Heliyon 10 (2024) e32950

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

Physical, mechanical, and durability properties of concrete containing different waste synthetic fibers for green environment – A critical review

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ARTICLE INFO

Keywords:
Waste synthetic fiber
Recycling method
Concrete
Safe environment

ABSTRACT

The world is facing a major challenge on ways to manage the waste synthetic materials that are potentially polluting the environment. So, by 2040 it is estimated from the total synthetic textile products that will be produced, the accumulated synthetic textile waste will be more than 73.77 %, if recycling of waste may not be managed by novel technology in different sectors. Hence, this is a great challenge coming to the world if it is not effectively recycled mainly to be used in the construction sector which covers a broad area. However, detailed critical review is needed to gather different authors result on waste synthetic fiber effectively utilized in construction materials like in a concrete. So, the present study reviewed, the effects of waste synthetic fibers specifically, which are covering many numbers of synthetic materials; polyester, nylon, and polyethylene replacement on the physical, mechanical, durability, and microstructural properties of concrete. As the review of most researchers indicates, reinforcing the waste synthetic fibers in the concrete by 0.1–1% to the weight of cement reduces workability, improves compressive, flexural, splitting tensile strength, and enhances durability. Specifically, adding around 0.5 % doses to the volume of the concrete makes good resistance to water absorption, chloride ion penetration, acidic attack, elevated temperature resistance below 600°C, and lessen concrete content hence, cost effective compared to the control concrete mixture. Besides these, the employment of waste synthetic fibers makes dense microstructure, consequently minimizes the crack occurrence and propagation.

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https://doi.org/10.1016/j.heliyon.2024.e32950
Received 23 March 2024; Received in revised form 22 May 2024; Accepted 22 May 2024
Available online 13 June 2024

1. Introduction

Waste management of synthetic materials are a major challenge to the world, which is due to its non-biodegradability that pollutes lands and oceans [1–4]. However, because of fastest growth of the world economy the production of synthetic fibers from 2020 to 2030 will be higher than 2010–2020 as shown in Fig. 1, hence up to 2020, from total produced textile fibers 71.4 % disposed on the land or incinerated. Also, from 1900 onward, less than 11 % of waste textiles is estimated to have been recycled [5–7]. Therefore as shown in Fig. 2, currently waste synthetic materials are polluting the environment and changing the aesthetic value of the land in addition to causing many diseases to the society. Also, waste synthetic fibers in the environment cause the death of marine animals especially, turtles, and sea lions by 380,000 annually [8], and causes more than 90 million USD in economic losses [9].

Besides these as shown in Fig. 3, by 2040 it is estimated from the total textile products will be produced, the accumulated textile waste will be more than 73.77 %, if recycling of those waste will not be managed by recycling and then being used in various sectors, such as construction industry that covers a broad area which can reduce this environmental challenge [5,10].

Nylon fiber is a group of polymeric materials which are commonly known as poly-amides used in plastic bags for wrapping and tight packing, carpets, ropes, clothes, tires, nets, aerospace, automotive, in electronics systems, and military applications. It is light-weight, has high tensile strength, and is more sustainable [13,14]. Polyester and polyethylene are other types of synthetic products mainly used for producing plastic bottles, wires cables, and clothes [15–19]. However, those three synthetic products are non-biodegradable and impose critical risks to the environment when disposed [20], while their production is much higher in the present and future to be produced by the textile industry as shown in Fig. 1.

So, researchers investigated ways to reduces the impact of waste synthetic fibers and thus mitigate hazards from the environment, which is mostly by replacing waste synthetic fibers in the concrete mixture [21–25]. That is because, synthetic fibers are ductile materials while concrete is a brittle material with low tensile strength, fracture toughness, strain capacity, and weak energy absorption [26–32], hence, synthetic fiber replacement in concrete is crucial in increasing ductility and tensile strength, lessens shrinkage cracks, and protecting the matrix of concrete from different adverse environments [33–35]. Especially, the replacement of waste synthetic fiber in the concrete matrix contributes a beneficial influence on most concrete engineering properties [36–40], in addition to alleviating the environmental and socio-economic impact of waste synthetic materials [36,41–46]. Generally, waste synthetic materials like nylon, polyester, and polyethylene waste as a replacement in concrete in the construction sector can give mutual benefits for providing significant improvements in strain capacity, crack, and impact resistance of concrete through dual effects, bridging action, and refinement of pore distribution while keeping safe environment [47–51].

1.1. Review significance

By 2040 the total synthetic textile products produced will be more than 73.77 %, if recycling of those waste is not implemented and being used in different sectors [5]. Hence, this is a great challenge coming to the world if it is not effectively recycled and reused mainly in construction sectors which covers a broad area. However, it needs a detailed critical review of different authors result to be waste synthetic fiber effectively utilized in construction materials mainly in concrete. So, the present study reviewed the effects of waste synthetic fibers specifically, which are covering much number of synthetic materials i. e polyester, nylon, and polyethylene replacement on physical, mechanical, durability, and micro structural properties of concrete. Furthermore, the most practicable method and easy way of waste synthetic materials recycling process which can effectively implemented in cementitious materials have been highlighted. Generally, this review analysis and conclusion can be very useful for any reader interested in this field, especially

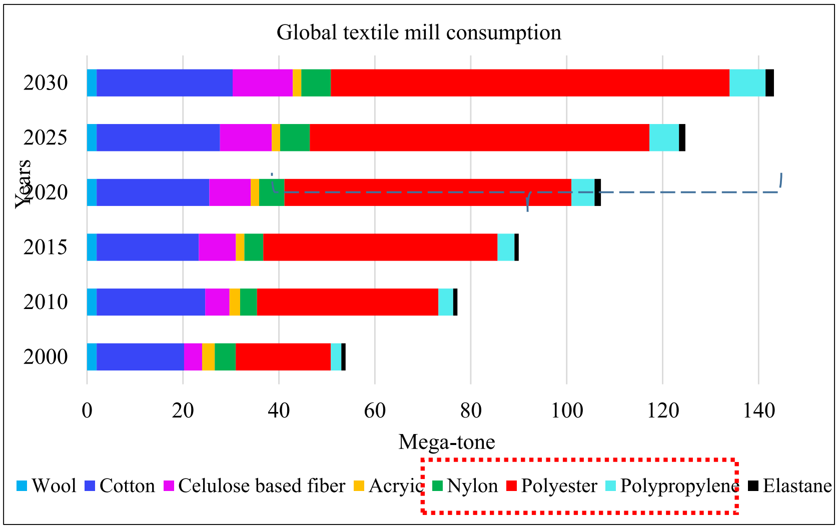

Fig. 1. Market growth for synthetic fibers at current and future predicted total fiber demand from Mackenzie, [11].

Fig. 2. Different synthetic wastes from texture industries and household [12].

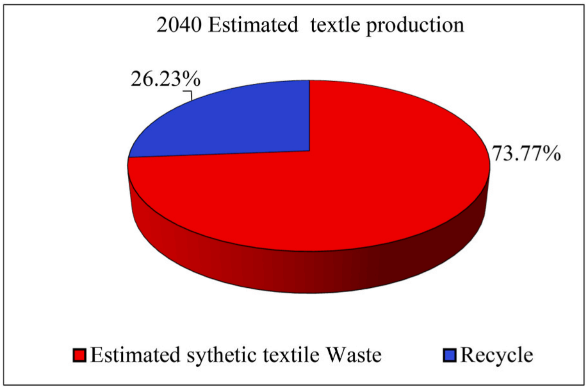

Fig. 3. Estimated textile products waste and recycle at 2040 from Jonsson et al. [5].

anyone working in the construction industry and waste synthetic materials management body. Also, the recommendation given in this work can open new ideas for future researchers to find new or improved ways to reduce more waste synthetic fibers from the environment.

1.2. Recycling techniques for waste synthetic fibers for construction materials

As presented in Fig. 4, a huge amount of the waste synthetic fibers can come from either post-consumer or industry which can be household items, carpets, clothes, packages, and plastic bottles that are dropping critical environmental challenges. Mostly, the conventional recycling methods of synthetic fibers are based on mechanical, thermal, and chemical processes [1]. However, in the construction industries, the preferable recycling of waste synthetic fibers are by mechanical method which is easier and cost-effective than other methods [52,53]. As shown in Fig. 3, this method commonly implemented by the reprocessing of waste synthetic materials by physical means and it has a cleaning or leaching process and drying if the waste material needs [52,53], and then cutting by hand or milling waste synthetic fibers through the machine into different fiber shapes and various as preferred dimensions to be the fibers effectively used in the reinforcing of cementing materials [54].

2. Materials and method adopted for reviewing process

The literature and information are gathered from the Google scholars that include publishers of Elsevier, Taylor and Francis, Springer, Wiley, etc. On full discussion and evaluation on the ways to adopt waste synthetic reinforcement in construction materials, especially in concrete. So, it has seen from synthetic materials polyester, nylon, and polyethylene materials are mostly produced and

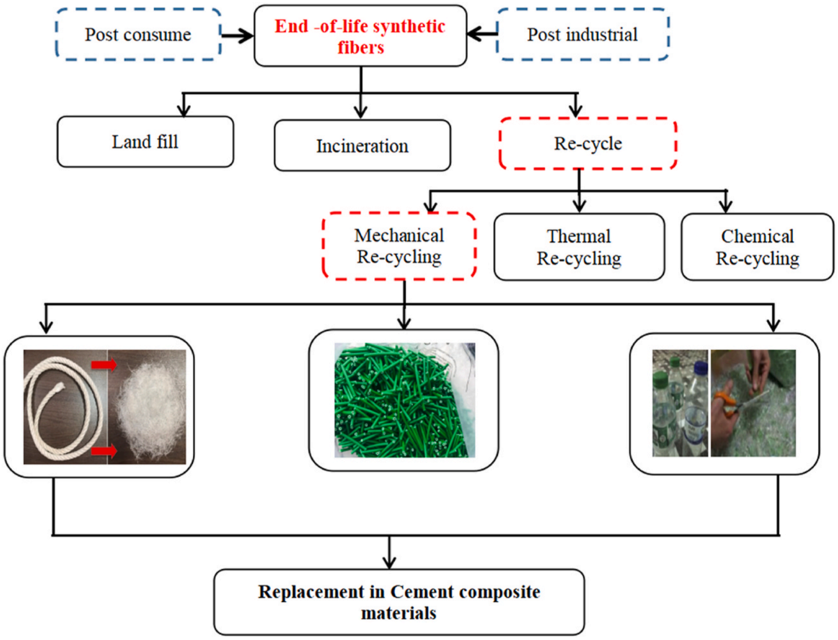

Fig. 4. End of synthetic fibers life from Goncalves et al. [55] reproduced.

expected to be used more in the future than other synthetic materials. So, the present study detail reviewed the most effective method of recycling waste synthetic materials to be implemented in concrete reinforcement and reviewed the effect of using those three waste synthetic materials on the physical, mechanical, durability, and micro-structural properties of concrete. The methodology to analyze the review and all used literature respective to its publication year are presented in Figs. 5 and 6.

3. Effect of WSF on physical properties

3.1. Workability

The reinforcement of polyethylene fiber in concrete significantly affects the workability, especially by increasing the fiber content can lead to more lessening of the workability of the concrete [56–60]. However, conventional concrete is able to cover some difficulties like high flow ability, pass-ability, and stability [61]. So, the present study reviewed different literature on the effect reported on the workability versus the employment of different waste synthetic fibers in the concrete as shown in Fig. 7, hence, most of the reviewed literature found lessening of workability due to reinforcing cementitious material by waste synthetic fiber and increasing the doses of waste synthetic fiber more reduces the workability of cementing materials.

As Nasr et al. [43] found that the employment of synthetic fibers have a negative effects on the concrete flow ability and pass-ability and a positive effects on concrete detachment. Also, the study reported the increase in length and quantity of fiber, more reduces the flow-ability and pass-ability of concrete while resistance against detachment is enhanced. Hence, while the fiber content increases, the inter-facial bond capacity between the fiber and cement paste becomes flexible since the additional fibers consume the binder of the cement paste to cover the fiber [62]. Generally, the reduction of workability of concrete by the employment of waste synthetic fiber can be solved by the addition of admixture without increasing the water content [56].

3.2. Density of concrete

The reinforcement of synthetic fiber in cementitious materials reduces the density [63,64], specifically, the replacement of waste synthetic fiber in concrete lessens the density [43,65,66]. Also, Tamrin & Nurdiana [67], investigated on the waste polyethylene fiber employment in the concrete mixture and found the density of concrete reduced and get more lighter concrete due to being reinforced by waste polyethylene fiber, which is mainly the waste polyethylene fiber have low density compared to the concrete mixture. The same observation with Abdulridha et al. [62] that reported the employment of waste nylon rope fiber lessens the density by 3.1 % for 1 % fiber replacement in the concrete.

Besides these, as shown in Fig. 8a,b the Abdulridha et al. [62] and Farooq et al. [68] found the employment of waste synthetic fiber rope and nylon fiber respectively slightly increased at lower fiber substitution and while the doses of waste synthetic fiber increases the density fall down compared to the control concrete mixture. That is decreases in density due to the specific gravity of waste synthetic fiber is much lower than the concrete [69]. Generally, the reduction of bulk density while increasing the waste synthetic fiber in cementitious materials is crucial for massive concrete production to have lighter concrete especially, for high-rise building and massive

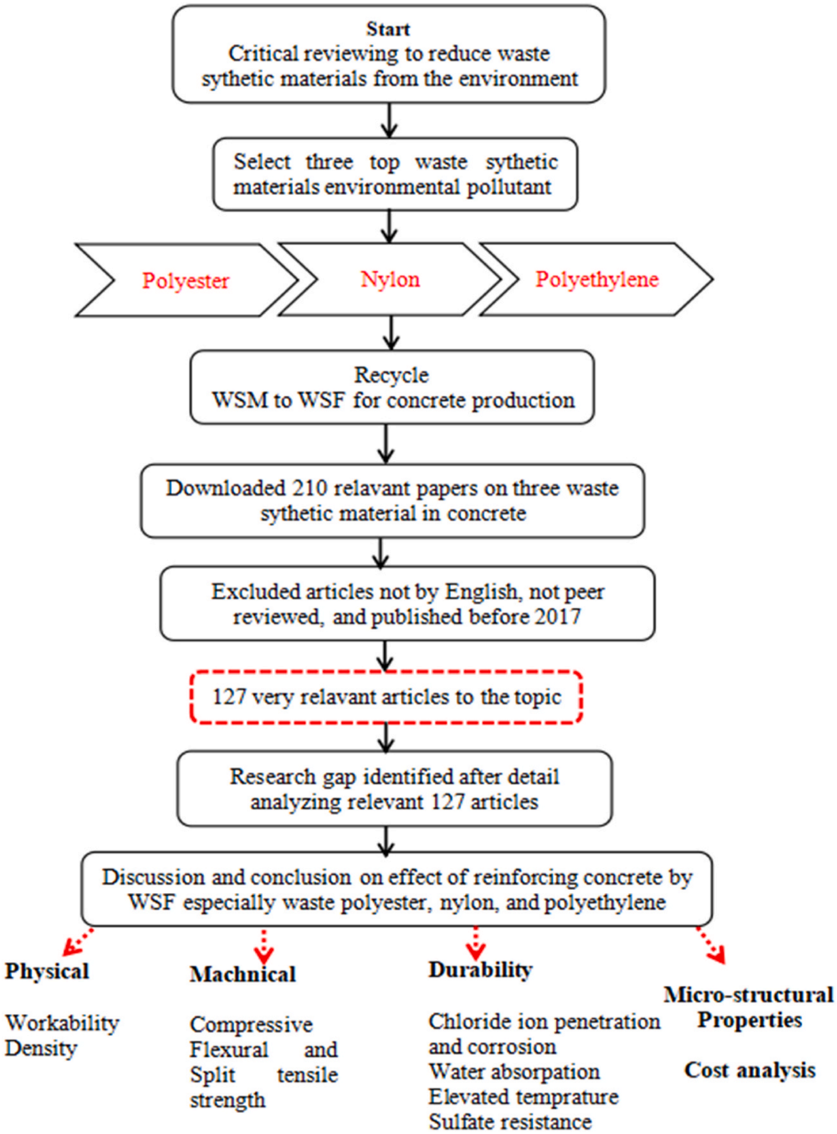

Fig. 5. Review process and literature screening.

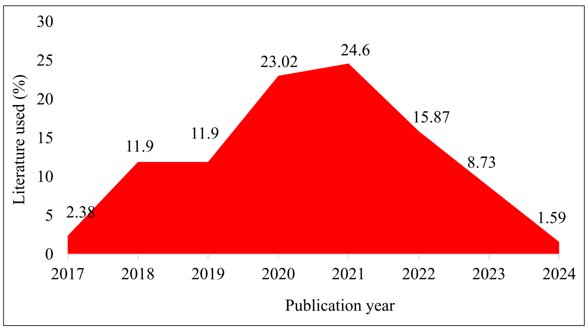

Fig. 6. Publication year of used literature.

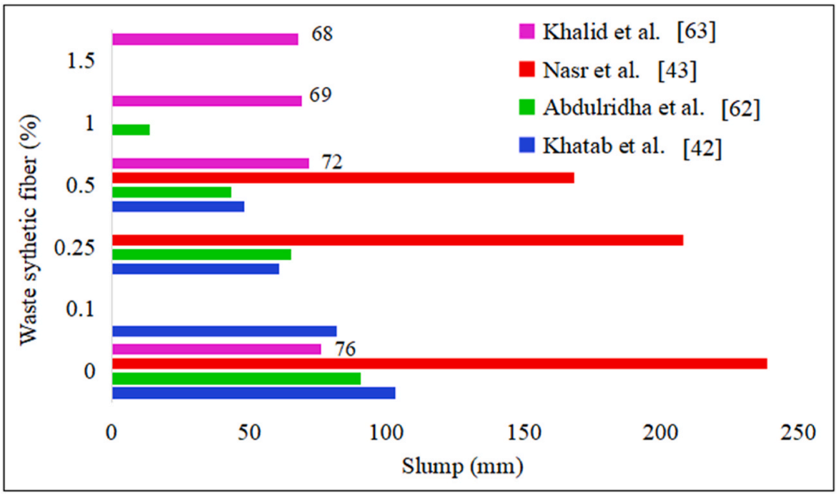

Fig. 7. Workability results of different waste synthetic fiber reinforced concrete from different authors.

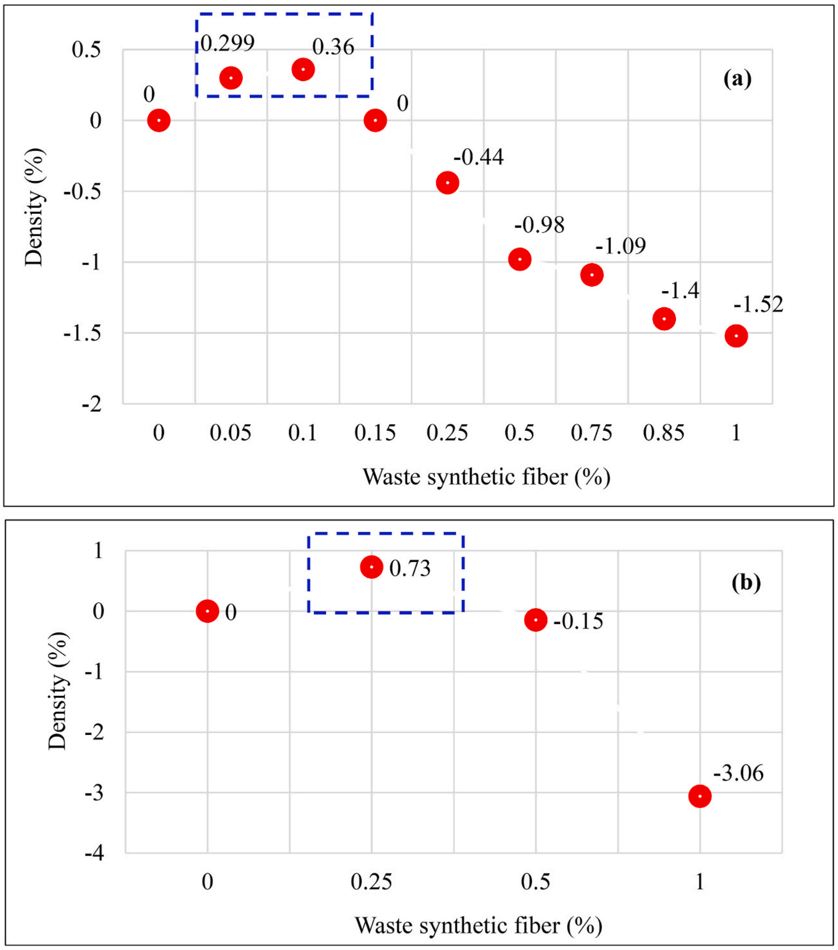

Fig. 8. Density of concrete reinforced by different doses of waste synthetic fibers (a) from scrap brushes Farooq et al. [68] and (b) from rope tie Abdulridha et al. [62] permission Elsevier.

constructions [70].

4. Effect of WSF on mechanical properties

4.1. Compressive strength

The reinforcement of waste synthetic fiber in the concrete mixture improves the compressive strength [71–75]. Nasr et al. [43] reported that 0.25 % of waste plastic fiber improved strength by 16.8 % and 21.5 % at the concrete age of 28 and 56 days. However, the increase in synthetic fiber content in the concrete mixture can reduce linearly the concrete compressive strength [76,77]. Abdulridha et al. [62] investigated the effect of reinforcing the concrete by waste nylon fiber from the rope wire by 0 %, 0.25 %, 0.5 %, and 1 % to the weight of the concrete mixture and found that the replacement of waste rope fiber by 0.5 % improves compressive strength by 22 % compared to the control mixture. However, the study reported increasing the content of waste rope fiber decreases the compressive strength.

Also, as presented in Fig. 9, many researchers found that the replacement of waste synthetic fibers increases the compressive strength, especially, Khalid et al. [63] get optimum compressive strength by 0.5 % replacement while Tiwari et al. [13] and Adnan & Dawood [54], found optimum compressive strength of concrete by 1 % and 1.5 % replacement of waste wire cable and plastic container fibers which commonly improved by 17.48 % and 42.08 % compared to the respective control mixture as presented in Table 1. Their results indicate the importance of employing waste synthetic fibers in the concrete mix, which is basically due to fibers improve the interfacial bond between the paste and aggregate at specified doses, in addition to reducing the environmental pollution challenging the world due to waste synthetic materials.

4.2. Flexural strength

Reinforcing concrete by waste plastic fibers was successfully used to improve the concrete flexural toughness compared to the control mixture, besides lessening the environmental pollution due to waste synthetic polyester, nylon, and polyethylene fibers [79–82]. This is basically due to the reinforced cementitious materials by waste synthetic fiber increases the ductility of cementing materials, consequently, improves the flexural capacity and post cracking strength [76,83,84]. Also, as Nasr et al. and Abbas [43,85] found increasing the fiber content in cement composite materials can more raises the concrete flexural strength.

Besides these, as shown in Fig. 10 various researchers reported different waste synthetic fiber improves the flexural strength of cement composite materials. Especially as presented in Table 1, Adnan & Dawood [54], and Tiwari et al. [13] found optimum flexural strength by the 1.5 % and 1 % replacement of waste synthetic fibers compared to the control mixture. This is due to the employment of waste synthetic fiber improves the ductility of the concrete matrix which consequently, improves the ultimate bending capacity of cementitious material.

Furthermore, the waste nylon fiber is more effective to compensate the flexural capacity of lightly corroded steel reinforced concrete beams. Hence, waste nylon fiber in the cement composite materials are beneficial to repair the deteriorated concrete part while recycling the waste synthetic fiber used to maintain a clean environment and cost-effective construction works [86].

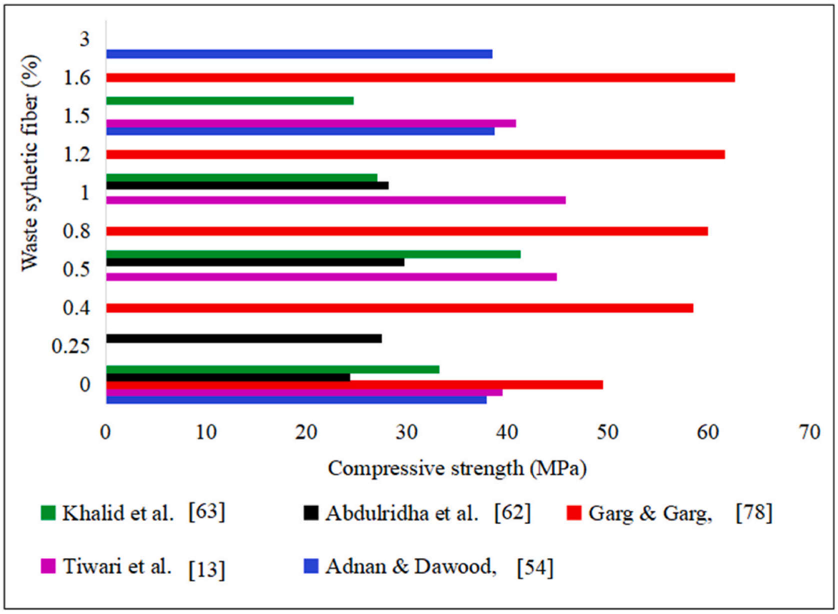

Fig. 9. Compressive strength of concrete reinforced by different waste synthetic fibers at 28 days reported by different authors.

Table 1
Optimum mechanical properties obtained by different researchers at 28 days by reinforcing cement composite materials through waste synthetic fibers.

Type of WSF	Source of WSF	W/C	WSF dimensions		Optimum CS at 28 days		Optimum FS at 28 days		Optimum TS at 28 days		Any admixture	References
			Diameter (mm)	Length (mm)	Dose (%)	Increase (%)	Dose (%)	Increase (%)	Dose (%)	Increase (%)		
Nylon	Scrap paint brushes	0.45	0.25–0.5	25–40	0.15	7	0.75	24.20	0.25	14.1	Plasticizer	[68]
PE	Waste containers	0.41	4 width	40	1.5	42.08	1.5	22.75	–	–	–	[54]
Nylon	Cable tie	–	2.5	0.3–50	1	17.48	1	46	1	37.41	–	[13]
PE	–	0.40	–	12	1.2	26	–	–	1.2	34	silica-fume	[78]
PET	–	–	12	18	0.55	6.54	0.55	16.22	0.55	44.44	–	[17]
Nylon	rope	0.5	0.19	15	0.5	22	0.25	4.3	–	–	SP	[62]
PE	wire	–	1.17	40	0.5	24.4	–	–	0.5	3.74	–	[63]
PET	–	–	–	–	0.5	1.52	0.5	12.5	0.5	18.96	–	[49]

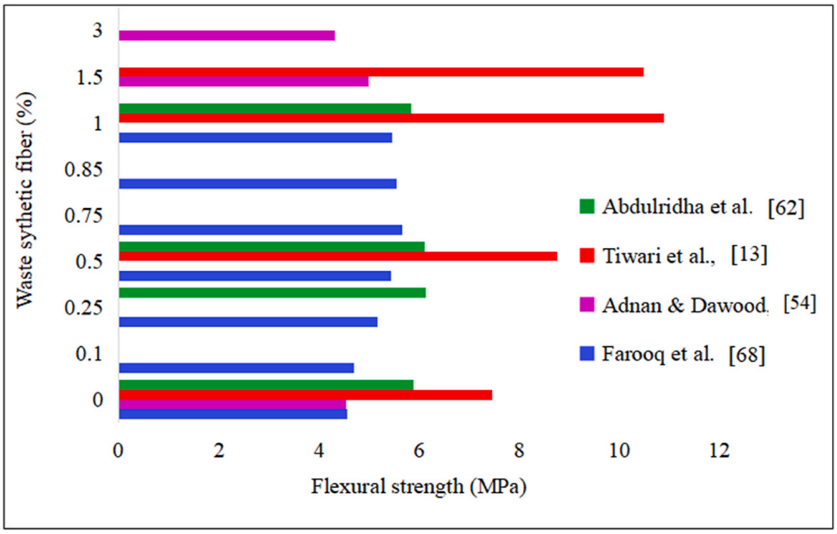

Fig. 10. Flexural strength of concrete reinforced by different waste synthetic fiber at 28 days reported by different authors.

4.3. Split tensile strength

The employment of waste synthetic fiber in concrete significantly increases the tensile strength of concrete compared to the control mixture [87–90], and tensile strength mainly depends on the content of fiber, while the concrete properties like compressive strength and toughness are not beneficial by the higher proportion of the fiber contents [58,76,87,91,92]. Also, Mita et al. [57] reported that nylon fiber improved the tensile strength of cement composite material at any sampled replacement and water-to-cement ratios. Besides these, Mohammed & Mohammed [93], found polyethylene fiber substitution in cementing materials significantly improves the splitting tensile strength.

Furthermore, as shown in Fig. 11, the report of different researcher results indicate the employment of waste synthetic fibers in the concrete mixture improves the splitting tensile strength. Especially as presented in Table 1, Garg & Garg [78], and Tiwari et al. [13] found the replacement of polyethylene fiber and nylon cable tie by 1.2 % and 1 % in concrete can give optimum tensile strength by 34 % and 37.41 % respectively compared to the control mixture without waste synthetic fiber. That is due to the reason fibers could resist tensile force by its ductile behaviour which can improves the split tensile strength of concrete while used in the concrete mixtures.

Also, the same observation with Mokhatar et al. [94] found WSF can significantly improve the tensile strength capacity of concrete. Hence, this study reported waste synthetic fiber has the capacity to replicate the existing steel fiber and lessens the quantity of waste

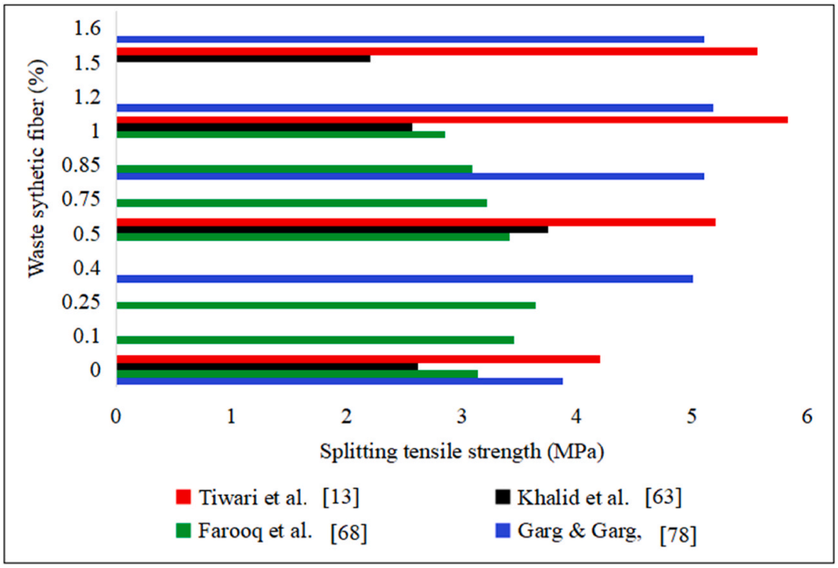

Fig. 11. Split tensile strength of concrete reinforced by different waste synthetic fiber at 28 days reported by different authors.

synthetic products disposed on the land and enhance a clean environment for the upcoming generation.

4.4. Elastic modulus

The initial slope of stress and strain curve is elastic modulus [95]. The employment of WSF in cement concrete reduces the elastic modulus compared to the control mixture, especially, increasing the dose of WSF in concrete significantly reduces the elastic modulus [96]. The same observation with Daneshfar et al. [95] found that the addition of WSF above 0.4 % in concrete lessens the elastic modulus, this may be while raising the amount of WSF employed in concrete may reduce the binding with cement composite which can reduce holding stress capacity. However, have seen limited studies on the elastic modulus of concrete reinforced with WSF, hence, needs to be detailed investigation.

5. Effect of WSF on durability

5.1. Water absorption

The penetration of water and harmful chemicals into the concrete matrix is highly dependent on the volume of voids in the concrete [97–99]. Hence, the water absorption can determine the permeable concrete pores. Farooq et al. [68] investigated on the use of nylon

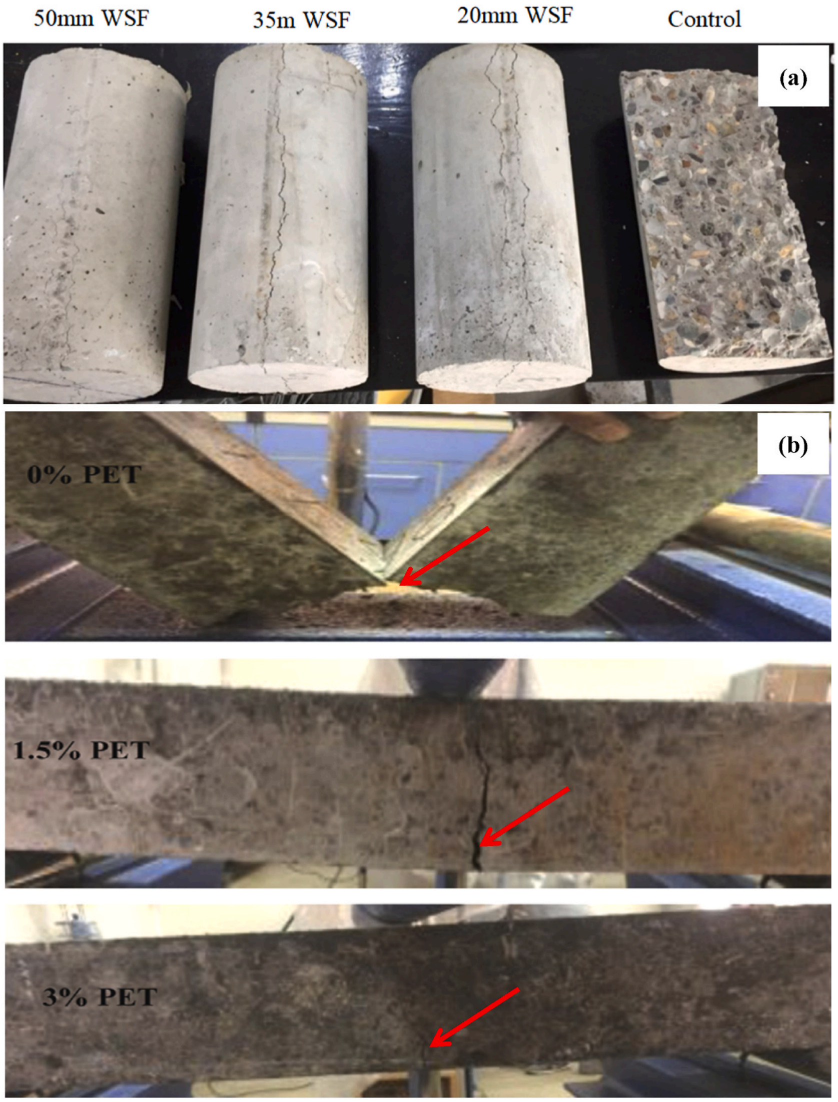

Fig. 12. Crack resistant behavior of control and waste synthetic fiber reinforced concrete after (a) split tensile strength test and (b) flexural strength test from Mohammed & Mohammed [93], and Adnan & Dawood [54], respectively, permission Elsevier.

fiber from scrap brush in concrete mixture and found the use of waste scrap brush in concrete by 0.5 % reduced the water absorption of 11.5 % compared to the control concrete mixture. This is basically due to the reason the smaller content of fiber can easily dispersed homogeneously throughout the concrete matrix and form the inter-facial bond with the sand and cement paste that consequently, lessens the water absorption. However, the study observed increasing the waste nylon fiber dose significantly increased the water absorption, specifically the addition of 1 % waste nylon fiber increased the water absorption by 11.5 % compared to the concrete mixture. That is basically because of adding the higher fiber content in concrete can cause porosity which water can penetrate in to the concrete matrix. Also, the same observation with Nasr et al. [43] found that the employment of waste synthetic fiber sourced from nylon in concrete reduced the water absorption compared to the concrete control mixture. This is very beneficial since the penetration of moisture and water into concrete can make corrosion of steel reinforced concrete, and hence causes a reduction of concrete strength and durability [100,101].

5.2. Crack pattern and crack propagation analysis

Cracking is sign of failure in concrete at applied tensile load when it exceeds the concrete tensile strength [54]. Basically, reinforcing the concrete with synthetic fiber significantly improves crack occurrence, good abrasion resistance, and reduces crack dispersion due to synthetic fibers have higher ductility than concrete [102–106]. Specifically, employing the waste synthetic fiber can reduce the crack propagation, and crack width of concrete under ultimate strength loading [23,62,107,108]. Most of the literature found increasing the synthetic fiber content and length increases the resistance to the crack occurrence of concrete [109,110]. This is shown in Fig. 12a, by Mohammed & Mohammed [93], studied the effect of employing waste polyethylene fiber in concrete by different fiber length 20, 35, and 50 mm, hence, found the concrete without waste fiber fractured into two, this is mainly because of concrete is commonly brittle material can not much resist the tensile load. However, as this study found concrete with waste polyethylene fiber can not suddenly fracture like the control specimen. Besides these, increasing the fiber length can significantly reduce the crack propagation and crack width due to the applied ultimate tensile load. This maybe while the length of waste polyethylene fiber increases the number of aggregate and cement paste interlocking together improved, consequently increases the resistance of crack occurrence on the concrete face.

The same observation Farooq et al. and Bui et al. [111] investigated the effect of waste synthetic fiber of polyethylene sourced from plastic bottle employment by different doses. This study observed that increasing the dose of waste synthetic fiber significantly reduces the crack propagation and crack width while the control mixture is totally broken in to half by the ultimate flexural load as shown in Fig. 12b. This is mainly due to increasing the dose of waste synthetic fiber, it is increasing the plastic-ability of concrete that can more resist crack occurrence [112,113].

5.3. Chloride ion penetration and corrosion resistance

Chloride migration is an important technique to measure the chloride ion penetration to the concrete, which is mainly crucial to indicate the durability and service life of steel reinforced concrete structures [114]. That is by measuring the quantity of chloride that can migrate in the concrete matrix which can cause corrosion of steel bars [99,115,116]. Hence, as shown in Fig. 13, the employment of waste synthetic fiber in the concrete significantly lessened the chloride ion migration at the lower substitution up to 0.5 % and found 29.2 % optimum reduction of chloride migration by 0.15 % waste nylon fiber employment in the concrete mixture compared to the control mixture. However, further increase of the waste nylon fiber reduces the chloride ion penetration resistance in the concrete matrix compared to the control mixture. The same observation with Chen et al. [117] found that increasing the replacement of synthetic fiber can downfall concrete chloride migration resistance. This is mainly due to the reason the higher replacement of waste synthetic fiber can cause the void occurrence in the concrete matrix that can allow the migration of chloride.

Besides these, Bhogayata C. & Arora K [118], investigated the employment of waste synthetic fiber in concrete to assess the

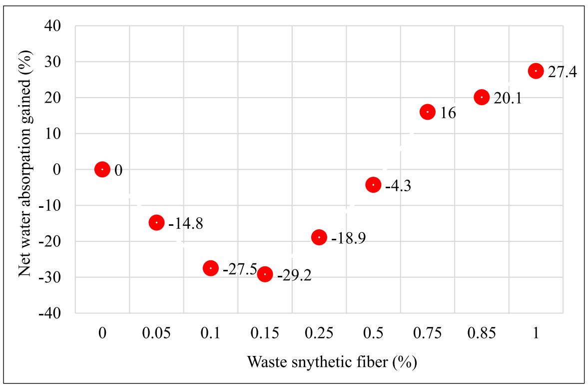

Fig. 13. The net water absorption capacity of concrete reinforced by different doses of waste synthetic fibers from nylon scrap brushes from Farooq et al. [68] permission Elsevier.

accelerated corrosion resistance. So, the study found the reinforcement of concrete by waste synthetic fiber improves the corrosion of steel bars reinforced concrete compared to the control mixture without waste synthetic fiber. Especially, the study found employing waste synthetic fibers by 1 % to the weight of concrete is 10 % more resistant than conventional concrete. This is mainly due to waste synthetic fibers are impermeable materials and can permit good holding together of the concrete matrix that mitigates the entrance of chloride ions and resists the corrosion of steel bars in concrete structures [117,119,120].

5.4. Elevated temperature

The employment of waste synthetic fibers in the cement/concrete matrix enhanced the residual strength of the whole composite at elevated temperatures [13,36]. The same observation that reinforcing concrete by waste polyethylene and nylon fiber improves the resistance at high temperatures and good tensile strength retained after elevated temperatures [67,121]. This may be due to the reinforcing concrete by waste synthetic fiber tighten the concrete matrix cement paste with sand that makes a dense structure which elevated temperature cannot easily penetrate inside the matrix. However, as Tayebi & Nematzadeh [96], found raising the heat can reduce the mechanical properties and reported above 600°C greatest drops of mechanical properties can occur on concrete.

Uygunog [122], studied on thermal and electrical properties of concrete reinforced by polyester and found improved resistance to a thermal conductivity rate of 33.94 % and electric resistance by 214.89 % compared to the concrete control mixture at 28 days. The highest electrical resistivity was observed in specimens of waste nylon fiber reinforced concrete and therefore, it can be recommended for structures requiring higher electrical resistivity, with high compressive strength and better durability [123].

5.5. Sulfate resistance

The reinforcement of waste synthetic fiber in the concrete mixture improves the acidic attack resistance compared to the control mixture. As Aarthi & Arunachalam [119] found the employment of polyethylene fiber in concrete which was cured in 3 % dilute sulfuric acid improved the weight loss of the concrete by 7.93 % compared to the control mix. This has occurred mainly because the added waste synthetic fiber can tight and more hold together the matrix of concrete, especially the bond between the sand and cement paste consequently can mitigate the penetration of acid not to affect the concrete structure [117,119]. The same observation, Bankir & Sevim [124] reported that polypropylene fiber incorporation in the concrete mixture improves the acidic attack, specifically, 5 % concentrated sulfuric acid attack compared to the control mixture.

5.6. Microstructure

The employment of waste synthetic fibers in the concrete mixture can make dense microstructures. Li L. et al. [125] studied the effect of synthetic fiber reinforcement in concrete and found as shown in Fig. 14, the waste synthetic fiber blended concrete is more agglomerated due to the tie and holding together effects of waste synthetic fiber which can bond paste to sand compared to the control concrete mixture. Hence, the study reported the more agglomerated concrete matrix incorporated with the waste synthetic fiber can more bridge the expansion of cracks, which makes an improved crack resistance of concrete compared to the control mixture.

In addition to these, Xiangfeng L [126] studied the reinforcement of waste polyester in the concrete mixture and found the microstructure of waste synthetic fiber reinforced has more bonds and friction at the interface. Also, the study observed the more bonded microstructure of waste synthetic fiber reinforced concrete can mitigate the development of cracks and significantly cost-effective cementitious material production ina safe environment.

Furthermore, the employment of waste synthetic fibers in concrete makes an isotropic uniform material, dense matrix, improves the microstructure of concrete, and controls the propagation of micro-cracks in concrete. This means the randomly distributed synthetic fibers in the concrete matrix arrest the propagation of cracks, consequently improves the tensile strength of the concrete structures [56,58,127].

6. Cost reduction of WSF in the concrete volume

Plane concrete is highly resistance to compressive load, however, weak by tensile load resistance. Hence, steel bar and fiber employment is very crucial to improve concrete tensile strength capability [26–28]. Moreover, blending waste synthetic fibers in concrete are important in reduction of environmental pollution and improvement of concrete tensile strength. So, the present study reviewed how much concrete volume reduction can be recorded while the users are employing WSF in the construction industries especially, in the structural element of the building such as columns. So, this review considered the column dimension which is commonly used in many construction works 2.8 m height by 30 cm^2 area and 12 diameter bar having 2.75 cm height with 6 diameter stirrup having 110 cm length at 25 cm intervals throughout the steel bar height as show in Fig. 15. Hence, the comparison between reinforcing steel bar and WSF on cost reduction due to concrete volume change is assessed.

As shown in Table 2, the employment of WSF by 0.5–0.55 % used by different authors more reduces the volume of concrete compared to steel bar employment and hence, can more reduces the cost of concrete due to lessening of the concrete volume, also, indirectly lessens concrete ingredients as currently demanding large amounts of natural resources such as sand and aggregate. Also, its use decreases the volume of massive concrete production consequently the amount of cement produced decreases. Besides these, different authors have found WSF substitution in concrete improves the tensile strength up to 13–44 % compared to plane concrete, in addition to reducing waste synthetic material from the environment. Generally, the employment of WSF in concrete can potentially

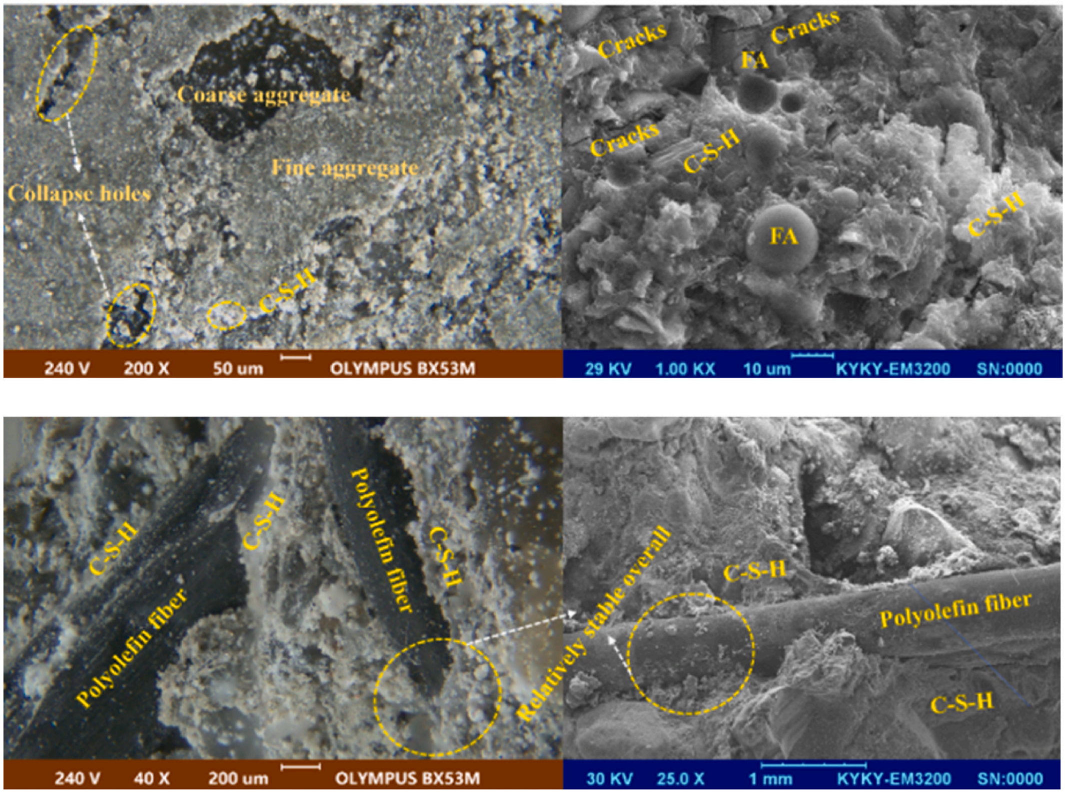

Fig. 14. Micro-structural image of control and synthetic (polyolefin) fiber reinforced concrete from Li L. et al. [125] permission Elsevier.

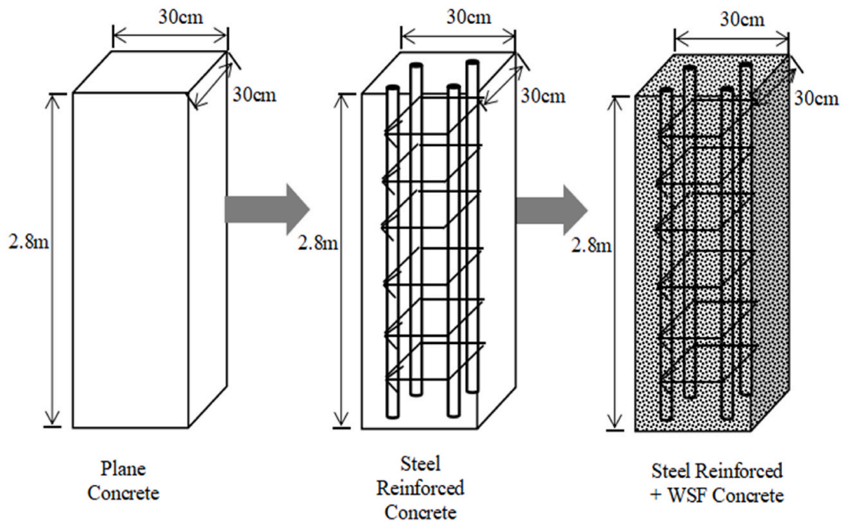

Fig. 15. Concrete column dimensions used for estimation of volume reduction by WSF.

reduce the cost of concrete, increase strength, and durability, and highly reduce environmental pollution which eventually supports the sustainability of environmental aesthetic values.

7. Discussion

The present study detail reviewed the effect of employing WSF on physical, durability, and mechanical properties of concrete. Hence, it have seen that the reinforcement of WSF can improve most of the concrete properties. Specifically, the employment of WSF in

Table 2
Concrete volume change by reinforcing steel and WSF for cost reduction referring Fig. 15.

Optimum TS by WSF			Volume changes of taken column				
References	Dose (%)	Improved TS (%)	Plane concrete (cm^3)	Steel reinforced concrete (cm^3)	WSF reinforced concrete (cm^3)	Volume of concrete reduced by:	
						Steel (cm^3)	WSF (cm^3)
[49]	0.5	18.96	252,000	251676.706	250,740	323.294	1260
[17]	0.55	44.44	252,000	251676.706	250,614	323.294	1386
[63]	0.5	13.74	252,000	251676.706	250,740	323.294	1260

concrete reduces the fresh concrete density, which is beneficial to have light weight fresh cementing materials mainly for massive concrete production that can significantly reduce the transportation cost of fresh concrete mix. Also, reinforcing WSF in concrete improves the compressive, flexural, and split tensile strength of concrete, especially, from up to 1 % of WSF significantly improve the strength.

Besides these, the employment of WSF in concrete improves durability, mainly, can reduce water absorption, chloride ion penetration, improve sulfate resistance, and elevated temperature resistance below 600°C. This is due to reinforcing WSF in concrete can tight the concrete matrix together that can make denser structure which can resist in different adverse environment. Moreover, the employment of WSF in the concrete improves the crack penetration and propagation, especially, increasing the amount and length of WSF in concrete significantly improve the crack resistance of concrete. Generally, besides improving concrete property reinforcing concrete by WSF highly reduces plastic waste environmental pollution and lessens concrete production costs.

8. Conclusions

The effects of incorporating waste synthetic fibers in concrete have been reviewed, specifically, the present review detail assessed the reinforcement of concrete mixture by waste polyethylene, nylon, and polyester on the physical, mechanical, durability, and micro-structural properties of concrete. Besides these, it is assessed the efficient and cost effective technique of recycling waste synthetic material to synthetic fibers to be employed in concrete. Hence, the following conclusions have been found.

- The reinforcement of waste synthetic fiber in concrete reduces the workability compared to the control mixture. Especially, workability decreases more while increasing the waste synthetic fiber length and doses.
- The density of concrete reinforced by waste synthetic fiber slightly increases at lower fiber substitution as many literatures found, however, increasing the dose reduces the density of cementitious materials.
- As the review of most researchers indicate the reinforcement of waste synthetic fiber in concrete mixture by 0.1–1% to the weight of cement improves the compressive, flexural, and splitting tensile strength compared to the control mixture. Also, as the review of different literature reveals, increasing the fiber content can increase the tensile strength of waste synthetic fiber blended concrete.
- The waste synthetic fiber employed concrete has higher durability than the control mixture, specifically, as many literatures found 0.5 % of waste synthetic fiber blended concrete has good resistance in water absorption, chloride ion penetration, active corrosion, acidic attack, and elevated temperature resistant at below 600°C than the control concrete mixture.
- The employment of waste synthetic fibers in the concrete mixture can make dense microstructure, hence, a more agglomerated concrete matrix incorporated by waste synthetic fiber can more bridge the expansion of cracks, which makes an improved crack resistance of concrete compared to the control mixture.
- Also, the review observed a mechanical technique of the recycling process method is more applicable for waste synthetic fiber incorporation in the concrete.

Generally, reinforcing the waste synthetic fiber in concrete can reduce the volume of concrete, improve the mechanical, durability, and micro-structural properties of concrete compared to conventional concrete, in addition to having cost effective concrete production in a safe environment.

Future perspective

In the review of most studies, the effect of different shapes of waste synthetic fiber employment in concrete properties such as on physical, mechanical, and durability of cementitious materials was not well applied. However, it is well known that the surface shapes of fibers can affects the interface bond of fiber and concrete matrix. Hence, it needs consideration to assess the effects of using different shapes of waste synthetic fiber in concrete.

Another consideration is that the effects of different durability properties of waste synthetic fiber reinforced concrete is not investigated in depth. So, the author recommends a detail investigation on the effect of waste synthetic fibers employed in concrete on various durability indicator properties. Also, it have seen a limited studies on the effect of employing waste synthetic materials in the structural behaviour of concrete other than the studied properties by the present work, hence, need in future to be detail investigated.

CRediT authorship contribution statement

Tsion Amsalu Fode: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Yusufu Abeid Chande Jande:** Writing – review & editing, Supervision. **Thomas Kivevele:** Writing – review & editing, Supervision.

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 paper.

Acknowledgment

The authors are thankful to the Partnership for Applied Sciences, Engineering, and Technology (PASET) - Regional Scholarship and Innovation Fund (RSIF) for the support of this study.

Abbreviations

CS	Compressive Strength
FS	Flexural Strength
PE	Polyethylene
PET	Polyester
SP	Superplasticizer
TS	Tensile Strength
WSF	Waste Synthetic Fiber
WSM	Waste Synthetic Materials

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