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Durability of polypropylene fiber reinforced concrete: Literatures review

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ABSTRACT: Use of polypropylene fibers to reinforce concrete has attracted widespread attention from both researchers and construction industry because of the numerous characteristics they have, compared to other types of fibers. This paper critically reviews the current state of knowledge of impacting the inclusion of polypropylene fibers on concrete durability. Detailed review on the different durability properties including: permeability, sorptivity, water absorption, chloride diffusion, carbonation, and frost resistance. Based on the literatures review, the incorporation of polypropylene fibers with various rates into the concrete can limit the development of cracks by forming a bond bridge and modifying the pore network, and thus enhancing the durability. However, some researchers reported that this enhancement can be fulfilled with a certain rate of added fibers which, if it is exceeded, will have opposite effects.

Keywords: Polypropylene fibers, Concrete, Reinforcement, Durability

1 INTRODUCTION

The Concrete is a feeble tensile construction substance, that is predominatingly suffering from fissures associated with fresh and hardening conditions. Both major feebleness of concrete including, its brittleness and its feebleness at the tenseness, and hence the ductility is restricted. Commonly, the fibers inclusion in the concrete can considerably ameliorate its mechanical performance. The benefit of their inclusion is to recompense for the fragility in terms of tensity and ductility and also to get a concrete with fewer cracks, with the capacity of performance amelioration being robustly reliant on the kind, form, and rate of fibers (Fallah and Nematzadeh 2017, Karahan and Atiş 2011).
Polypropylene is one of the most effective commodity fibers, amounting to an annual output capability of four million tons (Nair and Varghese 2017). It is produced from homopolymer polypropylene resin in various forms and dimensions, and with varying features (Bentur and Mindess 2006). Polypropylene fibers are characterized by the smallest density and thermal conductivity, the largest strain fracture, and plausible tensile strength, nearly not absorbent to water, well resisting against chemicals attack while their modulus of elasticity is so little, and cost effectiveness (Ahmed et al. 2020, Ahmed et al. 2020, Nair and Varghese 2017, Zongjin 2011). Therefore, when they are incorporated into the concrete mixture, there is a marked enhancement in its ductility and restriction of fissures generation due to their specific characteristics (Zhang and Li 2013). The polypropylene fibers utilizing to reinforce the concrete and cement products, may be produce in three dissimilar styles: monofilaments, films or membranes and ejected tapes or strips.
The whole styles of these fibers can be efficaciously employed for this purpose (Bentur and Mindess 2006). As well there is other classification of the polypropylene fibers from where their size. They are micro and macro fibers. From manufacturing viewpoint, the micro polypropylene fibers have dimensions of (5-100) mm in diameter and (5-30) mm in length. The small amount of these fibers is chosen for restricting the fissures of plastic shrinkage. In contrast, the incorporation of macro fibers in the reinforced concrete enhance its durability to a large extent through a reduction of steel corrosion (Wang et al. 2019).
With the evolution of concrete technology in the recent decades, the polypropylene fibers have been widely utilized in construction to improve the durability (Wang et al. 2019) (Salemi and Behfarnia 2013). Fissuring, regardless of the cause of its occurrence is paramount parameter affecting the durability of concrete due to that these fissures are considered as pathways to deleterious chemicals

aggression. Exterior fissures augment the surface subjected to exterior factors and thus the overall permeability of the concrete cover (Medina et al. 2014). The excellence of micro polypropylene fibers concerning the shrinkage fissures is dominant and the durability properties were largely investigated (Wang et al. 2019). Possessing to the light mass, stellar resistance against abrasion, corrosion acids and alkalis attack, limited conduction of heat as well as little cost, polypropylene fibers are significantly utilized in concrete reinforcement in the marine structures. Incorporation of these fibers to the concrete could strengthen it against the tensity, lessen the shrinkage of the fresh concrete in different whether in the case of dryness or stormy, enhance the fracture toughness, and lessen the brittle fracture of the concrete. The whole mentioned impacts clarify that incorporating polypropylene fibers may decrease the concrete fissures and alter its pore structure, that way getting better the concrete impermeability. In comparison with the traditional concrete, the polypropylene-reinforced concrete is more impervious and has a limited capillary porosity as a result of addition of polypropylene fibers (Liu et al. 2019, Bentegri et al. 2020). Existence of the polypropylene fibers in the concrete can lower both the amount and volume of the extremely small voids, leading to make porosity smaller at the contact area about the particles of aggregate (Afroughsabet and Ozbakkaloglu 2015). It is recognized that incorporation of polypropylene fibers in concrete exhibits premium durability on subjection to cycles of freezing and thawing. It is anticipated that these fibers to be efficient in lowering deterioration caused by frost due to their fissure-restraining characteristics (Karahan and Atiş 2011). In general the influence of polypropylene fibers on the concrete performance differs counting on the quality, length, and quantity of fibers, the mix proportion, and the characteristics of the concrete ingredients utilized. The common outputs are that penetrability, resistance against abrasivity impact, sorptivity, and chlorides diffusion are whole considerably progressed through the inclusion of polypropylene fibers (Toutanji 1999, Sadrinejad et al. 2018).

2 RESEARCH OBJECTIVE

The purpose of this paper is to give a comprehensive review on the durability properties of polypropylene fiber reinforced concrete relient on the experimental results obtainable from published studies. These properties encompass permeability, sorpitivity, water absorption, chloride diffusion, carbonation and frost resistance. Perception the durability of concrete reinforcing with polypropylene fibers may supply a fundamental for prospective studies and widen its usages in the construction sector. The presenting negativities and research needs for further knowledge on the durability properties of polypropylene reinforced concrete are as well highlighted. Eventually, conclusions of research correlated with concrete reinforced with polypropylene fibers from perspective of durability are offered with a view to efficaciously boost further application of polypropylene fibers.

3 IMPACT OF POLYPROPLYNE FIBERS ON THE DURABILITY PROPERTIES OF THE CONCRETE

3.1 *Permeability*

Generally, the presence of the polypropylene fibers in the concrete attains a less impermeability compared to traditional concrete and also the total porosity makes smaller when the polypropylene volume is enhanced in the mixture. The incorporation of polypropylene fibers in the concrete can lower its fissures and change its pore structure, and therefore ameliorating the water repelling behavior of concrete (Liu et al. 2019). From microstructural point of view, polypropylene fibers have no contribution in the chemical reactions, and may decrease both the penetrability and porosity by means of the impact of pores filling, resulting in considerable enhancement of the concrete microstructure and amelioration of structure durability (Yuan and Jia 2021). Many experimental studies denoted that the concrete penetrability reduced with the fibers volume growing due to porosity lessening and tortuosity's augmenting (Li and Liu 2020, Liu et al. 2019).

Sun and Xu showed that polypropylene fibers have notably lowered the breakthrough of water, and the dosage of 0.9 kg/m^3 of these fibers achieves the best overall conduct of the concrete mixture utilized in this study (Sun and Xu 2009).

Maruthachalam et al. used fibrillated polypropylene fibers by different volumetric rates of (0, 0.1, 0.2, 0.3)% in the high performance concretes. The outcomes found that the increment of fibrillated polypropylene fibers content makes the concrete mixture further durable. As shown in Figure 1. the mixture containing 0.3% of these fibers has lowest permeability coefficients at 28 and 56 days compared to the other mixtures (Maruthachalam et al. 2011).

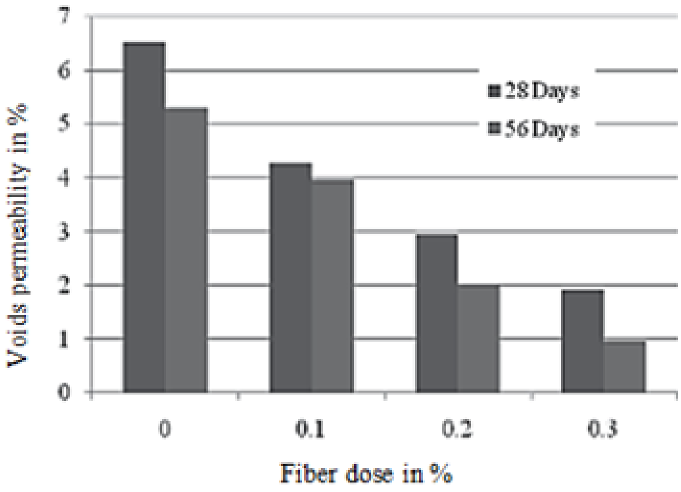


Figure 1. Comparison of voids permeability and fiber dosage (Maruthachalam et al. 2011)

Bagherzadeh et al. examined the effectiveness of polypropylene fibers in two dissimilar lengths (12 mm and 19 mm) and contents (0.1% and 0.3%) on the air and water permeability coefficients of concrete. It was obviously shown that increasing fibers content in the concrete have a remarkable impact on the air and water penetration conduct of concrete (Bagherzadeh et al. 2012).

Kakooei et al. reported that the polypropylene fibers reinforced concrete specimens containing four different contents (0 , 0.5, 1.5, 2) kg/m^3 have less permeability coefficients compared to the plain mixture. Polypropylene fibers could hinder the fissures generation in the concrete through a formulation of link bridge. However, the fiber content of 1.5 kg/m^3 displayed ameliorated outputs in permeability coefficient of the concrete mixture (Kakooei et al. 2012).

Ramezanianpour et al. studied the impact of diverse amounts of polypropylene fibers (0, 0.5, 0.7, 0.9, 1.5, 2, 4) kg/m^3 on water permeability of concrete mixtures at 28 days. It was exhibited that the depths of water permeation for the whole polypropylene reinforced concrete mixtures at 28 days were lower than that of plain concrete excluding the mixture owning 4 kg/m^3 of polypropylene fibers. The least permeation depth is around 7.7 mm for the mixture having 0.7 kg/m^3 of polypropylene fibers, that was lower than that of plain concrete by 30%. The lowering and thereafter increment in the water permeation depth was possibly ascribed to that the porosity increment is linked with the fibers amount augmentation. Both depths of water breakthrough for the plain concrete and the polypropylene reinforced mixture containing 4 kg/m^3 of fibers were approach (Ramezanianpour et al. 2013).

Zhang and Li reported that the polypropylene fibers in contents (0.06, 0.08, 0.1, 0.12)% could considerably reduce depth of permeable water in the concrete mixtures. When the fibers content is reached 0.12%, the depth of permeable water lowers to 7 mm in comparison with the plain mixture that has a depth around 8.7 mm. Furthermore, the microfissures were restricted in the reinforced concretes due to the effective inclusion of the polypropylene fibers. These microfissures considered as channels for water passing, and they were become further tight because of fibers existence (Zhang and Li 2013).

Medina et al. used varied volume percentages of polypropylene fibers (0, 0.03, 0.07, 0.1, 0.13)% to investigate the water permeability of concrete mixtures. They noticed that the concretes containing 0.07% fibers achieved a lowering of permeability coefficient by 32%. Greater volumes of the added fibers decrease the amounts of both the permeability coefficient and the surrounded space (Medina et al. 2014).

Rahmani et al. studied the influence of polypropylene fibers by three volumes of (0.1, 0.2, 0.3)% on concrete permeability. Incorporating fibers up to 0.2% decreases the penetration depth. However, the depth was enhanced by exceeding fibers volume to more than 0.2%. The reason behind that was the higher porosity of the specimens as a result of fibers content growing. It was reported that the cause for lowering the permeability around 50% with fibers existence is ascribed to the positioning of fibers between the pored interconnectedness passages and their blocking, leading to the elimination of the capillary feature and the penetrability lowers (Rahmani et al. 2019).

The aforementioned studies can be summarized in Table 1 as the follows:

Table 1. Effect of polypropylene fibers on the permeability of concrete

Fibers characteristics	Fibers dosage	Note	Reference
Fibrillated fibers, length = 38 mm, density = 0.91 g/cm^3, modulus of elasticity = 3.5 GPa	(0.1, 0.2, 0.3)% by volume	Mixture containing 0.3% has least permeability coefficients	Maruthachalam et al. 2011

Short fibers, length = (12-19) mm, density = 0.91 g/cm^3, modulus of elasticity = 5 GPa	(0.1,0.3) % by volume	Both the air and water permeability coefficients are minimized	Bagherzadeh et al. 2012
Short fibers, lengths = (10-20) mm, density = 0.91 g/cm^3, modulus of elasticity = 4.1 GPa	(0.06, 0.08, 0.1, 0.12)% by volume	At content of 0.12%, the depth of permeable water reduced	Zhang and Li 2013
Short fibers, lengths = 19 mm, density = 0.9 g/cm^3, modulus of elasticity = 3.45 GPa	(0.03, 0.07, 0.1, 0.13)% by volume	Mixture containing 0.07% attained a decreased permeability coefficient	Medina et al. 2014
Short fibers, lengths = 18 mm, density = 0.9 g/cm^3	(0.1, 0.2, 0.3)% by volume	Volume up to 0.2% lowers the permeability	Rahmani et al. 2019)
Short fibers, lengths = (12-19) mm density = 0.91 g/cm^3, modulus of elasticity = 3.5 GPa	(0.45, 0.9, 1.35) kg/m^3	Content of 0.9 kg/m^3 of achieved the largest reduction of permeability coefficients	Sun and Xu 2009
Short fibers, density = 0.91 g/cm^3, modulus of elasticity = (3.5-6.8) GPa	(0.5, 1.5, 2) kg/m^3	Content of 1.5 kg/m^3 appeared a better improvement of permeability coefficients results	Kakooei et al. 2012
Short fibers, lengths = 12 mm, density = 0.91 g/cm^3, modulus of elasticity = (3.5-3.9) GPa	(0.5, 0.7, 0.9, 1.5, 2, 4) kg/m^3	Permeability coefficients lowered at the contents (0.5-2) kg/m^3	Ramezanianpour et al. 2013

However, there are some studies on water and gas permeability of the polypropylene fiber reinforced concrete that have opposite results to the findings of the above-mentioned studies. These studies indicated that the permeability diminishes as the fiber dosage grows up to a particular level, and then the permeability enhances and at times it is even larger than for the traditional mixture (without fibers). Commonly, this is an outcome of little workability and the exaggerated content of fibers in the mixture (Blazy and Blazy 2021). The studies reported that fiber may increase ITZ and can act as a bridge between pores which might increase the water and gas permeability coefficients (Islam and Gupta 2016).

3.2 *Sorptivity*

The sorptivity coefficient can be considered as the concrete durability index. For the fibers reinforced concrete, the sorptivity is diminished in comparison to the traditional concrete due with a reason of the fibers impact from where pores filling, resulting in lack in the pore space linkage.

Karahan and Atiş explored the sorptivity of the polypropylene fibers reinforced concrete mixtures having different rates of (0.05, 0.10, 0.20)%. They revealed that the incorporation of polypropylene fibers in the concrete improves the coefficients of sorptivity for 28 days (Karahan and Atiş 2011).

Ramezanianpour et al. investigated the effect of various amounts of polypropylene fibers (0, 0.5, 0.7, 0.9, 1.5, 2, 4) kg/m^3 on the sorptivity coefficient of concrete at 28 days. The sorptivity coefficients for all polypropylene fiber reinforced concretes are less than that of reference concrete (without fibers) by 26% on account of the great decrease in capillary porosity and interconnection of pores as a result of fibers usage. As exhibited in Figure 2. the specimens containing 0.9 kg/m^3 of polypropylene fibers achieved the smallest sorptivity coefficient whereas concrete specimens owning 4 kg/m^3 attained similar results to the reference mixture because of its higher porosity (Ramezanianpour et al. 2013).

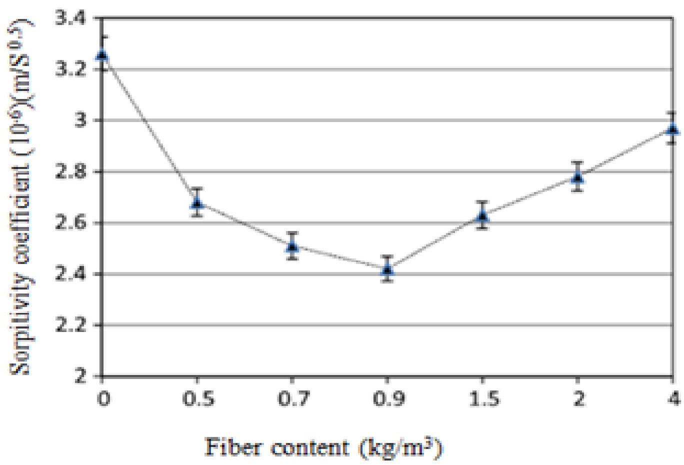


Figure 2. Sorptivity coefficient versus fiber content in sorptivity tests at the age of 28 days (Ramezanianpour et al. 2013).

Da Costa determined the sorptivity capacity of the High-Performance Fiber-Reinforced Cementitious Composites (HPFRCC) having 2% of polypropylene fibers. With respect to the traditional concrete, the inclusion of polypropylene fibers boosts the proportion of pores in the transition zone between the fiber and the cementing matrix. It is thought that the fine polypropylene fibers appear a larger proportion of transition zones with the cementing matrix than the transition zones between the coarse aggregate and cementing matrix exist in the concrete (Da Costa et al. 2019).

Zeyad et al. studied the sorptivity of the high strength concrete mixtures containing three volumetric rates of polypropylene fibers (0.2, 0.35, 0.50)%. Adding fibers results in growing the major surface absorption for whole reinforced mixtures in regard with the plain mixtures. This is ascribed to the impact of polypropylene fibers on decreasing workability, leading to supplemental pores in the polypropylene reinforced concrete mixture in comparison to the plain mixture (Zeyad et al. 2020).

Rashid found that the incorporation of two volumes (0.4, 0.6)% of polypropylene fibers in in the prestressed concrete girders subjecting to normal weathering (open atmosphere for 3 years) lessened the sorptivity coefficients in regard with the conventional mixture (Rashid 2020).

3.3 *Water absorption*

When Concrete durability is widely conjugated with its capability of water absorption since the amount of absorption represents as a mark of impedance or easiness for the passage of water and gases inside the concrete (Zeyad et al. 2020, Corpas et al. 2013). The absorption rate is a measuring of total porosity and pore size of the hardened concrete, and provides beneficial knowledge about the pore structure in terms of the size of pores and the interconnection between them. Generally, the studies on water absorption of the fibrous concrete have been quite restricted. However, many of them reported that the water absorption of the polypropylene fiber reinforced concrete was less than that of plain concrete (Afroughsabet and Ozbakkaloglu 2015, Da Costa et al. 2019, Fallah and Nematzadeh 2017, Blazy and Blazy 2021).

Maruthachalam et al. measured the water absorption of fibrillated polypropylene fiber reinforced high performance concrete. Fibrillated polypropylene fibers were included by diverse volumes of (0, 0.1, 0.2, 0.3)%. They observed that the growth of fibrillated polypropylene fibers volume makes the mixture highly durable. The concrete mixture owning 0.3% of fibrillated polypropylene fibers has lowest rate of absorption compared to the rest mixtures (Maruthachalam et al. 2011).

Nili and Afroughsabet noticed that the addition of polypropylene fibers by three volumetric rates (0.2, 0.3, 0.5)% notably affected on the water absorption of concrete specimens for both early and later ages as shown in Figure 3., and the greater fibers amount, the smaller water absorption (Nili and Afroughsabet 2012).

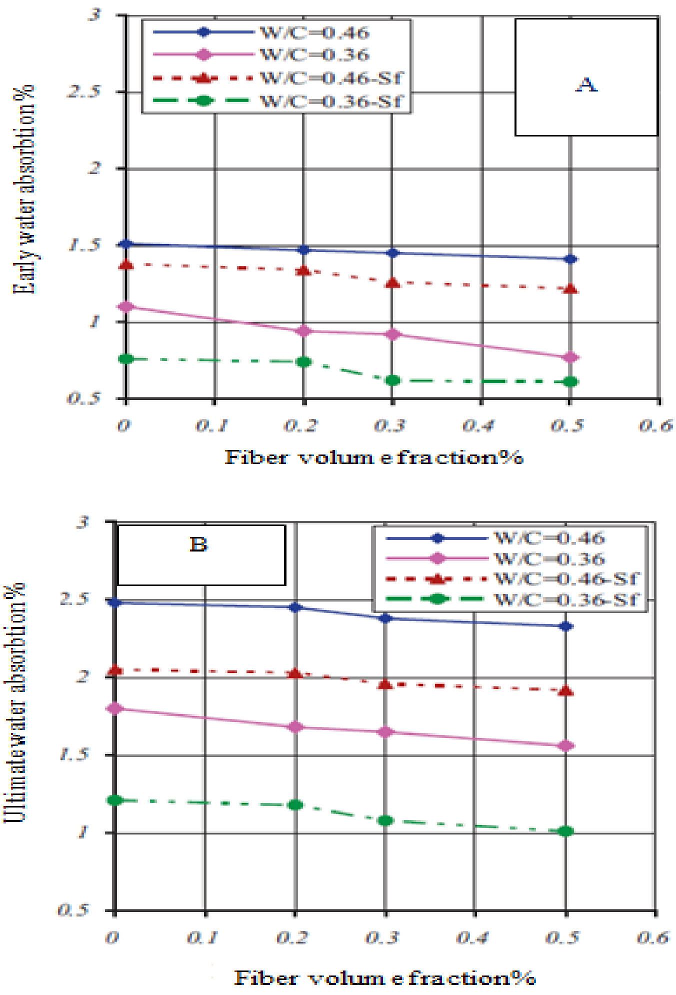


Figure 3. Water absorption of concrete versus fiber volume fractions at (a) early age and (b) later age (Nili and Afroughsabet 2012).

Behfarnia and Behravan used different rates of polypropylene (Barchip) fibers (0, 0.4, 0.6, 0.8)% by volume to examine the water absorption of the high performance concrete mixtures. Compared to the traditional mixture (0% fibers), it was observed that the percentages of water absorption were reduced by 50% in the polypropylene fibers reinforced specimens submerged in water for 28 days, and as well the percentages of water absorption were diminished by 30% in the polypropylene fibers reinforced specimens that submerged in 100% NaCl solution for four months. The lower capability of water absorption was caused by the occlusion of pores as a result of permeation of chlorides (Behfarnia and Behravan 2014).

Paradava and Pitroda reported that the fibers content of 0.3% reduced the absorption of water at 28 days of cement mortar containing polypropylene fibers with various proportions of (0, 0.1, 0.2, 0.3)% by weight of cement (Pradava and Pitoda 2014).

Afroughsabet and Ozbakkaloglu remarked that the polypropylene fibers inclusion by three volumes of (0.15, 0.30, 0.45)% favourablly impacts by lowering the absorption capacity of the high strength concrete mixtures, and this lowering persisted with the fibers rate growing. The mixture contains around 0.45% of polypropylene fibers achieved the smallest absorption of water (Afroughsabet and Ozbakkaloglu 2015).

Kashiyani, et al. investigated the water absorption at 28 days for the polypropylene fibers reinforced concretes containing five volumetric percentages of (0.1, 0.2, 0.3, 0.4, 0.5)% in upper and lower stratum of the typical paver unit. The authors concluded that the fibers content of 0.4% attained a maximum reduction of the water absorption in the concrete paver unit (Kashiyani et al. 2013).

Fallah and Nematzadeh used various volumes of polypropylene fibers of (0.1, 0.2, 0.3, 0.4, 0.5)% in high strength concrete mixtures. The results indicate that the small volume fraction of fibers in concrete attains a decrease in the water absorption, whereas using large volume fractions of polypropylene fibers lead to the reverse (Fallah and Nematzadeh 2017).

Zia and Ali reported the lower absorption capacity for polypropylene fiber reinforced concrete containing 5% of fibers (by weight of cement) compared to the conventional concrete (Zia and Ali 2018).

Mardani et al. showed that the water absorption of the concrete mixtures with polypropylene fibers were lowered in comparative with the traditional mixture. The maximum lowering was observed in the concrete mixture having a volumetric rate of 0.8% of fibers. An increment in the water absorption of the mixtures was observed at the rate of 1% of fibers in the concrete mixture (Mardani-Aghabaglou et al. 2018).

Liu et al. remarked that the water absorption rates reduced by (10.6, 19.6, 26.3) % when the quantities of the polypropylene fibers were (0.45, 0.90, 1.35) kg/m^3 consecutively. Furthermore, when the polypropylene volume grows, the absorbed water quantity lowers. It can be summarized that the polypropylene fibers can ameliorate the capability of water repelling for the high performance concrete specimens regularly. The fibers retard the water impermeability during its early stage, whereas they influence a bit on it at the advanced ages (Liu et al. 2019).

Da Costa et al. studied the water absorption rate of the High-Performance Fiber-Reinforced Cementitious Composites (HPFRCC) having 2% of polypropylene fibers. The authors believed that the existence of these fibers provides much pores in regard to the traditional concrete, these pores are likely located at the transition zone between the fibers and the cement matrix. Thus, the volume of this zone was enlarged as more than the volume of the transition zone between the aggregate and matrix because of few pores which did not have the capability of water absorption. So, they could not enlarge the zone volume (Da Costa et al. 2019).

Rashid conducted that the addition of volumes (0.4, 0.6)% of polypropylene fibers to the prestressed concrete girders exposing to normal weathering (open atmosphere for 3 years) made the water absorption smaller around 3% and 8% consecutively in comparison to the conventional mixture. From durability viewpoint, it is evident that the addition of polypropylene fibers is further advantageous on the ground that the curling kind of these fibers restrict their susceptibility to absorption of water in the concrete (Rashid 2020).

Yuan and Jia investigated the influence of polypropylene fiber through three volumes of (0.45, 0.90, 1.35)% on the water absorption of concrete. They reported that the fibers rate of 0.45% reduced the water absorption of the specimen, and it was increased with increasing volumetric rate. This may be ascribed to the several causes: fiber nature (i.e. hydrophobic), and its linkage type with the cement matrix is proportionally weak. Moreover, the larger volume of the polypropylene fibers enhances the inhomogeneity of the inner skeleton of the specimen (Yuan and Jia 2021).

The aforesaid studies that dealt with the influence of adding polypropylene fibers on the water absorption can be summarized in Table 2 as follows:

Table 2. Effect of polypropylene fibers on the water absorption of concrete

Fibers characteristics	Fibers dosage	Note	Reference
Fibrillated fibers, lengths = 38 mm, density = 0.91 g/cm^3, modulus of elasticity = 3.5 GPa	(0.1, 0.2, 0.3)% by volume	Mixture containing 0.3% has lowest water absorption	Maruthachalam et al. 2011

Short fibers, lengths = 12 mm, net density 0.91 g/cm^3	(0.2, 0.3, 0.5)% by volume	Volume rate of 0.5% shows the smaller water absorption	Nili and Afroughsabet 2012
Short fibers, lengths = (6 and 12) mm, net density = 0.91 g/cm^3, modulus of elasticity = (3.4 - 4.8) GPa	(0.1, 0.2, 0.3, 0.4, 0.5)% by volume	Fibers volume of 0.4% attained a maximum reduction of the water absorption	Kashiyani et al. 2013
Barchip fibers, lengths = 48 mm, net density = 0.92 g/cm^3, modulus of elasticity = 10 GPa	(0.4, 0.6, 0.8)% by volume	Mixture having 0.4% has lowest rate of water absorption	Behfarnia and Behravan 2014
Short fibers, lengths = 12 mm	(0.1, 0.2, 0.3)% by volume	Volume of 0.3% exhibited the smallest water absorption	Pradava and Pitoda 2014
Short fibers, lengths = 12 mm, net density = 0.91 g/cm^3	(0.15, 0.3, 0.45)% by volume	Absorption capacity is diminishing with the fibers rate enhancing	Afroughsabet and Ozbakkaloglu 2015
Short fibers, lengths = 12 mm, density = 0.91 g/cm^3 modulus of elasticity = 3.5 GPa	(0.1, 0.2, 0.3, 0.4 0.5)% by volume	Reduction in water absorption at rate 0.2%, while large rate of 0.5% lead to the opposite	Fallah and Nematzadeh 2017
lengths = 50 mm	5% by volume	Lowering in water absorption	Zia and Ali 2018
Prismatic fibers, density = 0.92 g/cm^3	(0.4, 0.8, 1)% by volume	Highest drop in water absorption at volumetric rate of 0.8% while the rate of 1% shows an increase in the water absorption	Mardani-Aghabaglou et al. 2018
Short fibers, Lengths = 12 mm, modulus of elasticity = 6 GPa	(0.45, 0.9, 1.35) kg/m^3	Absorption capacity is reducing with the volume rate boosting	Liu et al. 2019
Short fibers, lengths = 12 mm	(0.4, 0.6) kg/m^3	High content shows the less water absorption	Rashid 2020
Short fibers, lengths = 12 mm, density = 0.91 g/cm^3, modulus of elasticity = 4.8 GPa	(0.45, 0.90, 1.35) kg/m^3	Volumetric ratio of 0.45% appeared the lower water absorption but the larger rates achieved larger water absorption	Yuan and Jia 2021

However, some studies on water absorption of the fibrous concrete have opposite results to the findings of the above-mentioned studies (Karahan and Atiş 2011, Sadrmomtazi and Fasihi 2010, Selvi and Thandavamoorthy 2013, Fallah and Nematzadeh 2017, Zeyad et al. 2020, Mohamed 2006, Yuan and Jia 2021, Salemi and Behfarnia 2013). Blazy and Blazy stated that the influence of polypropylene fibers on water absorption cannot be obviously evaluated. One of the parameters, that may have a remarkable impact on it, is linked with workability: fibers spread in the mixture and porosity level (Blazy and Blazy 2021). The studies indicated that growing the fibers volume enhanced the absorption capacity of the concrete due to the weak dispersal of polypropylene fibers in mixture, leading to flocculate the fibers in the mixtures, and thus augment the pore size of the cement matrix (Sadrmomtazi and Fasihi 2010, Karahan and Atiş 2011, Mardani-Aghabaglou et al. 2018). Yuan and Jia reported that the nature of polypropylene fibers themselves in terms of hydrophobicity, and the nature of their bonding with the matrix that is comparatively weak. Furthermore, the large amounts of polypropylene fibers improve the heterogeneity of the pore structure (Yuan and Jia 2021). Also Salemi and Behfarnia justified the slight increment of the water absorption to the mixing method that may create air bubbles in the zone between cement paste and fibers (Salemi and Behfarnia 2013).

3.4 *Chloride diffusion*

Fiber reinforced concrete has been vastly utilized in the functional engineering like harbors, roads pavement and another marine and offshore structures, some of which are subjected to the heavy mediums with chlorides. Thus, it is needful to assess the resistance against the chloride ingress of the fiber reinforced concrete for the purpose of foretelling the level of service of these structures. Recently, there have been several studies that conducted on the chloride ion penetration resistance of the fiber reinforced concrete like the polypropylene fiber reinforced concrete. Pursuant to the most recent investigations, it was evidently confirmed that the fibers have a particular efficiency in terms of enhancing the resistance against the chloride penetrability into concrete compared to the plain concrete (Liu et al. 2019, Liu et al. 2019, Sadrinejad et al. 2018).

Ramezanianpour et al. indicated that the polypropylene fibers addition in contents (0, 0.5, 0.7, 0.9, 1.5, 2, 4) kg/m^3 boosts the concrete resistance to chlorides ingress. Chlorides ingress has lowered to a great extent likely because of deficiency in the pores internal connectivity with restricted porosity, that have a capacity of protecting the reinforcement bars from the corrosiveness. The increment and thereafter lessening of charge passed accompanied with the fibers dosage may possibly be concerned to growth of porosity with growth of fibers dosage that can reduce the chlorides resistance more than the specimens containing small fibers dosage (Ramezanianpour et al. 2013).

Singh et al. used about (0.1-0.3)% of polypropylene fibers to concrete consecutively and examined the rapid chloride permeability at (7, 14, 28 and 56) days. It was found that polypropylene fibers could diminish the chloride penetrability of concrete in comparison to the plain concrete mixture (without fibers) (Singh et al. 2013).

Selvi and Thandavamoorthy studied the rapid chloride permeability of concrete reinforced by polypropylene fibers. It was noted that the chloride permeability results of the polypropylene fiber reinforced concrete were decreased at 7 and 28 days compared to the traditional concrete (Selvi and Thandavamoorthy 2013).

Behfarnia and Behravan measured the alterations in chloride diffusion of the high performance concrete mixtures owning various volumes of polypropylene (Barchip) fibers of (0, 0.4, 0.6, 0.8)% relative to the traditional mixture (0% fibers). The results indicated in general that the depths of chlorides for all mixtures were decreased due to the incorporation of fibers that potentially closed the pores in the cementitious matrix, leading to chloride depths dwindling (Behfarnia and Behravan, 2014).

Similar trend for Söylev and Özturan, and Afroughsabet et al. who reported that the inclusion of little volumetric rates of polypropylene fibers can greatly impact the concrete resistance to corrosion (Söylev and Özturan 2014, Afroughsabet et al. 2018).

Sadrinejad et al. examined the chlorides resistance for the reinforced concrete mixtures with two polyolefin and polypropylene fibers. Volumes of polyolefin fibers were about (0.5, 1, 1.5)% that replaced in part by polypropylene fibers at percentages of (0.1, 0.2)% . The chlorides penetration depth in the mixture containing 0.1% of polypropylene fibers was identical with that in conventional concrete (without fibers) and in mixture having 0.2% of fibers was reduced around 11% (Sadrinejad et al. 2018).

Liu et al. used three quantities of polypropylene fibers (0.45, 0.90, 1.35) kg/m^3 in the high performance concrete mixtures. As shown in Figure 4. the fibers inclusion in the high performance concretes ameliorates their resistance to chloride ions. When the polypropylene fibers quantity grew from 0.45 kg/m^3 to 1.35 kg/m^3, the chlorides amount at a depth of 15 mm lowered from 0.24% to 0.09%. The reasons behind that include a reduction of both the pore diameter and the porosity, a bond strengthening between C-S-H and calcium hydroxide, and a highly compacted contact area (Liu et al. 2019).

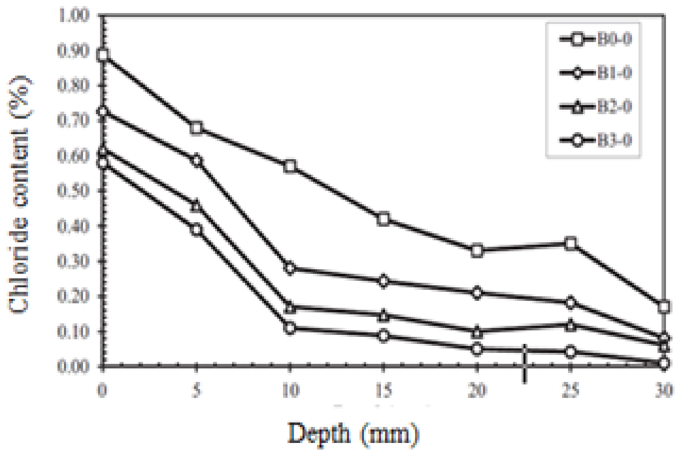


Figure 4. Chloride penetration test results of the intact samples with different polypropylene fibers contents (Liu et al. 2019).

The aforementioned studies can be in brief in Table 3 as follows:

Table 3. Effect of polypropylene fibers on the chloride diffusion of concrete

Fibers characteristics	Fibers dosage	Note	Reference
Crimped fibers, length = 48 mm, net density = 0.91 g/cm^3	(0.01, 0.02, 0.03)% by volume	Larger decrease in chloride ingress at the volumetric rate of 0.03%	Singh et al. 2013
Crimped fibers, lengths = 50 mm	4% by volume	Chloride diffusion results were lessened	Selvi and Thandavamoorthy 2013

Barchip fibers, lengths = 48 mm, net density = 0.92 g/cm^3, modulus of elasticity = 10 GPa	(0.4, 0.6, 0.8)% by volume	Depths of chlorides were reduced and the mixture that owning 0.8% of fibers has lowest chloride penetration depth	Behfarnia and Behravan 2014
Short fibers, lengths = 12 mm, net density = 0.91 g/cm^3 modulus of elasticity = 3.5 GPa	(0.1, 0.2) by volume	Chloride depth in mixture owning 0.1% was the same with that in plain mix, however the lowest penetration depth in the mix that having 0.2% fibers	Sadrinejad et al. 2018
Short fibers, lengths = 12 mm, density = 0.91 g/cm^3, modulus of elasticity = (3.5-3.9) GPa	(0.5, 0.7, 0.9, 1.5, 2, 4) kg/m^3	Chlorides ingress was lowered particularly at amount 0.7 kg/m^3	Ramezanianpour et al. 2013
Short fibers, Lengths = 12 mm, modulus of elasticity = 6 GPa	(0.45, 0.9, 1.35) kg/m^3	Chloride ions resistance is enhancing with the fibers ratio enhancing	Liu et al. 2019

In contrast Toutanji et al. reported that adding polypropylene fibers by rates (0, 0.1, 0.3, 0.5)% enhanced the chloride diffusion. This is ascribed to that polypropylene fibers enhance the voids proportion in the concrete on account of the coherence shortage of the cementitious matrix and weak fibers dispersal. When the fiber length prolonged from 12.5 mm to 19 mm, the concrete specimens displayed an improvement in chloride diffusion (Toutanji et al. 1998). Larbi and Polder, and Rashid noted that the polypropylene fibers do not reason any remarkable alteration in chloride penetration coefficient in comparison to the traditional mixture (Larbi and Polder 2007, Rashid 2020). Chen et al. also reported that the volume fraction of 0.1% of each of monofilament polypropylene synthetic fiber reinforced concrete and reticular polypropylene synthetic fiber reinforced concrete reduced the ion chloride permeability by 68% and 71% respectively, in comparative with the conventional concrete. This result was reversed when the dosage of each of them increased to 0.16% and 0.2%. Excessive volume of fibers is not difficult to agglomerate in the concrete, that supplies a channel for water breakthrough, what causes weak impermeability (Chen et al. 2018).

3.5 *Carbonation*

The carbonation mechanism of reinforced concrete by polypropylene fibers was restricted (Medina et al. 2015). The major cause of that is the presence of numerous pore paths and microfissures in the concrete, that in turn provides the passages for carbon dioxide ingress. A great extent of polypropylene fibers dispersing regularly in the concrete can formulate a reticulated skeleton, and the pore paths in concrete is lowered. In the meantime, the massive fibers contents in the matrix can fill the capillary pathways and minify the capillary porosity. Likewise, the efficient role of polypropylene fibers from where hindering the fissures development diminishes the microfissures quantity in the concrete that may be considered as passages of carbon dioxide ingress. Thus, the concrete resistance against carbonation can be enhanced as a result of polypropylene fibers incorporation (Zhang and Li 2013).
Medina et al. used four diverse rates of polypropylene fibers (0.03, 0.07, 0.1, 0.13)% in the natural pozzolan cement concrete. A dwindling of carbon dioxide ingress was observed for mixtures having polypropylene fibers volume amounting to 0.1%, in relation to conventional mixture. As the fibers volume is grown from 0% to 0.1% the minimal depth of carbonation reduces around 43%. Larger contents of polypropylene fibers fulfill larger depth of carbonation (Medina et al. 2014).
Zhang and Li assessed a carbonation depth of blended concrete mixtures with various rates of polypropylene fibers of (0.06, 0.08, 0.1, 0.12)%. Fibers significantly diminished the depth of carbonation which dwindles little by little with fibers rate increment as the rate is lower than 0.12% as appeared in Figure 1..(5). The excessive rates of polypropylene fibers may close the capillary pathways and lessen the capillary pore. Besides, the influence of polypropylene fibers from where inhibiting the fissures generation, restrict the microfissures in the concrete that possibly being paths for CO_2 ingression. Consequently, the existence of polypropylene fibers can boost the concrete resistance against carbonation (Zhang and Li 2013).

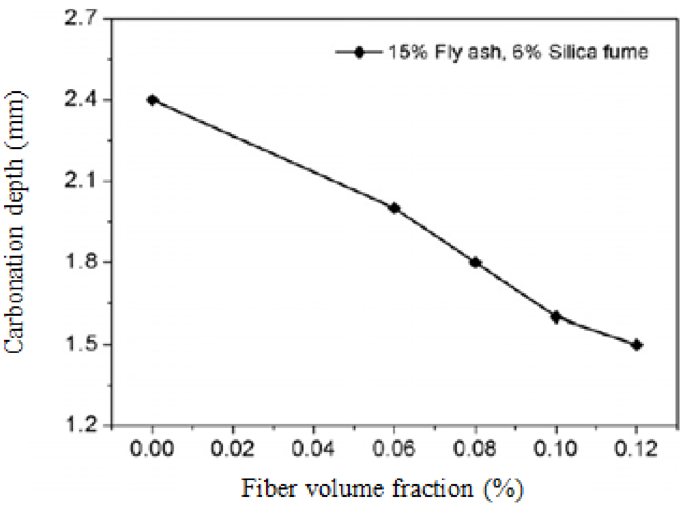


Figure 5. Effect of fiber volume fraction on carbonation depth (Zhang and Li 2013)

Medina et al. utilized different rates of polypropylene fibers (0, 0.03, 0.07, 0.1, 0.13)% in order to investigate the carbonation depth of NPC (Natural Pozzolan Cement) mixtures. It was noticed that the carbonation was latent in the polypropylene reinforced concrete mixtures on the ground that the fibers dominated the fissure geometry, resulting in decrease of the spreading paths of CO_2 (Medina et al. 2015).

The above studies can be summarized in Table 4 as the follows:

Table 4. Effect of polypropylene fibers on the carbonation of concrete

Fibers characteristics	Fibers dosage	Note	Reference
Short fibers, lengths = (10-20) mm, density = 0.91 g/cm^3, modulus of elasticity = 4.1 GPa	(0.06, 0.08, 0.1, 0.12)% by volume	Carbonation depths decreased little by little with the growing of fibers volume fraction	Zhang and Li 2013
Short fibers, lengths = 19 mm, density = 0.9 g/cm^3, modulus of elasticity = 3.45 GPa	(0.03, 0.07, 0.1, 0.13)% by volume	CO_2 diffusion is slower in time at low amounts of fibers (upper to 0.07%)	Medina et al. 2014
Short fibers, lengths = 19 mm, density = 0.9 g/cm^3, modulus of elasticity = 3.45 GPa	(0.03, 0.07, 0.1, 0.13)% by volume	Content of 0.07% shows the lowest carbonation depth	Medina et al. 2015

3.6 *Frost resistance*

It is anticipated that fibers to be efficient in lessening frosting damage due to their fissure-restraining advantages where water is probably to freeze. It is well known that the water existing in the pores of concrete augments its volume when it freezes, and therefore the concrete begins to extend and further tensile stresses generate. So, it may deteriorate the concrete while the tensile strength of the material will be overridden. Nonetheless, fibers that are spread in the concrete matrix can restrict this extension and reduce the deterioration caused by exposure to cycles of freezing and thawing (Zhang and Li 2013, Blazy and Blazy 2021, Rahmani et al. 2019). The usage of polypropylene fibers will fulfill a considerable keeping on repair fees in some weathers during occurrence of uniform and strict cycles of freezing and thawing (Richardson 2003).

Richardson studied the effect of addition of fibrillated polypropylene fibers was 0.91 kg/m3 with three lengths of (19, 38, 6.5) mm on the concrete specimens exposing to (0, 70, 150) cycles of freezing and thawing. It was indicated that there is an obvious relationship between the polypropylene fibers presence in concrete and freezing and thawing safeguard, thus improved durability (Richardson 2003).

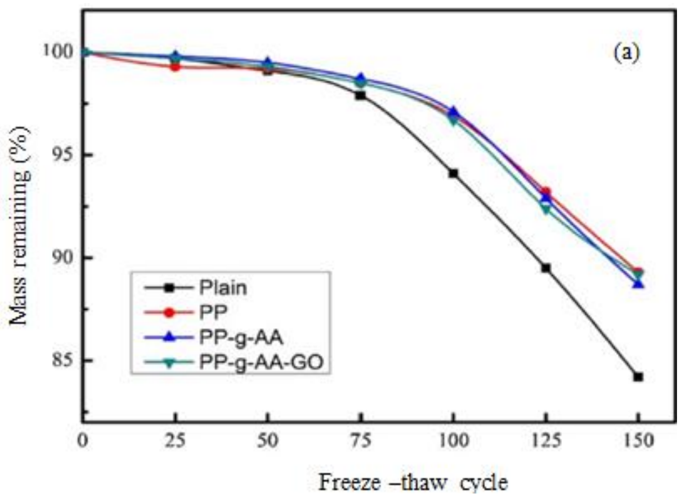
Richardson and Coventry reported that the incorporation of 0.9 kg/m3 of polypropylene fibers by a length of 19 mm enhance the concrete performance against about 50 cycles of freezing and thawing in comparison to the traditional concrete in terms of weight loss and compressive strength regardless on variation in the concrete mix proportion (Richardson and Coventry 2010).

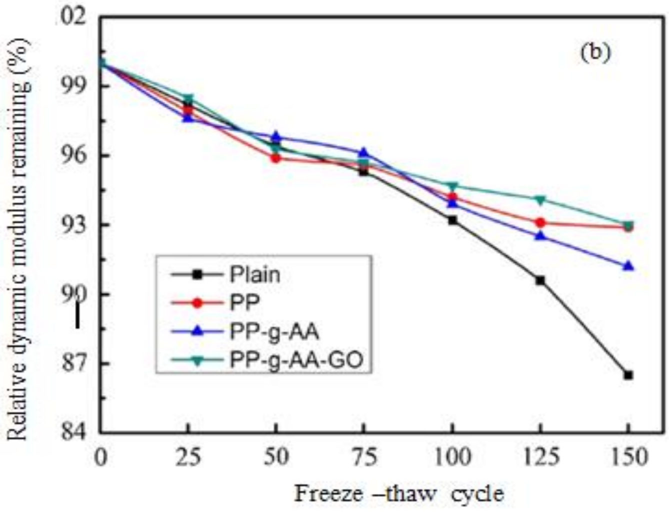
Karahan and Atiş showed that using of polypropylene fibers dosages (0.05, 0.10, 0.20)% achieved a slight enhancement of the specimen's resistance against around 50 cycles of freezing and thawing in comparison to the traditional specimens (without fibers). Thanks to the fibers distributing at random in concrete, that in turn restrict the extending caused by water freezing in the pore matrix (Karahan and Atiş 2011).

Salemi and Behfarnia found that the loss of concrete strength beyond 150 cycles of freezing and thawing lowers from 65% to 45.22% as the polypropylene volume grows from 0% to 0.2%. Both the weight loss and length change of reinforced concrete specimens diminish a little as fiber rate raises. This amelioration of frost resistance is most likely due to the improved tensile strength, fissure-restraining impact of polypropylene fibers, the bridge impact of fibers on fissures and transformation impact of fibers on disconnected cement blocks (Salemi and Behfarnia 2013).

Zhang and Li added observed that the anti-fissuring role of polypropylene fibers at volumes (0.06, 0.08)% lowers the microfissures proportion in concrete that may act as the leakage pathways of water probably concrete freeze. In contrast, the resistance begins to somewhat dwindle jointly when the fibers amount reached (0.1, 0.12)%. In this state, the growth of fibers proportion in the unit volume of concrete led to significantly narrow the distance between the fibers themselves. The closing fiber transition zones interact with each other and the amount of the feeble zones grows. As a result, the transition zone extremely becomes soft, and negatively influences on the concrete resistance to 300 cycles of freezing and thawing cycles (Zhang and Li 2013).

Feng et al. made a grafting for the polypropylene fibers by both acrylic acid and grapheme oxide with a purpose of enhancing a resistance of polypropylene fiber reinforced concrete to 150 cycles of freezing and thawing. It was exhibited that the supplemental polypropylene fibers in the concrete specimens sup-plied favorable impact on their resistances against cycles of freezing and thawing. As shown in Figure 6. specimens having grafted polypropylene fibers by acrylic acid and grapheme oxide fulfilled the greatest amounts of mass remaining, residual flexural strength, and relative dynamic modulus of elasticity (Feng et al. 2017).





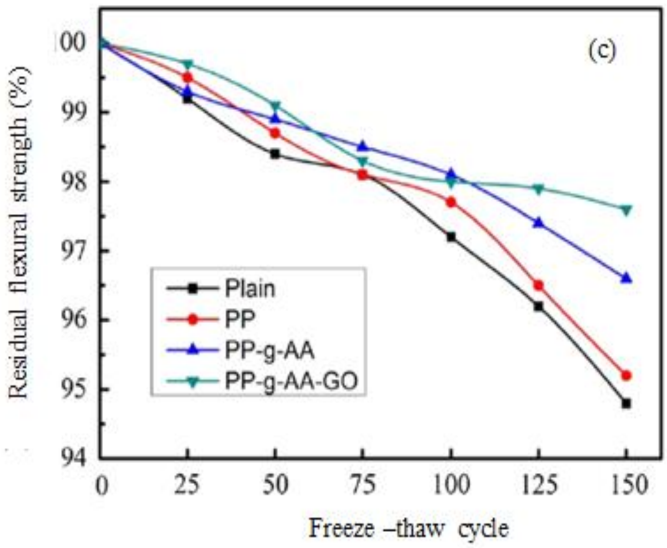


Figure 6. Performances of various PP fabrics reinforced concrete samples (a) Mass loss (b) Relative dynamic modulus of elasticity (c) Residual flexural strength (Feng et al. 2017).

Mardani et al. investigated the freezing and thawing resistance of three volumetric rates of polypropylene fibers (0.4, 0.8, 1)%. It was noticed that the mixtures containing 0.8% of polypropylene fibers exhibited a perfect resistance against 300 cycles of freezing and thawing, and above this volume the resistance was adversely impacted compared to the conventional mixture. Thereby, the entry of water to the capillary pores deteriorates the pore structure with inner extension through freezing (Mardani-Aghabaglou et al. 2018).

Nguyen et al. found that 2% of polypropylene fibers fulfilled a crucial performance in improving the durability of the high performance fiber reinforced cementitious composites after exposure to 180 cycles of freezing and thawing. The fissure bridging effect of the fibers retarded the chemicals spreading in the matrix, and lastly retrained the volume extending caused by freezing and thawing cycles (Nguyen et al. 2019).

Ren and Lai reported that the incorporation of 0.2% polypropylene fibers can enhance the concrete resistance against 300 cycles of freezing and thawing by 67% compared to the other contents (0.1, 0.4)% by weight of cement. Bridging impact of polypropylene fibers enhanced the tensile strength that was significant for frost resistance of concrete (Ren and Lai 2021).

The summary of the aforementioned studies can be shown in Table 5 as the follows:

Table 5. Effect of polypropylene fibers on the frost resistance of concrete

Fibers characteristics	Fibers dosage	Freezing and thawing cycles	Note	Reference
lengths = 19 mm, density = 0.91 g/cm^3,	(0.05, 0.1, 0.2)% by volume	50	Extension caused by freezing in the pore matrix was limited	Karahan and Atiş 2011
Lengths = 12 mm, diameter = 90 µm	(0.1, 0.2)% by volume	50, 150, 300	Loss of strength reduces as the fibers rate raises	Salemi and Behfarnia 2013
Short fibers, lengths = (10-20) mm, density = 0.91 g/cm^3, modulus of elasticity = 4.1 GPa	(0.06, 0.08, 0.1, 0.12)% by volume	300	Frost resistance lowers at the rates (0.1, 0.12)%	Zhang and Li 2013
Fabric	Single layer	150	Addition of fabrics in concrete improved its frost resistance	Feng et al. 2017
Short fibers, lengths = 5 mm, density = 0.92 g/cm^3	(0.4, 0.8, 1)% by volume	300	Good resistance, up to 0.8% of fibers	Mardani-Aghabaglou et al. 2018
Short fibers, lengths = 10 mm, density = 0.91 g/cm^3, modulus of elasticity = 9 GPa	2% by volume	90, 180	Frost resistance was enhanced	Nguyen et al. 2019
Reticulated fibers, lengths = 19 mm	(0.1, 0.2, 0.4)% by weight	300	Frost resistance was improved at 0.2%	Ren and Lai 2021
Long fibers, lengths = (19, 38, 6.5) mm	0.91 kg/m^3	70, 150	Fibers could boost the frost resistance	Richardson 2003
Lengths = 19 mm, diameter = 22 µm	0.9 kg/m^3	50	Frost resistance was improved	Richardson and Coventry 2010

However, some studies conflict with that in terms of the positive effect of polypropylene fibers addition on the concrete resistance to freezing and thawing cycles. These studies reported that the polypropylene fiber reinforced specimens did not display a remarkable alteration in their freezing and thawing performance (Zhang and Li 2013, Rahmani et al. 2019, Puertas et al. 2003, Wang et al., 2019). Chen-fei and Di-tao indicated that the concrete resistance against deicer-scaling is made less with the incorporation of polypropylene fibers by volumes (0.1, 0.3, 0.5) %. Because of the fibers restrict the extending of concrete's surface, the loss amount of both weight and dynamic modulus of elasticity were decreased little by little accompanied with the growing fibers content (Chen-fei and Di-tao 2011). Also Chen et al. reported that the volume fraction of 0.12% of each of monofilament polypropylene synthetic fiber reinforced concrete and reticular polypropylene synthetic fiber reinforced concrete boosts the frost resistance of pavement concrete mixtures, in comparative with the traditional concrete. The fiber amount is not the higher the preferable, but there presents a plausible threshold. Chen et al. stated that when the fiber volumetric rate is larger than the crucial level, the distribution of fibers in the concrete becomes bad, that is simple to agglomerate, and it will impact concrete resistance against freezing and thawing cycles in state(Chen et al. 2018).

4 CONCLUTION

This paper gives a comprehensive review on the effect of the incorporation of the polypropylene fibers to the concrete on various durability properties. The properties include permeability, sorptivity, water absorption, chloride diffusion, carbonation, and freeze–thaw resistance. Based on the survey of the published literatures, the following conclusions can be drawn:

1. The inclusion of polypropylene fibers with different volumes in the concrete can restrict its cracks by formulating bond bridge and alter its pore structure by reducing porosity and growing tortuosity, and thus making the water and gas permeability of concrete smaller.
2. The sorptivity capacity and water absorption of the polypropylene fibers reinforced concrete is decreased, compared to the plain concrete because of the effective role of polypropylene fibers in filling the pores, which leads to a deficiency of the pore space interconnection.
3. The depths of chloride ions penetration for polypropylene fiber reinforced mixtures were lowered because of the addition of fibers which potentially closed the pores in the cement matrix, resulting in shortening of chloride ions penetration depths.
4. The prominent function of polypropylene fibers in terms of preventing the cracks evolution reduces the microcracks extent in the concrete which are pathways of carbon dioxide penetration. Therefore, the resistance of concrete against carbonation can be boosted.
5. Polypropylene fibers in concrete could enhance its frost resistance. This is attributed to the enhanced tensile strength, cracks-restricting effect of polypropylene fibers, the bonding bridge effect of fibers on cracks and transition effect of fibers on disconnected cement blocks.
6. Several researchers already reported numerous superior durability properties of concrete containing polypropylene fibers with various dosages as compared to the plain concrete. Nevertheless, some researchers found that this improvement in the durability properties can be achieved at particular fiber dosage which, if it is overridden, will have reverse outputs. Thus, greater fiber dosage – improved property is not always a right.

The worse dispersal of fibers in the mixture results in fibers agglomeration and pore size increment of the cementitious matrix, and consequently it will negatively impact on concrete durability. Finally, it is necessary to analyze the mix proportion and ingredients as well as the fibers characteristics (type and geometry) in order to choose the optimum fiber dosage.

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