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# Influence of fibers on drying shrinkage in restrained concrete

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## HIGHLIGHTS

- Fibers do not have any considerable effect on compressive strength of the concretes.
- The drying shrinkage strength was highly dependent on fibers' modules of elasticity.
- The physical properties of fibers have direct effects on reducing the cracking width.
- The steel fibers showed the best performance due to their hook-shaped tail.
- Polypropylene fibers also showed better performance in preventing crack development.

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## ABSTRACT

Drying shrinkage cracks mainly start to develop at the exposed surface of the concrete elements due to the shrinkage strain caused by self-desiccation. For the purpose of controlling drying shrinkage cracks additions and fibers are used in fresh concretes in order to provide high early age mechanical capacity for moderating the crack development. The purpose of this study is to evaluate the performance of using different fibers in reducing the drying shrinkage and cracking under restrained conditions. To investigate the effectiveness of using both polymeric and metal fibers in concrete, three different types of fibers, including polypropylene fiber, polyolefin fibers, and steel fiber were used in this study. The maximum drying shrinkage strength was highly dependent on fibers' module of elasticity. The average length cracking and its pattern in fiber reinforced concretes were different than control concrete. The physical properties of fibers have direct effects on reducing the cracking width.



## 1. Introduction

Thin concrete structural elements with the higher surface to volume ratios, such as slabs, pavements, bridge decks, concrete industrial floor, tunnel concrete covers and concrete surface restorations, are generally susceptible to drying shrinkage in regions with warm and bluster weather conditions. In normal concretes with a water-cement ratio of higher than 0.45, drying shrinkage is considered the most significant reason for cracking at early ages [1]. Drying shrinkage starts after moist curing, depending on concrete properties (mixture design, concrete placement and curing methods), shape and ambient conditions (temperature, relative moisture, wind velocity) [2]. As a result, concrete elements with highly exposed surfaces (like slabs and prefabricated panels) are highly susceptible to adverse structural deteriorations in harsh environments, which can also be exacerbated by the drying wind [3]. However, it can be observed from the former studies that an addition of sufficient fibers would result in a great reduction of cracking followed by less shrinkage in concretes [4].

In controlling drying shrinkage cracks, two methods are recommended: measuring the water loss from the exposed surfaces of the elements and using connecting concrete components, which can lead to restraining cracks propagation. The first method involves monitoring the curing conditions and the water content controlling procedure; it also uses the shrinkage reducing additives in order to reduce tensile stresses. The second method consists of

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using concrete additives and fibers in fresh concretes. The purpose is to provide high early age mechanical capacity for moderating the crack development in a way that the presence of fibers would cause more cracks but with small dimensions. It may transfer tensile stresses by reducing stress concentration [5].

The orientation of cracks in standard concretes does not follow any certain direction, and cracks only extend vertically through each other from place to place. However, three types of strength (compressive, shearing and tensile) can be considered for crack development. Hence, by an addition of fibers into concrete regardless of other constituent components, two main parallel and perpendicular orientations can be observed between fibers and cracks. In the vertical case, fibers generally act as a stitch between the two faces of the crack, transferring the load by controlling high deflections of shrinkage, and increasing the tensile, and bending strength of concrete due to their high adhesive properties [6].

## 2. Literature review

Fiber reinforced concrete is a composite material in which tensile and bending strength would increase greatly by adding reinforcing fibers to the concrete mix. This composite mixture has integrity and appropriate cohesion, which allows the concrete to act as a ductile material to be used for producing full curvy resistance surfaces. One of fiber reinforced concrete's benefits is great energy absorption capacity. History of this technology includes the application of straw in building constructions [7,8]. Fiber reinforced concrete can be introduced as the advanced model of this technology in which the straw and clay are both substituted by natural or synthetic fibers and cement, respectively. Nowadays, the use of glass fiber, polypropylene, steel, carbon, and the production of different types of composite has become possible to utilize in several industrial applications, and implementing them in the developed world is highly appealing to the civil construction sectors [9–11]. Fiber reinforced concretes have sufficient properties, such as high ductility, high strength, great energy absorption capacity and resistance against cracking, all of which make them appropriate for numerous applications [12]. For instance, in the construction of industrial floors, this type of concrete can be used instead of general reinforced concrete, since it is considered one of the best materials used in resistant buildings that are resistant against impact loads such as shelters and storage warehouses for explosives [13]. Hence, it can be properly used in the airport runways construction. There are also some other applications for this type of concrete such as producing prefabricated segments like sunshade panels or shotcrete on curved surfaces like tunnel walls [14].

Generally, in structural applications, steel fibers can be used supplementary to steel bars by inhibiting the cracks, improving concrete resistance to impact loads, fatigue, shrinkage and thermal stresses [15]. High-strength concrete technology can be considered a breakthrough in concrete structures construction. In hardened concrete, strength and durability are regarded as the major factors. Some studies reported that by increasing the compressive strength, the concrete becomes more brittle [16,17]. While, groups of researchers indicated that the addition of fibers might significantly enhance the mechanical properties of concrete such as ductility and residual load-bearing capacity (toughness) [18–20]. The addition of steel fibers up to 1 percent (by volume) into plain concrete was reported to be useful for enhancing the splitting tensile strength up to 79% and increasing the average residual strength [21].

In dry weather conditions, while there is a difference between relative humidity in the concrete and ambient air, drying shrinkage would take place. While the saturated mixture is exposed to an environment with lower humidity, shrinkage would take place due to water loss by evaporation from its large capillary pores, which is followed by a reduction in volume [22,23]. In high-strength concretes with low moisture content, drying and autogenous shrinkages are considered dangerous threats due to their cracking potential. In normal concretes with general strength (lower than 34 MPa at the age of 28 days), autogenous shrinkage is less important than drying shrinkage [24]. The cracking in the concrete might be induced due to imposed forces of shrinkage caused by internal or external restraints under the certain boundary conditions. Since concrete structures are mainly restrained by the ground, foundation, bars, or other structural members, several tensile stresses would emerge in concrete, which can cause cracking by exceeding the concrete tensile strength value [25]. Thin members with large surfaces are susceptible to this type of cracking. The cracking time is mainly related to amount of the concrete desiccation, which is directly dependent on environmental conditions [26,27]. Mostly, cracking starts to take place on the surface of the concrete because drying starts at the surface and continues deeper [28]. Cracks which occur after hardening are mainly induced from drying shrinkage.

A group of researchers studied the shrinkage of cement mortar matrices reinforced with cellulose fibers, short sisal and coconut fibers. The influence of curing method, mix proportions and partial replacement of ordinary Portland cement (OPC) by ground granulated blast-furnace slag and silica fume on the drying shrinkage of VFRC was also investigated. Free plastic shrinkage is significantly reduced by the inclusion of 0.2% volume fraction of sisal fibers in cement mortar. Also, fiber delays the initial cracking for restrained plastic shrinkage and effectively controls crack development at the early age of composite [29].

Surface layer drying and concrete reduction in volume and strength against volumetric changes of the lower layers would result in cracking in the surfaces. Generally, initial cracks appear in the corner of slabs without any specific patterns due to the fact that drying happens in three directions. The width of this crack is dependent on the amount of drying in concrete, the geometry of the member and also the distance between external restraints. For instance, in slabs located on the ground with a longer dimension than other ones, some cracks take place mainly in the middle, and some other ones occur diagonally in the corners. One or two-way slabs also follow the same trend. Hence, in the corner of the opening parts of the slabs, cracking is observed, too [30,31].

The main reason for drying shrinkage is water evaporation from capillary pores existing in hydrated cement paste through the surface of the concrete, which is exposed to an environment with low relative humidity. Available water in the capillary pores, which is formally called free water, would be held by capillary forces as a function of pore size in diameter. In fact, the smaller the pores in diameter, the more powerful the capillary force would be. By the time the tensile stress caused by capillary force in hydrated cement paste exceeds the local tensile strength, cracking would happen [32].

Some studies have been conducted to evaluate the effects of adding fibers on drying shrinkage of concrete. The addition of steel fibers into concrete was evaluated under restraint condition to simulate the role of steel reinforcement and to obtain the initial cracking time. Based on the results, some useful prediction models were proposed [17]. It has been proven that the addition of steel fibers up to 3 Vol.% can gradually improve the ultimate load and elastic modulus of ultra-high performance fiber reinforced concrete. It has also been observed that the steel fibers can only decrease the early shrinkage and cracking due to the bridging effect, and it has nothing important to do with concrete cracking after hardening [33,34]. A few studied concerned with the effects of using polypropylene fiber on drying shrinkage of concrete