET) mixture, this modification increased the flow value by about 6.67%, which gave the highest flow (800 mm) compared to the MOP mixtures. Therefore, it can be said that the fibers of geometric shapes have a great influence on the workability, so it can give better results due to the anchor behavior of the fibers in the cement mortar [25]. Fig. (7 B) shows the flow time variance (T_{500}mm) which is a relative index of viscosity. For the gamma ray PET fiber treatment, the flow time of T_{500}mm for MGR was increased by 16% compared to the MOP mixture. In contrast, the MGS mixture showed a significant decrease in T_{500}mm of about 28% compared to the MOP mixture. The reason for the increased flow time is that the fibers exposed to gamma rays possibly make the mixture thicker and more difficult to flow as a result of the increase in its hardness after this treatment. However, the results can be considered within the new SCC limits in the EFNARC Guidelines. The decrease in the flow time in MGS mix may be the result of the uniform distribution of the fibers of the geometric shapes and the solidification of the behavior of the fibers which leads to no pelletizing the fibers in the mixture, and this helps the mixture to flow for 500mm in less than 2.5 seconds.

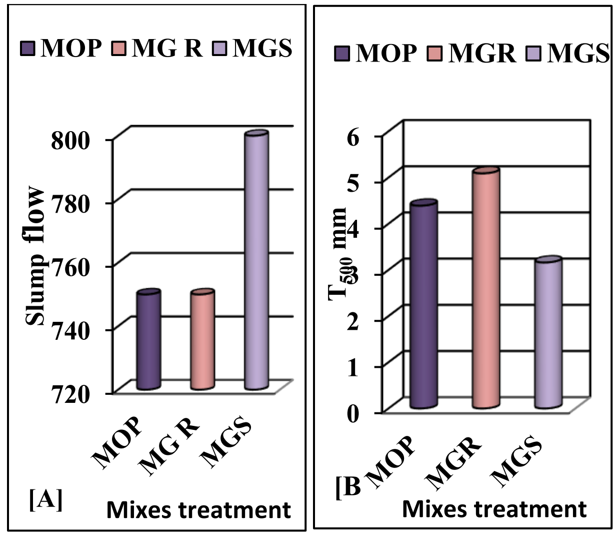

Figure 8. Relationship between of PET treatments and [A] Slump flow, [B] T500mm tests of SCC

Figure. 9 A, B shows the results of the L-box and sieve segregation test. The geometric modification of the PET fibers in the MGS mixture showed a significant negative effect on the passing ability. This may be due to the irregular slicing, which caused an obstruction to the passage of the mixture through the reinforcing bars. According to the results, the blocking ratios were 0.88, 0.77 and 0.31 for the MOP, MGR and MGS mixtures, respectively.

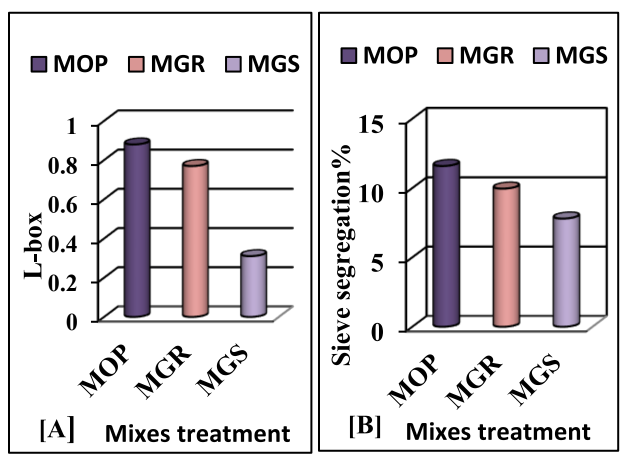

Figure 9. Effect of surface treatment and modification of PET fibers on blocking ratio and SI index

The remarkable bending of the PET fibers of greater stiffness, which occurred after physical processing, may be the reason for the very slight decrease in the passing ability of the MGR SCC mix as compared to the MOP SCC mix. As for the resistance to segregation test, The MGS mixture showed lower separation resistance compared to MOP, which may be due to the hydrophobic nature of the PET fibers before treatment. After exposing to gamma rays, a more roughness were observed in the surface of PET (as detected by the SEM images as shown in Fig.10), which can lead to increase the friction between the surface of the PET fiber and the cement mortar, and thus preventing the mixture from segregating.

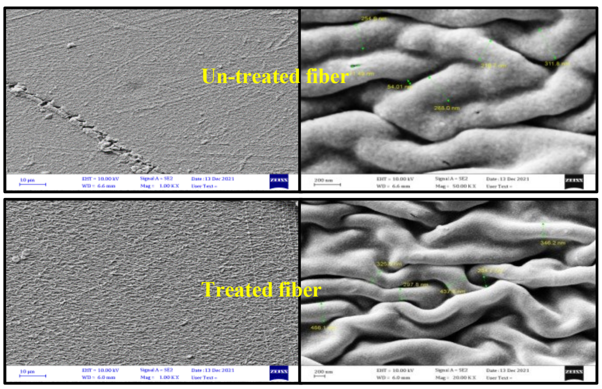

Figure 10. SEM images of treated PET fiber with gamma and un-treated PET fiber

On the contrary, MGS achieved little segregation index value as compared to the rest of the mixtures. This indicates the benefit of cutting the fibers in a non-uniform manner to reduce segregation of the SCC mixture. The possible reason for this is that the geometric E-section shaped fibers act like anchors, carrying the fiber particles within the matrix. The values of the SI class indices were 11.59%, 9.96% and 7.85 for all mixtures of MOP, MGR and MGS, respectively

3.2 Effect of surface treatment of PET fibers on hardened properties performance

3.2.1. Compressive strength

Figure 11 shows the effect of surface treatments and modification of PET fibers on the compressive strength of sustainable SCC at 7, 28 and 90 days of water curing. In general, there has been a continuous increase in compressive strength values with increasing age as a result of the improvement of cement hydration by water curing.

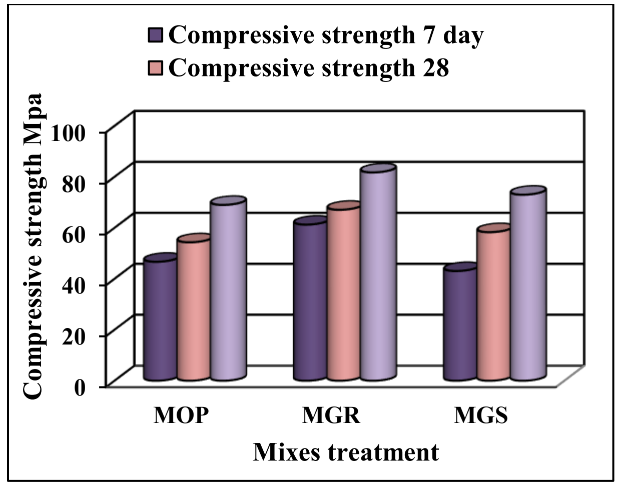

Figure 11. Relationship between PET fiber treatments and compressive strength of sustainable SCC at different ages

It can be seen from the figure that the compressive strength value at 28 days of age for the MGS and MGR mixtures increased by 7.33% and 23.47%, respectively. For fibers with a geometric shape, Comingstarful and Marthonga[34] claimed that the shape of the fibers had a significant influence on the failure of samples [34]. Furthermore, Abhishek and Sanjeev [13] said that the polyethylene terephthalate fibers with a geometric shape helped to improve the compressive strength due to the good bonding strength, and the lack of buildup unrelated to the surface area[13]. The applying of gamma radiation on PET fibers contributes to obtaining higher values of compressive strength. In short, the modified PET fibers continuously interact with the surfaces of the slurry components. Therefore, it leads to improved mechanical properties [35].

3.2.2. Tensile strength

Figure 12 shows the test results of splitting tensile and flexural strengths. The fiber-containing modified SCC showed better tensile strength values compared to the MOP-optimized mixture (4.1 MPa). The MGR mixture best result at 28 days which was 4.653MPa. The possible reasons for these results are the increase in the bonding strength between the treated and modified PET fibers and the cement matrix. This is due to the increase in the surface roughness of PET as detected by SEM examination after exposing to gamma radiation. It is known that the mechanical bonding in a composite material depends on the roughness of the components, the higher the roughness, the better the interaction at the interface.

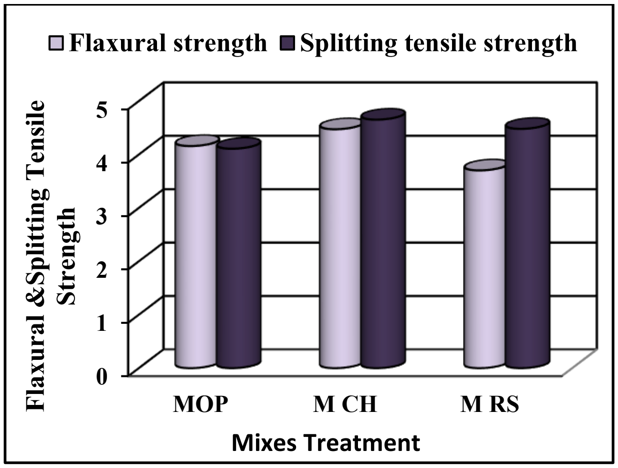

Figure 12. Relationship between of PET fiber treatments and splitting tensile and flexural strengths of SCC at 28 days

As for the flexural strength of in Fig. 11, the surface treatment of PET fibers with gamma rays also increased the bending strength by 12.93% as compared to the MOP mixture, with a very slight decrease in the flexural strength for the MGS mixture.

3.2.3. Modulus of elasticity

For the MGR and MGS mixtures, the modulus of elasticity increased by about 34.4% and 99.5%, as shown in Fig. 13 as compared to MOP mix.

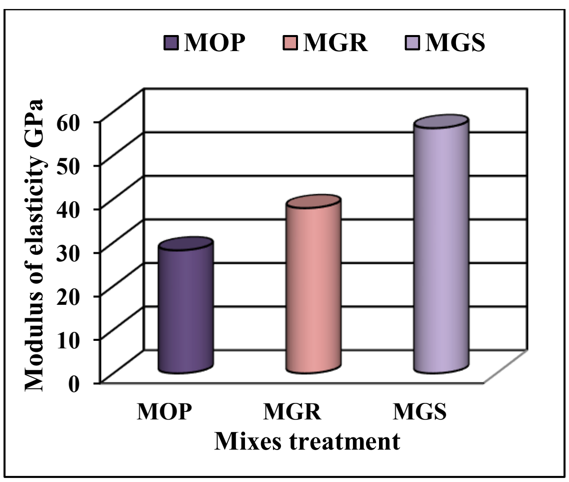

Figure 13. Relationship between PET fiber treatments and Modulus of elasticity of sustainable SCC at 28 days

The reason for the increased flexibility of concrete containing fibres is that the fibres can withstand applied stress. Untreated fibres may slip quickly and cannot handle more stress and thus reduce elasticity. On the other hand, treated fibres might not slip easily due to good bonding and can withstand the stresses of concrete under extreme applied loads, which may significantly increase the flexibility of concrete. In addition, Kumar [13] confirmed that non-straight fibres withstand stresses applied to concrete and give a high modulus of elasticity [13].

3.2.4. Impact strength

In general, adding modified PET fibers to the sustainable SCC has a positive effect on both numbers of blows and energy absorption as listed in Table 6.

Table 6. Detailed results of the impact strength test

Mix	Def. mm	No. of blows to cause			Energy Absorption Joule at		
		First crack	Initial failure	Ultimate failure	First crack	Initial failure	Ultimate failure
MOP	0.69	1	5	21	32.96	164.8	692
MGR	0.55	1	10	25	32.96	296.7	824
MGS	0.49	1	6	19	32.96	197.8	626

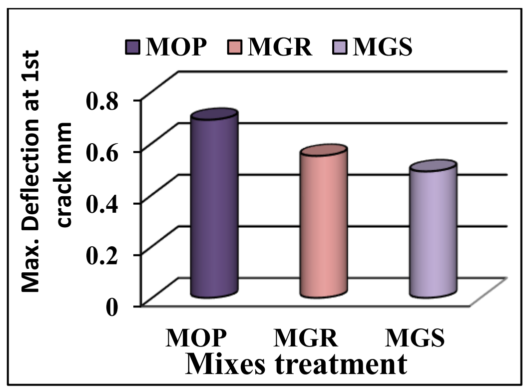

Figure **14.** Relationship between PET fiber treatments and Max. deflection at first crack for sustainable PET fiber reinforced SCC

The addition of plastic fibers exposed to gamma rays increased the number of blows required to cause final failure of the MGR mixture compared to MOP, while MGS slightly decreased the number of blows. The increase in the impact strength of the sustainable SCC containing fibers exposed to gamma rays might be as a result for the modification upon contact with the surface of the PET fibers to the concrete matrix. However, the MGS and MGR mixture showed superior performance in reducing the maximum deflection in the centre of the concrete slab as compared to the MOP mixture as shown in Fig. 14.

3.2.5. Dry density

Figure 15 shows the change in the dry density of PET fiber reinforced sustainable SCC after immersion in water for 28 days.

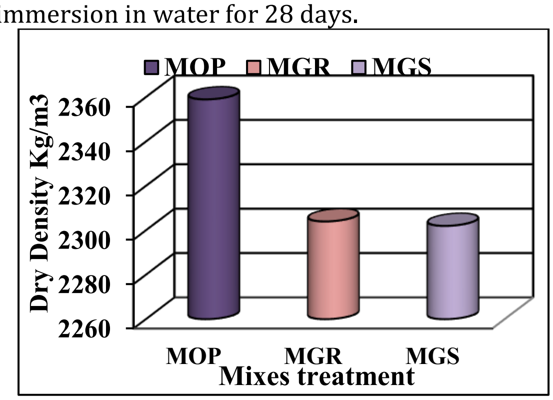

Figure 15. Relationship between PET fiber treatments and dry density of PET fiber reinforced sustainable SCC

The reference mix MOP was the densest followed by MGR and MGS concrete, respectively. Dry densities decreased by 2.33%, 2.42% for the mixtures compared to the MOP mixture respectively. In general, PET-engineered shaped fibers have reduced mixture weights compared to straight fibers, and the physically treated fibers after processing become less weight and stiffer compared to other fibers.

3.2.6 Ultra Pulse Velocity UPV

In order to verify the internal structure of the PET fiber reinforced sustainable SCC, all UPV values of the modified fiber reinforced SCC as well as the reference concrete samples were found in the range of (4.08 - 4.167) km/s as shown in Fig. 16.

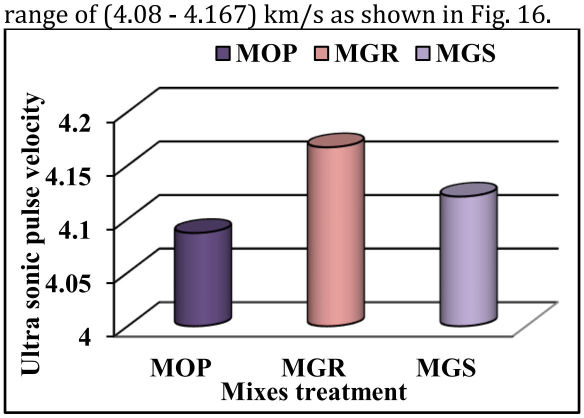

Figure 16. Relationship between PET fiber treatments and ultrasonic pules velocity of PET fiber reinforced sustainable SCC

This indicates that the quality of the concrete falls into the rank of "good and excellent". However, the inclusion of modified PET fibers was observed to increase UPV by only 0.83% and 1.96% for the MGS and MGR mixtures respectively as compared to control mix.

3.2.7 Porosity and water absorption

Results of porosity and water absorption tests at 28 days are shown in Fig. 17 A,B. The difference in the porosity and water absorption rate from the sustainable reference SCC and those with treated PET fibers indicated that concrete containing modified PET fibers has lower porosity and water absorption compared to the MOP mixture.

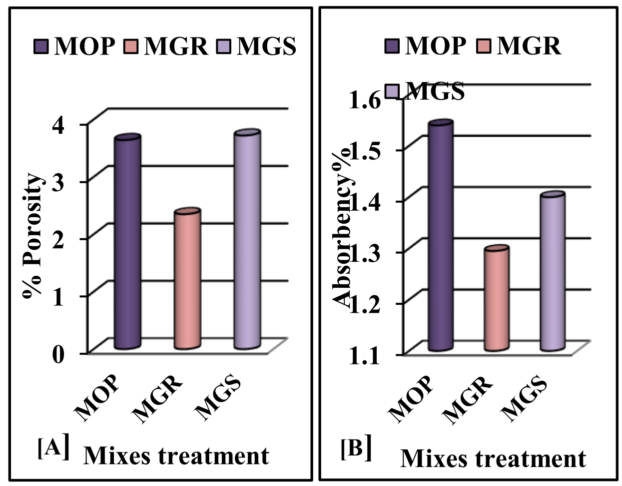

Figure 17. Relationship between PET fiber treatments, porosity and water absorption of PET fiber reinforced sustainable SCC

The porosity of MGR decreased significantly by about 35.44%. However, for the MGS mixture, the porosity value increased by only 2.2%, so it can be said that the geometrical shapes fibers do not significantly affect the porosity. The water absorption decreased by 15.58% and 22.1% for the MGR and MGS mixes respectively. After the fiber surface modification, the weak boundary layers around PET fibers might be removed can be considered as the main factor in cutting pore continuity near the surface of the PET fiber.

4. Conclusions

Based on the results obtained from of the current study, the following concluding observations can be drawn:

1-A slight negative effect of treated fibers was recorded on slump flow, T_{500} mm, L-box, and sieve segregation tests. However, the fresh results obtained were within the limits of the EFNARC guidelines for fresh SCC.

2-The addition of treated and modified PET fibers to the optimized sustainable SCC mixture (MOP) improved the compressive strength by about 7.33% and 23.4% for MGS mix (SCC containing PET with treated surface by gamma radiation) and MGR mix (SCC containing PET with modified shape E-section) respectively.

3-A more obvious improvements in tensile strength compared to MOP mix were recorded due to the addition of treated and modified PET fibers in the sustainable SCC. The tensile strength of MGS and MGR mixes increased by 13.9% and 18.31%, while the flexural strength of the fiber-reinforced SCC exposed to gamma rays was slightly improved, yet a slight decreased in the flexural strength of MGS mixture was found.

4-With the treatment and modification of the PET fiber surface, the modulus of elasticity of SCC increased significantly at 28 days, and these increases in MGR and MGS mixtures were 34.4% and 99.5%, compared with the control optimized PET fibers reinforced SCC mixture.

5-PET fiber treatment and modification improved the impact strength of SCC as compared to control mix. It was found that the MGR mixture showed better results than MGS and control ones in terms of the number of blows to cause the failure and absorbing more energy with low max deflection at the mid span of the SCC slabs.

6-Adding the treated and modified PET fibers to the optimized SCC mixture MOP reduced the dry density by small percentages with a slight increase in the UPV values for the MGS and MGR mixtures as compared to the control SCC.

7-The treated and modified PET fibers effectively reduced the porosity and water absorption of the sustainable PET fiber reinforced SCC.

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