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Polymer fibers and effects on the properties of concrete

Polimer lifler ve beton özelliklerine etkileri

Cüneyt DOĞAN*[1,a], İsmail DEMİR[1,b]
[1]*Department of Civil Engineering, Afyon Kocatepe University, 03200, Afyonkarahisar, Turkey*

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Abstract
Concrete is an indispensable material for today's construction industry and it is the most used building material globally. Strength and easy accessibility are important properties of concrete. Contrary to its high compressive strength, low tensile strength, brittle structure, and crack formation are problems that must be solved in order to build safe buildings. Today, using polymer fibers to prevent possible cracks on the concrete is the focus of many researchers. In the review article was presented a comprehensive literature review of polymer fibers include polypropylene (PP) polyethylene (PE) polyethylene terephthalate (PET), polyamide (PA), polyvinyl alcohol (PVA), and polyacrylonitrile (PAN) fiber properties, as well as the use of these polymer fibers in concrete. Our purposes in this study were to review, all aspects previous studies of fiber reinforced concrete were compared to determine concrete parameters such as shrinkage and crack formation, compression, splitting tensile and flexural strength, toughness, and modulus of elasticity. As a result, it has shown that the polymer fibers decrease the formation of cracks in concrete and increase durability, mechanical properties such as flexural strength and splitting tensile strength.

Keywords: Fiber reinforced concrete, Polyacrylonitrile fibers, Polyethylene terephthalate fibers, Polypropylene fibers, Polyvinyl alcohol fibers

Öz
Beton, günümüz inşaat endüstrisi için vazgeçilmez bir elemandır ve dünya çapında en çok kullanılan yapı malzemesidir. Dayanım ve kolay erişilebilirlik, betonun önemli özellikleridir. Yüksek basınç dayanımının aksine, düşük çekme dayanımı, kırılgan yapısı ve çatlak oluşumu, güvenli binalar inşa etmek için çözülmesi gereken sorunlardır. Günümüzde betonda olası çatlakları önlemek için polimer lif kullanımı birçok araştırmacının odak noktasıdır. Bu derleme makale, polipropilen (PP) polietilen (PE) polietilen tereftalat (PET), poliamid (PA), polivinil alkol (PVA) ve poliakrilonitril (PAN) lif özelliklerinin yanı sıra bu polimer liflerin betonda kullanımını araştıran deneysel çalışmaların kapsamlı bir literatür taramasını sunmaktadır. Bu çalışmadaki amacımız, büzülme ve çatlak oluşumu, basınç, çekme ve eğilme dayanımı, tokluk ve elastisite modülü gibi beton parametrelerini belirlemek için fiber takviyeli beton ile ilgili önceki çalışmaları tüm yönleriyle karşılaştırmaktır. Sonuç olarak, polimer liflerin betonda çatlak oluşumunu azalttığı ve dayanıklılığı, çekme dayanımı gibi mekanik özellikleri ve yarmada çekme dayanımını arttırdığı gösterilmiştir.

***Anahtar kelimeler**: Lif takviyeli beton, Poliakrilonitril lif, Polietilen tereftalat lif, Polipropilen lif, Polivinil alkol lif*

*[a] Cüneyt DOĞAN; cdogan@usr.aku.edu.tr, Tel: (0553) 1906270, orcid.org/0000-0002-6662-8381
[b] orcid.org/0000-0001-8493-0309

1. Introduction

Concrete is the most widely used building material due to its many known advantages such as low cost, availability, and wide applicability. However, concrete is a semi-brittle material and its low tensile strength, poor resistance to crack formation and propagation are the main disadvantages of conventional concrete (Afroughsabet and Ozbakkaloglu, 2015).

Cracks usually develop over time due to various reasons such as plastic shrinkage in fresh concrete, shrinkage in hardened concrete, and mechanical loads. Cracks increase the permeability of concrete, expose its microstructure to harmful substances such as moisture, chloride, sulfate, bromine, and cause corrosion in steel reinforcement (Ahmed and Mihashi, 2007; Köksal et al., 2008). Therefore, improving the strength and durability of hardened concrete is an important goal for researchers (Nili and Afroughsabet, 2012). The fracture mechanics are affected by factors such as shrinkage and thermal change as well as curing conditions and modulus of elasticity (Krauss et al., 1996).

Plastic shrinkage cracking is a major cause of poor performance in cementitious composites. In particular, fresh concrete on large surfaces such as bridge floors or pavement and parking garage floors is affected by evaporation at high temperatures, causing plastic shrinkage cracking before the concrete hardened (Kim et al., 2008; Pelisser et al., 2010). Crack formation occurs as a result of plastic shrinkage when the surface evaporation rate of concrete exceeds 1.0 kg/m2/h and it prevents concrete from reaching its design strength (ACI Committee 305, 2000; Myers et al., 2008).

In order to prevent crack formation, fibers can be used in cementitious composites which result in increasing tensile strength, ductility, toughness, and durability (Ezeldin and Balaguru, 1989). The effectiveness of fiber reinforcement depends on many factors, including matrix properties and fiber geometry, size, type, volume, and distribution (Ganesan et al., 2013). The use of fiber in concrete is an economical and effective way to achieve the desired strength and ductility of concrete (Bentur and Mindess, 2006).

The use of fiber-reinforced cement composites for various structural applications has become widespread all over the world. The flexural strength and toughness properties of these composites can be significantly improved by using different fiber types. The performance of the composite mainly depends on fiber and matrix compatibility in terms of strength, elasticity, and load transfer related to surface adhesion properties. Steel, glass, carbon, and polymer-based fibers are widely used in many fiber-reinforced composite applications. Polymer-based fibers are versatile and their performance in composites is quite different from each other (Wu and Li, 1999; Li, 2001). Polymers are high molecular weight, solid and non-metallic compounds whose structure consists of small repeat units (Çavdar, 2013).

Considering its properties such as low cost, lightweight, and superior corrosion resistance, polymers with a wide range of uses such as automotive, consumer products, and household items have been used in concrete mixtures for 25 years (Fowler, 1999; Parenteau et al., 2012). PP fiber, PE fiber, PET fiber, PA fiber, PVA fiber, and PAN fiber are commonly used fibers in cementitous composites (Oh et al., 2005; Ochi et al., 2007). This paper disseminates information on the various properties of polymer fibers and effects of polymer fibers in concrete, which have been compiled by reviewing relevant previous studies.

2. Method

For the purpose of this review, research conducted on polymer fibers reinforced concrete was searched on Web of Science, Scopus, Springer Link, Taylor and Francis, and Google Scholar databases. Keywords are selected “PP fiber reinforced concrete”, “PE fiber reinforced concrete”, “PET fiber reinforced concrete”, “PA fiber reinforced concrete”, “PVA fiber reinforced concrete”, “PAN fiber reinforced concrete” for research. The major database searched was Web of Science and a total of 1060 documents found based on keywords search in 1975 to 2020 timespan. It has been thoroughly investigated the relevance of titles, keywords, and abstracts to the subject, and only studies related to polymer fibers reinforced concrete were selected. Experimental studies selected which carried out flexural, compressive, splitting tensile, chloride ion penetration, density, modulus of elasticity, and first crack strength tests for hardened concrete and slump test for fresh concrete in this literature review. All results were investigated for each study and these results were tabulated to compare more clearly.

3. Fiber reinforced concrete

Fiber-reinforced concrete (FRC) is defined as concrete made using aggregate, fiber, and hydraulic cement (ACI Comite 544, 2002). In the use of fibers, it is aimed to increase tensile strength, durability, crack control, and hardness in cement composites. The performance of FRC varies according to the type of fiber used (Madhavi et al., 2015). Reinforcing fibers are expected to be durable, easily dispersible, and have good mechanical properties to be effective (Wang et al., 2000). The use of fiber in cement composites is at the forefront due to the control of cracks caused by shrinkage, which significantly affects strength and durability, (Naaman and Reinhardt, 2006; Kim et al., 2008; Foti, 2011).

Polymer fibers offer better performance than steel or glass fibers (Oh et al., 2007). Corrosion of steel fibers is a factor that reduces the durability of steel fiber reinforced concrete that will result spalling (Granju and Balouch, 2005). Polymer fibers are more resistant to alkaline reactions, rusting, chlorine, and salt, which offer a more advantageous material (Gao et al., 2010). Therefore, the use of polymer fibers as concrete reinforcement improves the mechanical properties of concrete as well as decreases the structural weight (Bolat et al., 2014). As monofilaments, multifilaments, or as collated fibrillated fiber bundles, polymer fibers can be produced; their properties are related to the degree of crystallinity (Martínez-Barrera et al., 2011). Multifilament polymer fibers are more effective than fibrillated bundle polymer fibers at spalling resistance. This is because the diameter of polymer fibers of multifilaments is smaller than that of polymer fibers of fibrillated bundles (Çavdar, 2013). On the other hand, monofilament fiber has a higher modulus of elasticity and stiffness for the rough shape (Hsie et al., 2008).

In concretes where two or more fibers are used as reinforcement, which is called hybrid FRC, fibers develop different reactions to crack formation (Pakravan et al., 2017). In the hybrid FRC, the properties of each fiber are provided at a synergy (Banthia and Soleimani, 2005). In well-designed hybrid reinforced composites, the harmony between fibers provides concrete with better mechanical properties than a single type of fiber reinforcement (Rashiddadash et al., 2014).

3.1. Polypropylene fibers

PP is one of the most widely used polymer in packaging, automotive, and consumer products, invented in 1954 (Busico and Cipullo, 2001; Parenteau et al., 2012). It is produced by polymerizing the propylene gas obtained from petroleum under high temperature and pressure followed turned into the fiber by the melt spinning method (Madhavi et al., 2014). PP has a weak environmental stress cracking resistance and low impact resistance at low temperature is an issue that should be considered in various applications (Li et al., 2000).

PP fibers called the new generation that are produced on a global scale of 4 million tons annually (Madhavi et al., 2014). PP fibers have a density of 0.91 g/cm^3, a tensile strength of 500 - 700 MPa, an modulus of elasticity of 2800 MPa, and an elongation at break 25% (Olgun, 2013). PP fibers have low strength and modulus of elasticity compared to steel fibers. On the other hand, PP fibers help prevent plastic cracks with their ductility, fineness, and dispersion properties (Bayasi and McIntyre, 2002). PP fibers with low modulus of elasticity are used in small proportions to control shrinkage in concrete because the modulus of elasticity of both concrete and PP fibers are close to each other during the first hours of hardening (Banthia and Gupta, 2006). PP fibers are not expected to increase the strength of concrete, but it is aimed to increase its ductility, durability, and impact resistance (Alhozaimy et al., 1996; Toutanji et al., 1998; Pakravan and Ozbakkaloglu, 2019).

PP is hydrophobic and inert as well as resistant to plastic shrinkage cracking and is very stable in the alkaline environment of concrete. However, it has disadvantages such as low modulus of elasticity, poor fire resistance, sensitivity to sunlight (Kurtz and Balaguru, 2000; Deng and Li, 2007).

It has been found that PP fibers increase the compressive strength of structural lightweight aggregate concrete (Libre et al., 2011; Yap et al., 2013), reduce workability (Patel et al., 2012; Thirumurugan and Sivakumar, 2013), bridge cracks in self-compacting concrete and prevents it from spreading (Qian and Stroeven, 2000; Gencel et al., 2011), improve parameters such as fracture toughness, fracture energy, effective crack length and crack width in FRC (Maalej and Li, 1995; Zhang and Li, 2013), and increase corrosion resistance in FRC (Sanjuán et al., 1996).

3.2. Polyethylene fibers

PE is an inert polymer that is resistant to pressure, radiation, and low temperatures. PE consists of carbon and hydrogen and depending on the production pressure, there are 2 types of PE as low-density polyethylene and high-density polyethylene (Zhong et al., 2018). PE fibers have a tensile strength of 80-590 MPa and a modulus of elasticity of 5 GPa (Hughes and Hannant, 1982).

There is a great interest in using PE fiber in FRC, and up to 4% volume fraction can be used in concrete mixtures (Hughes, 1984; Santos et al., 2005). Increasing the volume fraction of PE fiber increases the maximum tensile strain at peak load, as well as increasing the PE fiber length increases the strain hardening (Ahmed and Maalej, 2009).

The use of 1% and higher volume fractions of PE fiber causes a decrease in the compressive strength and an increase in the flexural strength (Choi et al., 2014). Moreover, a significant increase occurs in ultimate load at the post-cracking (Said and Razak, 2015).

3.3. Polyethylene terephthalate fibers

PET is one of the most used polymer materials in the packaging of various products. Packages made of PET are lightweight, transparent, highly resistant to impacts, and non-toxic. All these features have made it important in the polymer market and global industry (Ávila Córdoba et al., 2013).

PET is widely used in fiber, particle, or flake forms to achieve superior properties in FRC (Pelisser et al., 2012). Fibers obtained from PET bottles can be used in the concrete matrix at a high rate of up to 3% of cement weight (Ochi et al., 2007). PET fibers have a density of 1.41 g/cm^3 and the modulus of elasticity of 1700 MPa (Awaja and Pavel, 2005).

Today, PET wastes are disposed of by burying or burning. However, among the disposal methods, it is possible to use PET wastes that are converted to fiber form by PET recycling in FRC (Kim et al., 2010). PET fibers can be obtained from PET wastes by a simple cutting method without any chemical treatment (Foti, 2013).

3.4. Polyamide fibers

PA, known as nylon, is a polymer formed with a linear macromolecule polymer of the amide chain, and its commercial success is due to its outstanding properties and economically viablity (Rouette, 2001; Fangueiro et al., 2008). PA fibers have a tensile strength of 1000 MPa, a modulus of elasticity of 6 GPa, and an elongation at break of 10% (Ludirdja and Young, 1992).

PA fibers are moderately hydrophilic and exhibit an even distribution of cracks with load application, as they absorb shock waves created in PA FRC (Canal et al., 2004; Kim et al., 2015). PA has a wide range of use as a concrete coating, repair mortar, shotcrete, and precast concrete elements with its easy mixing and applicability. Also, corrosion resistance, durability, high tensile strength compared to PP and PE fibers, PA fibers are very beneficial fibers (Khajuria and Balaguru, 1991). PA fiber reinforcement exhibits a significant increase in splitting tensile strenth and flexural strength (Guler, 2018). PA fiber reinforcement in the prestressed concrete decreases the compressive strength and modulus of elasticity, while increasing the energy dissipation capacity (Choun and Park, 2015).

3.5. Polyvinyl alcohol fibers

PVA is one of the most common polymers with an annual production of 650000 tons on a global scale (Rong et al., 2009). PVA is produced by hydrolysis of vinyl acetate after polymerization and its crystallinity affects many mechanical properties as well as water resistance (Horikoshi et al., 2006; Tretinnikov and Zagorskaya, 2012). Also, PVA is the most common synthetic water-soluble polymer in production (Ramaraj, 2007).

PVA fibers have a density of 1.3 g/cm^3, elongation at break of 6%, and a nominal strength of 1620 MPa (Zhang et al., 2014). PVA fiber is a notable with significant acid resistance and excellent cement adherence. PVA FRC can be used in bridge decks, beams, and pipes due to its tensile hardening capacity (Zhang and Yang, 2019).

PVA fiber reinforcement reduces the compressive strength of engineered cementitious concrete (Said et al., 2015), while providing great improvements in compressive strength of geopolymer concrete and foam concrete (Flores-Johnson and Li, 2012; Tanyildizi and Yonar, 2016).

3.6. Polyacrylonitrile fibers

PAN fiber is a copolymer consisting of the first monomer of acrylonitrile and the second monomer of vinyl acetate (Barkoula et al., 2008). PAN has a high melting point, relatively insoluble polymer with an interconnected carbon chain, is widely used in textile and carbon fiber production (Dalton et al., 1999; Schwartz, 2002). PAN fibers without carbonization have a tensile strength of 550 MPa, a modulus of elasticity of 9400 MPa, and an elongation at break of 12.7% (Fraczek-Szczypta et al., 2009). Considering its unique mechanical properties, it is the strongest carbon fiber precursor (Cato and Edie, 2003).

Thanks to its mechanical properties and chemical resistance against acids, bases, and inorganic salts, it is very suitable for use in cement composite production., (Hahne et al., 1992). Even if used in low volume fractions in concrete, it provides significant benefits to the mechanical properties of concrete (Raivio and Sarvaranta, 1994).

Pan fiber reinforcement increases compressive strength, tensile strength, splitting tensile strength, impact energy and decreases permeability and average pore diameter (Deng et al., 2006; Fan, 2015; Chinchillas-Chinchillas et al., 2019).

4. Effects of polymer fibers on the properties of concrete

Polymer fibers have become increasingly popular in the construction industry as they combine the advantages of polymers such as high impact resistance and low weight with the high compressive strength and stiffness of concrete (Unterweger et al., 2014).

The adherence property of the polymer fiber is related to the critical fiber length. If the fiber length is shorter than the critical value, the fiber is pulled out of the concrete matrix by tensile force and the tensile strength of the composite is mainly determined by clamping. If the fiber length is longer than the critical value, the fiber breaks, and the strength of the composite is determined by the fiber tensile strength (Güllü et al., 2006). Good clamping provides effective stress transfer to the fiber in the cement matrix (Kawamata et al., 2001; Song et al., 2011).

In addition to reducing plastic shrinkage cracking, it has also been found that polymer fibers improve the mechanical properties of concrete. The polymer fibers can also be used to strengthen cement-based products under flexural/tensile loads. In this case, the fibers can be used in a cement matrix in high volume fractions of a minimum of 2% (Bentur and Mindess, 1990). At the same time, the use of polypropylene fibers at volumes as low as 0.1% has shown statistically significant improvements in toughness, impact resistance, and fatigue performance (Kurtz and Balaguru, 2000).

Low modulus of elasticity fibers such as PA and PP is effective in reducing cracking during plastic shrinkage, even at very low volume fractions. Its high performance in reducing cracking during plastic shrinkage has been proven and its use is widely accepted (Balaguru and Shah, 1992). Properties of polymer fibers such as ductility, tensile strength, modulus of elasticity, and flexibility should be taken into attention in order to achieve the targeted effect (Johnston, 2001).

PP, PE, and PVA fibers are used in engineered cementitious composites, although the properties vary according to fiber type. Engineered cementitious composites produced with PVA fiber provide higher toughness and flexural strength than the produced with PP fiber (Yang and Li, 2010). However, due to the hydrophilic nature of PVA fibers, the workability decreases as the volume fraction increases (Felekoğlu et al., 2009; Ahmed and Mihashi, 2011).

5. Physical and mechanical properties of FRC

Physical and mechanical results of fiber reinferced concrete including flexural strength, compressive strength, splitting tensile strength, chloride ion penetration, density, modulus of elasticity, first crack strength and slump results were summarized in Table 1.

In accordance with the literature, it was found that polymer fibers do not have a significant effect on compressive strength. On the other hand, it was found that PET reinforcement increased the compressive strength of cement-lime mortar by 50% and PVA reinforcement increased the compressive strength of foam concrete by 85%, which is attributed to the increase of specimen integrity by the fiber. The greatest decrease in compressive strength was observed at 37% in PA reinforced mortar. It has been found that polymer fibers increase the splitting tensile strength of all types of FRC. The greatest increase in splitting tensile strength was obtained by 25% in the 80 mm length PET reinforced ordinary FRC. Similarly, flexural strength is generally increased between 30% and 50%. Moreover, polymer fibers have been found to reduce workability. PP reinforced high strength concrete slump decreased by 115 mm, PET reinforced ordinary FRC slump decreased by 50mm.

Another important result obtained is that polymer fibers significantly increase the impact energy of concrete. The impact energy of PAN reinforced ordinary FRC increased by 250%. To avoid specimens from deterioration by the mechanisms of matrix cracking, fiber/matrix interface debonding, fiber pull-out, and fiber rupture, the introduced PAN fibers absorbed impact energy.

The increase in impact energy, ultimate load at the post-cracking, deflection capacity, strain at the peak stress, resistance to cracking, deflection at first crack, and the decrease in chlorine ion penetration, cracking area and permeability depth showed that polymer fibers prevent crack formation.

Table 1. Physical and mechanical results of fiber reinferced concrete

Type of fiber	**Type of FRC**	**Fiber volume fraktion (min-max)**	**Fiber length (L) Fiber diameter (Ø)**	**Physical and mechanical properties**	**Ref.**
PP	Tunnel Lining	0 – 0.8	L: 48mm Ø: 920 µm	No effect in the compressive strength 10% enhancement of the splitting tensile strength 17.5% enhancement of the fracture modulus 30% reduction in the chlorine ion penetration depth	Behfarnia and Behravan (2014)
PP	Mortar	0 – 1.2	L: 12 mm Ø: 18 µm	18.3% reduction in the compressive strength 4.2% reduction in the flexural strength 18% reduction in the modulus of dynamic elasticity	Çavdar (2014)
PP	High Strength Concrete	0 – 0.5	L: 12 mm Ø: 19 µm	9.2% reduction in the compressive strength 12.8% enhancement of the splitting tensile strength 115mm reduction on the slump	Fallah and Nematzadeh (2017)
PP	Lightweight Self-Compacting Concrete	0 – 0.3	L: 12 mm Ø: NA	No effect in the compressive strength 14.4% enhancement of the tensile strength 10.7% enhancement of the flexural strength 40% reduction in the viscosity	Mazaheripour et al. (2011)
PP	Natural Pozzolan Cement Concrete	0 – 0.13	L: 19 mm Ø: NA	8.5% reduction in the compressive strength 43% reduction in the chlorine ion penetration depth 65% reduction in the the cracking area no effect in the density	Flores-Medina et al. (2014)
PE	Lightweight Concrete	0 – 1.5	L: 30 mm Ø: 680 µm	30.7% reduction in the compressive strength 48% enhancement of the tensile strength 144.8% enhancement of the flexural strength	Choi et al. (2014)
PE	Engineered Cementitious Composite	1.0 – 2.5	L: 12 mm Ø: 38 µm	25% reduction in the compressive strength 79% enhancement of the ultimate load at the post-cracking	Said and Razak (2015)
PET	Ordinary FRC	0.5 – 1.0	L: 80 mm Ø: 200 µm	8% enhancement of the compressive strength 25% enhancement of the splitting tensile strength	Foti (2013)
PET	Mortar	0 – 2.0	L: 32 mm Ø: 14 µm	20% reduction in the first crack strength 17% enhancement of the ultimate flexural strength 0,49mm enhancement of the deflection capacity	da Silva Magalhães and Fernandes (2015)
PET	Ordinary FRC	0 – 0.3	L: 20 mm Ø: 25 µm	19,2% enhancement of the flexural strength 50mm reduction in the slump	Pelisser et al. (2012)
PET	Cement-Lime Mortar	0 – 1.5	L: 35 mm Ø: 1 mm	50% enhancement of the compressive strength 30% enhancement of the flexural strength	Pereira De Oliveira and CastroGomes (2011)
PA	Prestressed Concrete Containment Vessel	0 – 1.5	L: 30 mm Ø: 2.3 mm	11% reduction in the compressive strength 4% reduction in the modulus of elasticity 40% enhancement of maximum lateral displacement 200% enhancement of the energy dissipation capacity	Choun and Park (2015)
PA	Structural Lightweight	0 – 0.75	L: 12 mm Ø: 75 µm	No effect in the compressive strength 22.2% enhancement of the splitting tensile strength	Guler (2018)

	Aggregate Concrete			26.9% enhancement of the flexural strength	
PA	Ordinary FRC	0 – 1.0	L: 30 mm Ø: 500 µm	11% reduction in the compressive strength 53% enhancement of the flexural strength	Kim et al. (2015)
PA	Ordinary FRC	1.0 – 2.0	L: 30 mm Ø: 500 µm	no effect in the compressive strength 33.7% enhancement of the tensile strength 7.5% enhancement of the strain at the peak stress 96% enhancement of the fracture toughness	Kim et al. (2019)
PA	Mortar	0 – 2.0	L: 20 mm Ø: 0.35 µm	35% reduction in the compressive strength 41.6% enhancement of the flexural strength	Orasutthikul et al. (2017)
PA	Mortar	0 – 1.5	L: 12.7 mm Ø: 330 µm	37% reduction in the compressive strength 35% enhancement of the resistance to cracking	Spadea et al. (2015)
PVA	Foam Concrete	0 – 3.0	L: 8 mm Ø: 40 µm	85% enhancement of the compressive strength 22.5% enhancement of the modulus of elasticity	Flores-Johnson and Li (2012)
PVA	Ordinary FRC	0 – 0.5	L: 6 mm Ø: 14 µm	No effect in the compressive strength 32.5% enhancement of the flexural strength	Noushini et al. (2013)
PVA	Engineered Cementitious Composite	1.0 – 3.0	L: 12 mm Ø: 38 µm	20.2% reduction in the compressive strength 16.2% enhancement of ultimate load at post-cracking 0.563mm enhancement of the deflection at first crack 9.83mm enhancement of the deflection at failure	Said et al. (2015)
PVA	Geopolymer Concrete	0 – 2.0	L: NA Ø: NA	29% enhancement of the compressive strength 45% enhancement of the tensile strength	Tanyildizi and Yonar (2016)
PVA	Engineered Cementitious Composite	0 – 1.0	L: 12 mm Ø: 100 µm	50% enhancement of the flexural strength 200% enhancement of the flexural energy absorption capacity	Peyvandi et al. (2013)
PAN	Mortar	0 – 0.2	L: 15 µm Ø: 1.01 µm	15.9% enhancement of compressive strength 55.1% enhancement of the tensile strength	Chinchillas-Chinchillas et al. (2019)
PAN	Ordinary FRC	0 – 0.17	L: 12 mm Ø: 80 µm	13% enhancement of the splitting tensile strength 112% enhancement of the static tensile strength	Deng et al. (2006)
PAN	Ordinary FRC	0 – 2.0	L: 10 mm Ø: 20 µm	250% enhancement of the impact energy 18.4% reduction in the average pore diameter 19.8% reduction in the permeability depth	Fan (2015)

NA: Not applicable

6. Conclusion

According to the results of this study, the polymer fibers [I] reduce the shrinkage cracks in concrete, [II] increase the permeability resistance of the concrete, [III] increase the corrosion resistance of the concrete, [IV] increase the adherence at the interface of aggregate and cement matrix [V] increase flexural strength, [VI] and it contributes positively to the mechanical properties.

It has been found that PP fibers do not have a significant effect on the compressive strength of concrete but increase splitting tensile and flexural strength. It has also been determined to reduce slump, viscosity, and chlorine ion permeation. PE fibers reduce the compressive strength of concrete, increase tensile and flexural strengths as well as the ultimate load at the post-cracking. PET fibers reduce the workability of concrete as well as provide improvement in compressive strength, increase splitting tensile strength, ultimate flexural strength.

It has been observed that PA fibers slightly reduce compressive strength and modulus of elasticity, increase maximum lateral displacement, splitting tensile and flexural strength. PVA fibers significantly increase the compressive strength of cellular concrete such as foam concrete. It has also been observed that the modulus of elasticity, flexural strength, and deflection at first crack increased. PAN fibers increase impact energy, splitting tensile and static tensile strength, and decrease average pore diameter and permeability depth.

Polymer fiber surface properties affect the adherence between fibers and the cement matrix. The use of polymer fiber with a rough surface is an important criterion to prevent crack formation as it will provide better adherence.

Waste polymers are an important environmental problem. As in the case of PET, converting polymer waste into fibers in an easy and inexpensive way provides environmental and economic benefits. Recycled fiber production from waste polymer and determination of the usage conditions of these fibers in concrete will be an important research area.

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