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Investigation of the Usage Areas of Different Fiber Reinforced Concrete

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ABSTRACT

Nowadays, the need for concrete to be used in different areas has led to some concrete technology developments. One of the developments in this area is the production of fibrous concrete. It is a material that has a wide application area in fiber concrete, concrete and reinforced concrete building applications. Because of this widespread usage, many studies have been done to improve the properties of concrete. Fiber Reinforced Concrete obtained with different types of fibers added to concrete is one of these studies. Fiber-reinforced concrete; hydraulic cement, aggregate and discontinuous dispersed fibers mixed with water. The fibers are not very effective on the compressive strength of concrete, but they significantly increase the concrete's flexural toughness. Polymer fibers used in concrete are mostly preferred to reduce shrinkage. Metallic fibers such as steel fiber are used to increase toughness. Also nowadays, it is produced with steel fibers and ultra-high-performance concrete (UHPC).

ÖZ

Anahtar Kelimeler:
Lifli beton,
Plastik büzülme,
Tokluk,
İşlenebilirlik,
Eğilme dayanımı.

Günümüzde betonun farklı alanlarda kullanılması beton teknolojisinde bazı gelişmelere yol açmıştır. Bu alandaki gelişmelerden birisi de lifli beton üretimidir. Lifli beton, beton ve betonarme yapı uygulamalarında geniş uygulama alanına sahip bir malzemedir. Bu yaygın kullanım nedeniyle betonun özelliklerini iyileştirmek için birçok çalışma yapılmıştır. Betona eklenen farklı tipteki liflerle elde edilen lifli beton bu çalışmalardan birisidir. Lifli beton; su, çimento, agrega ve süreksiz dağılmış liflerden oluşmaktadır. Lifler beton basınç dayanımı üzerinde çok etkili değildir, ancak betonun eğilme tokluğunu önemli derecede arttırmaktadır. Betonda kullanılan polimer lifler daha çok büzülmeyi azaltmak için tercih edilirler. Çelik lif gibi metalik lifler ise tokluk arttırmak için kullanılmaktadır. Ayrıca, günümüzde çelik lifler ile ultra yüksek performanslı betonlarda (UYPB) üretilmektedir.

1. Introduction

A concrete structure is a material with a wide usage area. Because of this widespread usage, many studies have been done to improve the properties of concrete. Fiber-reinforced concrete obtained with different fibers added to concrete is one of these studies—fiber reinforced concrete; cement, aggregate, and discontinuous dispersed fibers.

One of the important features of the structural elements is their resistance to fire or high temperatures. Although fire or high-temperature effects are not considered during the buildings' design phase, they can only be used in special-purpose buildings such as factories, thermal plants, high-temperature chimneys so on. The exposure of a typical structure to high temperature is not considered much. However, especially industrial development brings more energy use and fire risk [1].

Considering the concrete as a whole, it is known that the thermal expansion of components such as hardened cement paste and aggregate is different from each other. Therefore, the concrete's temperature changes cause various volume changes in the constituents, crack formation, and decrease in concrete strength. This phenomenon is known as the thermal incompatibility of members in concrete. When the hardened cement paste is heated from room temperature to approximately 150 ºC, it expands to a maximum of 0.2%. When the temperature is increased from 150 ℃ to 300 ℃, the hardened cement paste starts to shrink. When the temperature is increased to 800 ℃, the cement paste's shrinkage can reach up to 2.2%. Generally, at high temperatures above 150 ℃, aggregates begin to expand and disperse, while the cement paste shrinks due to the hydration products' dehydration. Therefore, thermal expansions and cracks develop under high-temperature conditions. In this respect, the behavior of concrete under high temperatures arouses curiosity [2].

By adding fibers into the concrete, the concrete is given new properties and specific properties are increased. Fibers commonly used in concrete today; steel, polymer, glass and carbon-based. The addition of fibers to concrete; is one of the most effective methods for improving the tensile and flexural strength of concrete, energy consumption capacity and crack growth properties. In addition to its superior additives, the extent to which glass fiber reinforced concrete will improve fire performance has been considered a void of debate [3].

2. Fiber Types for Concrete

It is a composite material produced using essential components such as concrete, aggregate, cement and water. The tensile strength and tensile unit deformation capacity of concrete are very low. To improve these weak properties of concrete, fibers produced from different materials and having high technical properties are added and the type of concrete obtained is called fibrous concrete. Today, fiber, concrete, natural, steel, polymer and glass-based fibers are widely used. The use of fibers in concrete, the concrete's resistance to crack development and increase the ductility property and concrete; strength and energy absorption capacity properties. The most critical factors affecting fibrous concrete properties are the slenderness ratio, the amount of fiber, and the fiber's homogeneous distribution in the concrete matrix. Homogeneously dispersed fibers prevent cracks in the concrete and slow the cracks' progression in the concrete, making the concrete more durable [4].

The use of fibers in building materials is a method that has been practiced since ancient times. The use of fiber, the first examples of which were seen using straw in adobe, has gained diversity and functionality with application examples such as steel, polymer and glass. There are many types of fibers in terms of application areas [5].

Natural Fiber

Natural fibers; fibers used in the form obtained from natural sources such as animals, plants, and minerals [46]. For example, adobe, known as a traditional material, uses straw from vegetable fibers combined with clay pulp. It is also known that flax or hemp fibers, animal fibers such as horsetail, goat hair are used in gypsum, plaster and plasterboard applications [6].

Natural Fibers Types:

- Animal Fibers
- Vegetable Fibers
- Mineral Fibers

Physical properties of some natural fibers are given in Table 1:

Table 1. Physical Properties of Different Types of Natural Fibers [7]

Fiber Type	Specific Gravity (gr / cm^3)	Maximum Elongation (%)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)
Mineral Wool	2,7	0,6	69-117	483-759
Cotton-Wool	1.5	10-25	6.9	414-621
Cotton	1.5	3-10	4.8	414-690
Horse fiber	2.62	3	29.49	630
Goat fiber	2.64	5	22.57	455

Steel Fiber

Metals are widely used in industry and construction today due to their high plastic deformation capabilities. Fiber formation of metals is also used for many years. Physical properties of some metallic fibers are given in Table 2:

Table 2. Typical properties of some metallic fibers [8].

	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Melting Temperature (°C)	Metal Specific Weight (gr / cm^3)
W (Tungsten)	2890 (<250 µm) 3150 (<125 µm) 3850 (<25 µm)	350	3410	19.3
Mo (Molybdenum)	2200	330	2625	10,2
Cu (Copper)	450	125	1083	8.9
Be (Beryllium)	1100	310	1350	1.8
Al (Aluminium)	300	70	660	2.7
Stainless steel (0.05 mm)	2400	198	1535	7.8
0.9% Carbon Steel (0.1mm)	4000	210	1300	7.9

Stainless steel fibers are the most commonly used metallic fibers. The fact that the fibers are made of stainless steel eliminates the defect of metals being corroded, and the high elasticity module and strength of steel make the steel fiber superior to all other fibers.

In American Standard ASTM A 820-96 [9], which classifies steel fibers used in concrete reinforcement and specifies their properties, steel fibers are classified in 4 different ways. These:

- Type 1: Cold drawn steel fibers,
- Type 2: Steel fibers cut from plate,
- Type 3: Rolled steel fibers,
- Type 4: Other fibers

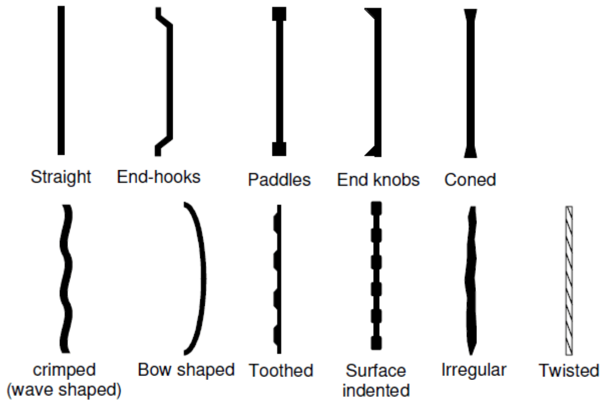

Figure 1. Some of the standard shapes of steel fibers [9]

These fibers are only classified according to the way they occur. The Turkish standard TS 10513-92 [11] also separates the fibers according to their types as follows:

- A: Straight, smooth surface fibers,
- B: fibers deformed along their entire length,
- C: Fibers with hook ends.

Class B fibers, according to the way they are deformed along their length;

- Fibers with indentations (notches) on them,
- Wavy (curled) fibers throughout its length,
- Moon shape wavy fibers

Class C fibers according to the end hooks;

- Fibers with twisted ends,
- It is divided into two as curled fibers at one end.

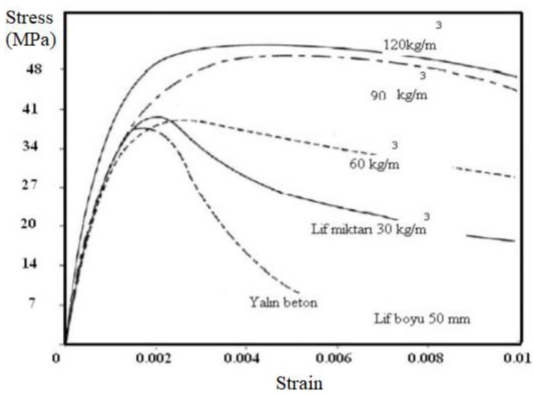

Figure 2. Normal strength concrete with steel fiber stress-strain [44]

Metals are widely used in the construction sector today due to their high deformation properties. Among the metallic fibers added to concrete, steel fibers are the most commonly used. Steel fibers are made of either carbon steel or stainless steel. The task of steel fibers is to create adhesion force in concrete. The frictional forces in the concrete are irregular due to micro-cracks in the material. Therefore, by using steel fibers in concrete, it is provided to transfer the tensile forces formed in weak areas as a bridge [12].

The properties and classification of steel fibers to be used in concrete are divided into four groups according to American standard ASTM A 820-96. These; cold drawn fibers, plate-cut fibers, melt-drawn fibers and other fibers [13].

Table 3. Physical Properties of Steel Fibers [7]

Fiber Type	Specific Gravity (gr/cm^3)	Maximum Elongation (%)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)
Steel	7,8	0,5-3,5	200	276-2760

Polymer Fiber

The main types of polymer fibers; polypropylene, nylon, polyethylene, aramid and perlon. Polypropylene fibers are the most suitable fiber added to cement paste from polymer fibers. These fibers are an essential reinforcement material with their high strength, resistance and low costs. It is also preferable that the polypropylene reinforcement material's surface is not hydrophobic, so it does not get lumpy in the cement-bonded matrix material [14].

The most important effect of polypropylene fibers in concrete is to control the cracks caused by plastic shrinkage within the first few hours after casting. The hardening of the concrete is slower than the rate at which the concrete gains strength and the shrinkage caused by the shrinkage in the first stage of the setting. This causes plastic shrinkage. polypropylene fibers provide resistance to these shrinkage stresses and minimize cracking risk due to shrinkage [15].

Fiber volume ratios are used as 0.1% - 0.05%. The processing of polymer fiber concretes on the type, length, content, and concrete strength. The fibers that are added to concrete from polymer fibers and give the best results are polypropylene fibers. Just like steel fibers, polypropylene fibers can also increase some properties of concrete. Polypropylene fibers are available in both fiber pulp and singular forms. There is little difference between fiber types [16].

An important feature of high-performance concretes is to reduce the water/binder ratio very low by using a superplasticizer. Due to the decrease in water content, there is little perspiration in these concretes. If silica fume is also used as an additional binder, a significant part of the free water is bound and sweating is hardly seen due to the large surface area of the silica fume grains. Concrete becomes very sensitive to plastic shrinkage cracks. For this reason, plastic shrinkage is prevented by adding a minimal amount of polymer-based fibers to high-performance concretes while not much effect on mechanical properties [17].

High-performance concrete is not resistant to fire has gained importance after the fire in 1996, especially in the English Channel between England and France [18]. Figure 3 shows the load-deflection curve of concrete produced with polymer fiber.

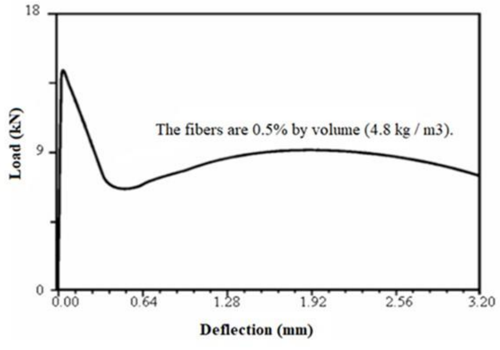

Figure 3. Typical load-deflection curve for polymer fiber-reinforced composites [19].

Polymer fibers cannot effectively increase the mechanical properties of concrete than steel fibers and negatively affect applications used more than a specific value. However, they add energy absorption properties to concrete, even if only a little, and are particularly effective in plastic shrinkage. PP fibers do not create a strength-increasing reinforcement effect in hardened concrete. Their impact is valid in the plastic phase of concrete and they act as a kind of additive material [20].

Another benefit of adding polymeric fibers to concrete is to ensure that the concrete is less damaged in fire due to the escape of water vapor that expands in the concrete at high temperatures. In high-performance concretes, the fact that the gaps are minimal, few and unrelated, prevents water vapor escape. As a result, the outer shell of the concrete bursts and pours. As a precaution, it is recommended to add polypropylene fiber to concrete. These fibers, which melt at temperature, create the necessary voids and channels and allow water vapor to escape [21]. The most important effect of polypropylene (PP) fiber in concrete or plaster is to control cracks that will occur due to plastic shrinkage within the first few hours after casting. In the first stage of hardening, the formation of concrete strength is slower than the rate of occurrence of internal tensile stresses caused by shrinkage. This plastic shrinkage is a natural result of the chemical reaction between water and cement and water evaporation. PP fibers create resistance to shrinkage stress and minimize cracks' risk due to shrinkage [20].

The typical load-deflection curve of a beam containing 0.5% single polypropylene fiber is shown in Figure 1. From this figure, it is seen that the load capacity drops significantly after the first crack. The low amount of fiber by volume added and the fibers' low elasticity modulus are factors in this behavior. Such a reduction can be observed even where the volumetric fiber percentage is 0.1%. [19].

Table 4. Physical properties of Polymer fibers [7]

Fiber Type	Specific Gravity (gr/cm^3)	Maximum Elongation (%)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)
Polypropylene	0.91	40 to 100	1.35 - 1.79	24.1 - 97.0
PVA	1.30	220.7	16.1	800
Polyethylene	0.95	3–4	10 - 22	2.9 - 5.1

Glass Fiber

Glass fibers; rigid, corrosion-resistant, flexible and lightweight materials [47]. It also does not react with other materials and is low cost. Because of these properties, it is widely used in industrial applications. Since glass fibers have high strength, defects on the fiber surface are both small in number and small in size [22].

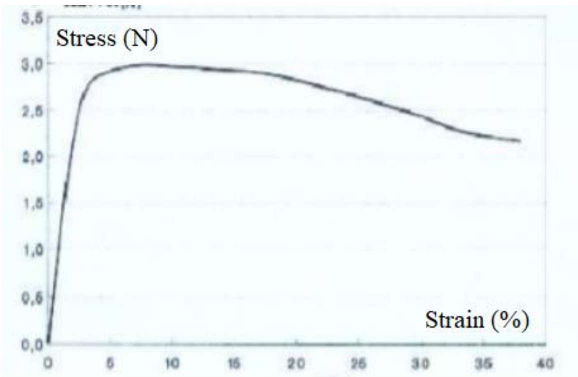

Figure 4. Stress and strain of a sample glass fiber [42]

Glass fibers have a high degree of hardness and are resistant to abrasion. Also, they are not very reactive products. In addition to these advantages, it also appears as flexible, lightweight and low-cost fibers. Glass fibers are divided into classes within themselves. Although all-glass fibers have similar elasticity modules, they have different strength values and their resistance against environmental influences is also different. E-type fibers are fibers with low tensile strength and low chemical resistance. S-type fibers have higher strength and higher cost. Other C-type fibers can be used in applications requiring corrosion resistance [48]. The physical properties of some glass fiber types are given in Table 5.

Table 5. Physical and mechanical properties of some glass fibers [8]

Glass Fiber Type	Modulus of Elasticity (GPa)	Tensile Strength (GPa)	Specific Gravity (gr / cm^3)
CEM-FİL	80	–	2,7
C	70	1.7-2.8	2.48
S	85	2.0-4.5	2.48
E	69-72	1.7-3.5	2.54

Basalt Fiber

The most important properties of these fibers are that they can be obtained easily [45]. However, it is a problem that these fibers tend to break down in an alkaline environment. To solve this problem, additives that reduce the alkalinity of concrete should be used. The oldest known natural fibers are straw and horse mane. Other natural fibers used with Portland cement consist of fibers such as bamboo, coconut, sugarcane and wood [23]. Basalt is among the materials used recently to produce fabrics made of fibers and threads. Basalt fibers obtained by melting basalt rock at high temperatures are non-polluting, corrosion-resistant, insulating, and elastic. One of the first studies evaluating the effects of basalt fibers on improving concrete properties is Sim et al. (2005). Basalt fabric, on the other hand, appears as an alternative to carbon and synthetic fiber fabrics, which are similar products in the construction sector, and also, with its high mechanical properties, chemical resistance, sound and heat insulation properties, especially in the automotive sector, aviation, defense industry, shipping, etc. It is used in many sectors [24].

Table 6. Physical Properties of Basalt Fiber Concrete [25]

Fiber Type	Density (g/cm^3)	Maximum Elongation (%)	Modulus of Elasticity (GPa)	Tensile Strength (GPa)
Basalt Fiber	2.67	3.15	85–87	2.8–3.1

Basalt fiber reinforcement produced in the form of steel used in reinforced concrete structures using basalt fibers and epoxy resin is also one of the products used to reinforce steel in some structural elements in many countries, especially in countries such as America, Russia and Ukraine. Fiber reinforcement constitutes an important alternative for reinforcement steel, especially in structural elements with corrosion risk. Basalt fiber reinforcement, which has higher strength than reinforcement steel, is approximately three times lighter than steel reinforcement. At the same time, the thermal expansion coefficient is very close to the expansion coefficient of concrete. Considering its high resistance to alkali reactions, it has the potential to be an alternative to reinforcing steel in many areas [26].

Carbon Fiber

Advantages of carbon fibers: available in many shapes and sizes with a wide variety of features, elasticity module too high, very high strength, very low density, good thermal stability in the absence of oxygen (O_2), very high thermal conductivity, which gives good properties to fatigue, low coefficient of thermal expansion, excellent creep resistance, good chemical resistance, low electrical resistance.

Disadvantages of carbon fiber; ıts cost is relatively high, but prices drop over time, low stress leading to fracture, compressive strength less than tensile strength and does not give improved compressive properties to more significant diameter fiber, low impact resistance, it is electrically conductive. It does not cause damage to electrical systems. Care required when handling carbon fiber oxidizes at temperatures above 450 °C, anisotropic, with different characteristics in axial and transverse directions.

Table 7. Physical Properties of Carbon Fiber [44]

Fiber Type	Density (g/cm^3)	Elastic Module/Density Ratio (mm^2/s^2)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)
Carbon Fiber	1,8-2,2	130-380	240-830	2200-5600

3. Fiber Reinforced Concrete Properties

Steel fiber reinforced concrete has high energy absorption capacity, impact and fatigue resistance. The steel fiber reinforcement makes the composite mechanics completely different [27].

In the case of steel fiber reinforced concrete, the crack zone stresses are carried through the fibers after the first crack formation. Some of these stresses are carried by the fiber itself, and some of these stresses are transferred to the solid regions of the matrix by acting as bridges. The energy required for the formation of the first crack in the fibrous concrete and the crack's growth is very high compared to the fibreless concrete [28].

Mechanical properties of steel fiber concrete are directly related to fiber length, shape, a percentage in concrete, slenderness ratio, type and quantity of cement, size of sample, shape, preparation methods, water/cement ratio, type of aggregate used and grain strength.

The effect of steel fibers on the compressive strength of concrete is not much. The increase in compressive strength of concrete by steel fibers rarely exceeds 25% [29].

It is the low performance of thin concrete against design which is its greatest weakness. For this reason, fiber reinforcement mainly increases the high deformation and tensile strength of concrete [30].

Composites are subjected to flexural loads in most cases. In all reinforced concrete cases, the increase in bending strength is higher than compressive and splitting tensile strength. The most important parameters affecting the flexural strength are the type, length, geometry, percentage of the volume, the structure of the matrix and sample dimensions. The increase in fiber ratio increases bending tensile, splitting tensile stresses, and makes the most difference in toughness [31].

Polypropylene fibers are the fibers that are used with concrete in polymer fibers and give the best results in polypropylene fiber reinforced concrete, splitting tensile strength increases. In contrast, the compressive strength and elasticity modules do not change much. Synthetic fibers are often used to improve fresh concrete properties in high-performance concrete [32].

In high-performance concretes, superplasticizers minimize the water/cement ratio. Also, thinner materials are used to reduce the void rate in concrete. Examples of these fine materials are silica fume. Silica fume is a very fine-grained material. This fine-grained structure retains mixed water in the concrete and does not allow sweating. Retention of most of the mixed water will cause the plastic shrinkage to change shape in the concrete. The addition of synthetic fibers to the concrete prevents shrinkage cracks and contributes to the concrete. Polypropylene and polyester fibers are among the most widely used polymer fibers. Also, polyolefin-based polymer fibers have been used in recent years. Polyolefin competes with other polymer fibers with its high modulus of elasticity, alkali resistance and improved mechanical behavior in concrete [33].

Nylon fiber reinforced concrete is a type of fiber-reinforced concrete developed by American Army Engineers in the 1960s to construct military structures resistant to blasting effects.

In the experimental studies, it was observed that the impact strengths of the concretes containing 0.5% by volume nylon fiber were approximately five times higher than those of plain concrete. It was observed that impact strength values of nylon fiber reinforced concrete with a fiber volume ratio of 1% were approximately 17 times higher than that of plain concrete [34].

In the experimental studies conducted on compressive strength and tensile strength of nylon fiber reinforced concrete, it was observed that nylon fibers did not cause a significant increase in compressive strength and tensile strength of splitting [35].

Regarding the tensile strength of nylon fiber reinforced concrete, some researchers have observed increased values, while others have not observed any significant increase or a slight increase. Therefore, there are conflicting results in the relevant publications on the tensile strength of flexural of nylon fiber reinforced concrete. This is because nylon has a high water absorption capability. Because if the water absorbed from the concrete mixing water does not leave enough water for cement hydration in the region around the fiber or if the fibers form a separating layer in the cement paste, this region becomes a defective region. Therefore, bending strength and compressive strength is low. However, it still increases the energy absorption capacity of concrete [36].

Glass fiber concretes are fibrous composites formed by mixing Portland cement, fine aggregate, alkali resistant glass fibers and specific additives. Glass fiber composites are flexible and have high impact resistance. The concrete's flexibility and low weight are encountered in many exterior and design applications [37].

Initially, alkali glass was used in the production of glass fibers. Thereupon, silicate glasses with a low alkali ratio were produced. These are called E-glass. Although E-glasses are used in many industries, they are not used frequently in the construction sector due to the alkali effect of concrete [38].

4. Fields of Use of Fiber Reinforced Concrete

Fiber composites are widely encountered in both industrial and construction sectors. Not every fiber will be compatible with all kinds of matrices, and not every fiber composite will be available in every application. Therefore, each different fiber composite is used in various application areas [39].

The use of fiber-reinforced concrete varies depending on the structure of the fibrous material. Steel fibers are primarily used in industrial facilities and highway pavements, bridge stands and piled floors, airport runways, explosion hazard buildings, hydraulic constructions with cavitation loads, tunnel and gallery constructions. Due to its high ductility and high tensile strength, steel fibers can be used in earthquake-resistant structures, sprayed concrete in tunnels, precast elements, road and safety structures.

On the other hand, synthetic fibers increase early plastic shrinkage and toughness of concrete and absorb the water in the concrete and prevent the water from getting away from the concrete [40].

Also, polymer fibers have started to replace steel fibers in shotcrete technology in recent years. This is because steel fiber is an abrasive material and can permanently damage shotcrete equipment. Polymer fibers, which are encouraged to be used more, appear to develop further with technology and leave the steel fibers behind. Glass fiber concretes are used frequently for exterior cladding by taking advantage of their lightweight and good workability. Polypropylene fibers have many applications. These fibers are mostly used in concrete road superstructures, industrial floors, shotcrete applications, airports, fire-resistant concrete structures, concrete pipes and military security structures [41].

On the other hand, glass fiber reinforced concrete is widely used in building facades, roofing, tribune elements, pipes and sound insulation walls due to their lightweight and good processing.

Table 8. Application areas of various fiber types [42]

Fiber Type	Applications
Glass	Precast panels, curtain wall coverings, sewer pipes, thin concrete roofs and plaster of concrete blocks.
Steel	Porous concretes used in roof applications, pavements, bridge slabs, fire-resistant elements, concrete pipes, airports, wind-resistant structures, tunnel coatings, ship keels.
Polypropyle	Basic scraping, prestressed piles, cladding panels, walkways, scaffolding

ne, nylon	elements of marinas, road patches, coating of large diameter underwater pipes.
Asbestos	Sheet metal pipes, sheets, fire-resistant materials and insulation materials, sewer pipes, corrugated and flat roof sheets, wall coverings.
Carbon	Wavy shaped roof covering elements, single or double layers of thin membrane structures, hulls, scaffolding boards.
Basalt Fiber	It can be applied to cement concrete in roads, bridges, airport runways, dams and other projects. Basalt fiber can be used as thermal insulation composite material

5. Conclusion

In this study, fiber types used in fibrous concrete production and their usage areas are examined. The most important factors affecting the performance of fibrous concrete; fiber type, geometry, volumetric utilization ratio, slenderness ratio and homogeneous distribution in concrete.

Fiber composites are materials used in the production of concrete that change the properties of fresh or hardened concrete or mortar and do not harm concrete properties when used in sufficient amounts.

Fiber composites added to concrete include setting accelerator admixtures, air-entraining admixtures, admixtures that increase the resistance of concrete to chemicals. The most common of these are superplasticizers.

While increasing the strength of concrete, the reduced water/cement ratio and the frequent use of fine-grained materials have created the need for such an additive and made it necessary to develop day by day.

Also, the fiber used in fiber reinforced concrete, which is increasing in use in today's concrete technology, decreases the collapse value of fresh concrete and causes the fibers to agglomerate. This creates a defect in concrete and adversely affects its mechanical and durability properties. For this reason, superplasticizers have a major role in improving and protecting the mechanical and durability properties of concrete.

Especially thanks to the new generation plasticizers developed in recent years, the water/cement ratio in concrete has been attracted to very low amounts.

Competing Interest / Conflict of Interest

All financial and non-financial competing interests must be declared in this section.

If you do not have any competing interests, please state "The authors declare that they have no competing interests" in this section.

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