



Shrinkage Behavior of Conventional and Nonconventional Concrete: A Review

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Abstract

Concrete is indeed one of the most consumed construction materials all over the world. In spite of that, its behavior towards absolute volume change is still faced with uncertainties in terms of chemical and physical reactions at different stages of its life span, starting from the early time of hydration process, which depends on various factors including water/cement ratio, concrete proportioning and surrounding environmental conditions. This interest in understanding and defining the different types of shrinkage and the factors impacting each one is driven by the importance of these volumetric variations in determining the concrete permeability, which ultimately controls its durability. Many studies have shown that the total prevention of concrete from undergoing shrinkage is impractical. However, different practices have been used to control various types of shrinkage in concrete and limit its magnitude. This paper provides a detailed review of the major and latest findings regarding concrete shrinkage types, influencing parameters, and their impacts on concrete properties. Also, it discusses the efficiency of the available chemical and mineral admixtures in controlling the shrinkage of concrete.

Keywords: Shrinkage; Autogenous Shrinkage; Plastic Shrinkage; Crack; Conventional Concrete; Nonconventional Concrete.

1. Introduction

Through its lifespan, concrete undergoes several physical and chemical changes, which normally led to shrinkage of concrete, especially at an early age, when the initial hydration processes take place [1]. The shrinkage of concrete at an early stage of hardening may lead to the initial formation of cracks that vary in shape and size and depends on the concrete constituents and surrounding conditions, including temperature and/or the moisture state that may lead to volumetric deformation [2, 3]. Shrinkage cracking starts to form while the concrete is still in the plastic state and continues through the hardened state due to the applied stress on concrete particles. These stresses are created as a result of the consumption of the mixing water existed within the cement paste, which takes place after losing the water available within the pores [4]. The shrinkage and formation of cracks within the concrete texture are nearly inevitable. Generally, cracks occur when the tensile stress in brittle material exceeds its rupture strength [5]. However, the interaction of the factors and parameters affecting the development and propagation of cracks in concrete makes it difficult to isolate the effect of each parameter alone [6]. The main nonlinear phenomena that govern the shrinking behavior of concrete at early-age may include the evolution of stiffness properties, development of thermal strains, creep, and cracks formation [7].

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These concerns in the making conventional concrete led not only to higher demand in producing nonconventional concretes with higher performance in terms of strength but also to a more durable mixture that provides a better shrinkage resistance. Currently, many studies, numerically or/and experimentally, in recent years have focused on the shrinkage behavior of concrete and the governing factors impacting different types of shrinkage, including chemical shrinkage, plastic shrinkage, drying shrinkage, carbonation shrinkage, and thermal shrinkage. The findings of these studies showed that the shrinkage properties are affected by the environmental conditions, aggregate type, cementitious materials, water/cement ratio, and chemical admixtures. Some cementitious replacements, such as fly ash, proved to improve the resistance of different types of concrete against shrinkage and development of cracks [8-10]. The use of recycled materials and polymeric waste has become a trend due to environmental consideration. Different shrinkage reducing admixtures are used in concrete to enhance its shrinkage properties. With all these factors on shrinkage behavior, it is necessary to provide a detailed review paper that collects and discusses the recent findings in the literature. Thus, this paper is intended to summarize and compare previous investigations on the shrinkage behavior of concrete.

Table 1. Research methodology

Databases Searched	Google Scholar, Scopus, Science Direct, Web of science
Some keywords used	Shrinkage, cracking of concrete, conventional, and nonconventional concrete.
Year range	1988–2020
Language	English
Types of publications covered	Original research articles, conference papers, review papers, reports
Criteria used to produce the preliminary database for initial review	<ul style="list-style-type: none"> • Most publications showing under the search results, using the above selection criteria, up to the last page of the search index, were downloaded. • A database was created in excel using the following: paper title, year published, shrinkage type, remarks of the study.
Criteria used to shortlist the final database for a detailed, comprehensive review that is presented in this manuscript	<ul style="list-style-type: none"> • Priority was given to a journal article where various authors reported similar studies in a journal and conference paper.

2. Types of Shrinkage

Various types of shrinkage can occur over the mixture's maturity process and life span, which are classified as autogenous, plastic, drying, carbonation, and thermal.

2.1. Autogenous Shrinkage

Autogenous shrinkage is mainly caused by the chemical contraction of cement, which takes place during the hydration process due to the consumption of the internal moisture content from the concrete subsurface [11]. ACI 116R describes the autogenous shrinkage as the "change in volume caused by continuous cement hydration, excluding the effects of applied load and change in either thermal condition or moisture content" [12]. Autogenous shrinkage cracking usually appears in the first few hours after concrete casting as it starts to harden. The autogenous shrinkage increases with decreasing water/cement (w/c) ratio [13-15]. Therefore, it is a concerning issue in high-strength and/or high-performance concrete mixtures [1, 3]. In concrete with a higher w/c, there can be a form of early cracking wherein the cracks are located directly over the steel [16]. The autogenous shrinkage strain needs to be controlled in the first 24 hr to avoid reaching a high value and subsequent premature cracks. The crucial period through which the highest tensile stresses occurred was recorded is after 24 to 48 hr from the setting time, and thus, proper autogenous shrinkage prevention is needed [17]. In earlier studies, autogenous shrinkage was not the main concern as it was noted to occur only at a meager w/c ratio away from the allowed practical ranges for standard concrete mixes at that time. However, usage of admixtures, as superplasticizers or silica fume, the concrete resistance to such a shrinkage noticed to be reduced [1]. On the other hand, increasing the aggregate content in the mixture reduces its autogenous shrinkage, as a result of the decrease in the total volume of the cement paste and the high volume stability of aggregate [13].

2.2. Plastic Shrinkage

This type refers to the shrinkage that occurs while the concrete is still in its plastic state, and the concrete constituents are weakly bonded. It happens when the rate of losing the mixture's water is higher than the rate of bleeding at the surface before the final setting [18, 19]. As the surface of concrete dries, a complex menisci process shapes the liquid between the particles at and near the surface, and as a result of capillary action; a tensile capillary pressure within the liquid phase is created, which eventually cause the development of plastic shrinkage as the pressure increases [19]. The content of cementitious materials used in a concrete mix, w/c ratio, and the surrounding environment are the main parameters that control plastic shrinkage cracking. The incorporation of higher fine materials within the mixture, such as silica fume, slag, or fly ash, will delay the final set of concrete and make the

cracking more likely to happen.

In the case of hot weather, low humidity, and high-speed wind, plastic shrinkage is highly expected [20, 21]. Its cracks usually take a linear shape, with no definite pattern and range from a few centimeters to a few meters in length. Typically, they weaken the concrete structure and allow the diffusion of moisture and other aggressive species into the concrete mass unless they are very shallow and narrow, which eventually cause the formation of reinforcement corrosion and lead to concrete failure [21]. Reinforcing concrete with fibers reduces the width of the cracks developed by plastic shrinkage where the higher the fiber volume, the smaller the width of the crack is achieved, in spite this additive increases the rate and magnitude of evaporation [22].

2.3. Drying Shrinkage

Similarly, this type describes the loss of water from evaporation; it usually starts in the first weeks and continues for months to develop [23]. The ambient conditions are the main factor affecting the rate of drying shrinkages, such as the relative humidity and temperature surrounding the concrete. Furthermore, the concrete characteristics, including w/c ratio, cement type, aggregate, and incorporating admixtures influence the value of drying shrinkage significantly [11]. Hence, it is recommended to reduce the w/c ratio in the mixture to a minimum amount with the usage of superplasticizer, which can decrease the intensity of drying shrinkage [9, 10]. Other measures to improve the behavior against drying shrinkage can be done by utilizing low heat cement or shrinkage cement. It can be achieved by modifying the w/c ratio and reducing the fine materials to the amount that can just produce adequate workability and finishing characteristics to prolong the time of moisture curing, setting contraction joints (temporary or permanent). Another technique is by using chemical admixtures such as a water reducer or shrinkage reducing admixtures. On the other hand, cracking can be controlled by good workmanship, proper proportioning of the mixture, and sufficient jointing performed soon after hardening [16].

2.4. Carbonation Shrinkage

The carbonation shrinkage is known to have the lesser severe consequences of carbonation on cementitious composites. It reorganizes the concrete microstructure, reduces concrete volume, declines paradoxical in the porosity, and varies differential shrinkage between the surface and the bulk of concrete [24]. Besides, drying and autogenous shrinkage, the concrete is also subjected to volume reductions due to the carbonation reactions [1]. These changes can increase the carbonation level, due to the formation of surface cracks, and thus reduce the initiation time preceding the corrosion of the steel reinforcement and is more severe for highly porous cementitious materials [24].

2.5. Thermal Shrinkage

The thermal shrinkage is swelling and contraction of concrete due to the stresses developed by the heat generated from the hydration process and the changes in temperature between the concrete and the surrounding conditions. This concrete heating process is also called thermal expansion in the early stage after casting and typically occurs in the first 12 hours. In general, if an even temperature with a gradient exists along the cross-section of concrete while it starts to cool down and reaches thermal equilibrium between its layers, a thermal strain is formed. This strain may spread cracks depending on the elasticity of thermal expansion and the size of the concrete section [3]. At later stages, thermal shrinkage will be developed due to the fluctuation in the concrete surface temperature and the ambient one, which could vary significantly between the inner and outer surface of the concrete section. Often, control joints are used to limit the thermal cracking developed by thermal expansions and volume change. Thermal stress is affected by many factors, including w/c ratio, aggregate type, a daily variation of temperature during construction, location of the structure, size of the structural members, construction quality. In addition, the formworks being used has a little impact on thermal stress [25].

3. Impacts of Aggregate Type on Shrinkage Behavior

Actually, as the content of coarse aggregate in concrete increases, its autogenous and drying shrinkage decrease at a given age [26]. Through the literature, various types of aggregate were used in a concreting application, which influences the shrinkage and cracking properties of concrete. This section discusses the findings of previous researches on the influence of aggregate type on the shrinkage of concrete.

3.1. Lightweight Aggregate Concrete

The aggregates with over bulk density than the common aggregates are defined as lightweight aggregates, and they can be produced from gasification of slag and/or fly ash with or without the addition of other waste materials. Lightweight aggregate can produce concretes with high compressive strength for different uses. It enhances the shrinkage properties as studies shown, the autogenous shrinkage is reduced when lightweight aggregates are used in concrete. Lightweight aggregates have a porous texture that tends to absorb and store water, and this water provides a

moisture source for the internal curing processes after concrete casting [17, 27, 28]. Using presoaked lightweight aggregate was reported to change the autogenous deformation type in the concrete from shrinkage to swelling [29]. In other respects, lightweight aggregate concrete showed less drying shrinkage in comparison to normal aggregate concrete due to the small shrinkage that lightweight aggregate exhibits [30, 31].

3.2. Recycled Aggregate Concrete

The use of recycled materials has become a trend in all sectors and the less the construction sector, and the use of recycled aggregates saves natural aggregates resources, including stones and rocks. The term recycled aggregate usually refers to demolition waste. However, the use of the recycled aggregates has an impact on the shrinkage properties of concrete as, adding more recycled aggregate instead of the natural one to concrete increases its drying shrinkage [32]. It was noted that recycled aggregate concrete reaches almost its full shrinkage within the first 28 days, considering the conservative ambient conditions and keeps increasing moderately up to 60 days, after which it starts to balance progressively. While under standard curing conditions, it shrinks in a fluctuation manner. Throughout the entire age, samples did not show considerable shrinkage. As the ambient temperature rises, the shrinkage increases at low relative humidity [33]. The shrinkage strain at 28 days of recycled coarse concrete is higher than the conventional aggregate concrete [34, 35]. Recycled aggregate concrete with a replacement of 20% had similar shrinkage to normal concrete at an early age and a 4% higher within the first 6 months. A 50% replacement resulted in around 10% higher shrinkage than that in normal concrete, while 100% replacement caused about 70% greater shrinkage compared to the control mixture concrete for the first six months [35, 36]. The inclusion of superplasticizer had the best effect on the carbonation depth, which is the most important property that is affected by construction and demolition waste recycled aggregate. In contrast, the chloride ingress had the lowest impact. The composition of the recycled aggregates affects the shrinkage more than the size of the aggregate fraction replaced. Superplasticizers does not enhance the shrinkage resistance of concrete with recycled aggregates sourced from construction and demolition wastes as that of recycled aggregates sourced from concrete [37]. In general, the curing age plays a key role in controlling the shrinkage of recycled aggregate concrete.

3.3. Polymeric Aggregate Concrete

Polystyrene aggregate is used in the production of lightweight concrete, which has been increasingly used in the construction world, considering that polystyrene aggregates produce low density concretes. Polystyrene aggregates showed higher shrinkage rates compared to plain concrete at an early age, and with the shrinkage increases as polystyrene aggregate content increases [38]. Similarly, the use of tire aggregate in concrete showed a higher shrinkage in comparison to normal reinforced concrete, and this can be attributed to the high w/c ratios of tire aggregate and to the low capacity of tire aggregate in restraining the shrinkage of the cement paste. The increase in aggregate size due to the use of tire aggregate increased the shrinkage [39]. Furthermore, using aggregate submerged in polymer latex or water repellent after drying it can decrease the shrinkage by almost 13% [42].

3.4. Other Types of Aggregate

For other types of aggregates produced from rocks and stones used in concrete, the shrinkage properties could vary depending on the condition and sizes. For instance, using shale instead of quartzite aggregate in concrete reduces its shrinkage. However, as the ratio of shale (either in sand or stone form) in aggregate gets higher, the long-term drying shrinkage increases proportionally [40]. Limestone aggregate concrete exhibited better performance against drying shrinkage compared to sandstone aggregate concrete due to the change in volume of the tested aggregates [41]. Granite rock is highly affected by its initial moisture condition, where initially wet granite rock showed higher ultimate shrinkage with shorter shrinkage half-time. Initially, dry granite rock showed lower ultimate shrinkage but longer shrinkage half-time. The addition of pre-dried aggregate can lower the shrinkage to almost 7%. Furthermore, using aggregate submerged in polymer latex or water repellent after drying it can decrease the shrinkage by almost 13% [42]. Concrete prepared with tailing sand and tailing stone in class 30 or class 60 exhibited lower drying shrinkage compared to natural sand and common crushed limestone. However, the drying shrinkage of concrete of class 60 was higher than that in class 30, regardless of whether tailing sand, tailing stone, natural sand, or common crushed limestone is used [43].

4. Influence of Supplementary Cementitious Materials on Shrinkage of Concrete

Ternary cementitious components, including ground granulated blast furnace slag and pozzolanic materials, are widely used in construction as a partial replacement of cement. These materials are also known to increase the mechanical and durable performance of concrete. However, alkali-activated slag concrete experienced higher total shrinkage than conventional concrete [44]. Due to the high chemical shrinkage, fine pore structure, and particle shape of blast furnace slag, the autogenous shrinkage of granulated blast furnace slag concrete increases with rising replacement level of blast furnace slag at the same w/c compared to plain concrete [45]. Under appropriate curing

conditions, the shrinkage of alkali-activated slag concrete is slightly reduced with shrinkage reducing agents [44]. Also, the use of blast furnace slag coarse aggregate instead of normal coarse aggregate in alkali-activated slag concrete was found to decrease the drying shrinkage remarkably [44]. Furthermore, the replacement of slag up to 15% increased the drying shrinkage. However, the use of a higher percentage resulted in decreasing the shrinkage [46-49].

While for concrete with 60% slag, cement replacement by volume showed a 35% reduction in shrinkage at 30 days and a 19% reduction in shrinkage at one year under 14 days of curing in comparison to plain cement mixes. Using slag cement with porous limestone coarse aggregate with water internally cured showed a more significant decrease in free shrinkage in comparison to plain cement mixes that have low absorption coarse aggregate [47]. Adding silica fume to concrete increased the plastic and drying shrinkage strain. Furthermore, silica fume cement concrete showed a 69% increment in plastic shrinkage than conventional concrete. Whereas, short-term shrinkage was higher in silica fume cement concrete, and the long-term was somewhat similar in both silica fume cement concrete and normal concrete [48, 50]. As concluded by Zhang et al. under 65% relative humidity and seven days curing, a w/c ratio in the range of 0.26 to 0.35 and a silica fume in the range of 0% to 10% of cement by mass, exhibited a higher total shrinkage due to the greater autogenous shrinkage with no effect on drying shrinkage. Reducing the w/c ratio from 0.35 to 0.30 in ordinary concrete with 0% silica fume resulted in a significant increase in autogenous shrinkage from 40 to 180 micro strains at 98 days. While in the case of concrete with silica fume up to 10% by the weight of cement, the autogenous shrinkage up to 98 days, Figure 1, was relatively high even at a w/c ratio of 0.35 (>200 micro strains) [14].

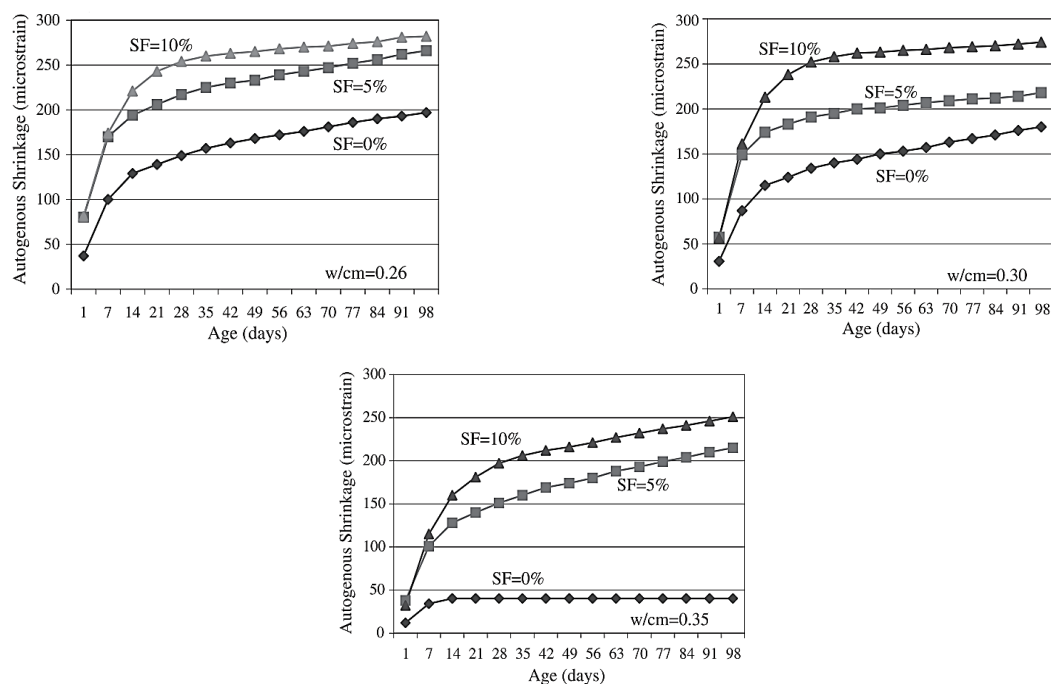


Figure 1. Effect of silica fume on the autogenous shrinkage of concrete [14]

The use of other supplementary materials such as fly ash shows a positive impact on concrete shrinkage behavior, whereas the content of fly ash increases, the drying shrinkage decreases [51]. A fly ash replacement beyond 10% will reduce the shrinkage considerably [52]. Using fly ash of 50% replacement or less resulted in decreasing the free drying shrinkage [9, 52]. The effect of fly ash in concrete has a higher on the drying shrinkage when wet curing time is reduced compared to ground granulated blast furnace slag and normal concrete [49]. Using fly ash and slag in concrete enhances the workability and reduces the plastic shrinkage area using 20% of fly ash and slag [53]. Micro silica and slag cement exhibited less drying shrinkage compared to the fly ash cement mixture [54]. Fly ash and iron ore tailing powder in concrete showed similar behavior in terms of autogenous shrinkage. As the replacement increased, the autogenous shrinkage reduced proportionally at the same water/binder [55]. Some other cement replacement fine materials can affect the shrinking property of concrete, such as using limestone powder in concrete showed less or equal drying shrinkage conventional cement concrete [56]. The concrete with 10% limestone powder showed moderately less drying shrinkage compared to traditional concrete of cement, while for 20% and 30% of limestone powder, drying shrinkage was less than in conventional cement concrete. This result is due to that drying shrinkage reduces as the water/binder ratio reduces and that as the cement content replaced by limestone powder increases, lesser hydration products and so smaller drying shrinkage [56, 57]. The addition of limestone powder to concrete decreases the autogenous shrinkage [58]. Replacement of cement paste by fine limestone exhibited a reduction in ultimate shrinkage strain by almost 28% [59]. Also, drying shrinkage of the concrete with 10% limestone powder is slightly smaller than that of plain cement concrete at 5 years, while that containing 20 and 30% limestone powder showed lower drying shrinkage as shown in Figure 2.

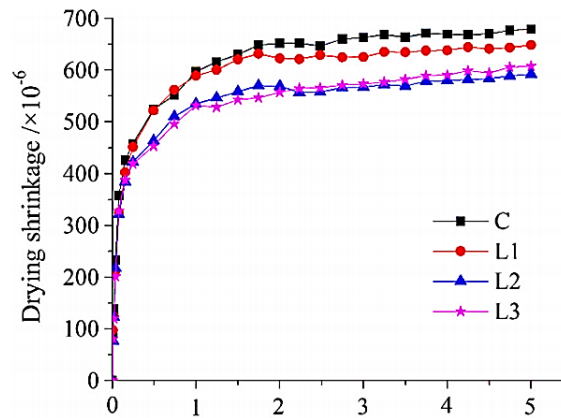


Figure 2. Drying shrinkage of concrete with 10%) limestone powder (L1), 20% (L2), and 30% (L3) [56]

Belferrag et al. [60] studied the effects of using river sand instead of dune sand on the drying shrinkage of concrete. They found that the concrete mixture containing 40% dune sand and 60% of river sand provides a remarkably enhanced performance than using 100% dune sand in concrete, as shown in Figure 3. The replacement of cement by metakaolin from 5% to 20%, decrease the drying shrinkage of concrete considerably. However, beyond 20% replacement, the effect of metakaolin was reversed, and shrinkage increased [61, 62]. Furthermore, using 100% glass cullet sand in concrete resulted in a 16% decrease of shrinkage, which can be attributed to near-zero porosity and water absorption characteristics by limiting the moisture movement from concrete to surroundings [63].

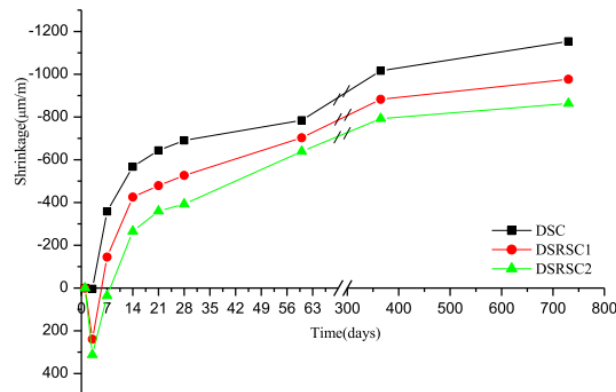


Figure 3. Drying shrinkage for the plain concrete with 100% dune sand (DSC), 0% dune sand and 50% river sand (DSRSC1), and 40% dune sand and 60% river sand (DSRSC2) [60]

5. Shrinkage Behavior of Various Concrete Mixtures

5.1. Plain Concrete with Admixtures

A study by Montani [64] has shown that using shrinkage reducing admixtures in plain concrete can result in decreasing the drying shrinkage by about 30%. Combining shrinkage reducing admixtures with pulverized fuel ash or slag leads to a reduced early age autogenous shrinkage [65]. Indeed, different water reducers were tested in terms of their influence on the resistance to plastic shrinkage, and all types of water reducer exhibited satisfactory performance. The polycarboxylate water reducer provided the best performance in comparison to wood calcium and naphthalene [66].

5.2. Self-Compacted Concrete

Previously, Craeye et al. [67] have studied the effect of w/c ratio on the autogenous shrinkage of self-compacting concrete. They concluded that using medium or high w/c ratio shows a great autogenous shrinkage on the first day. In addition, replacement of the total cement with limestone filler exhibits remarkable autogenous shrinkage. While increasing the paste, volume resulted in more shrinkage susceptibility, with only drying shrinkage affecting the paste and very low autogenous shrinkage. It was found that the restrained shrinkage increases along with the probability of cracking as the mineral admixture increases in the concrete mixture [68].

5.3. High-Strength Concrete

For concrete with higher strength, plastic shrinkage is the central consideration. Mora-Ruacho et al. [69] have studied the plastic shrinkage of both normal and high strength concretes and found that the cracking due to plastic

shrinkage is significant in high strength concrete and happens as fast as the exposure of surface starts. They concluded that the width of cracks reduces dramatically with the inclusion of hooked-ended steel fibers. Sicard et al. [70] reported that the drying shrinkage was reduced considerably by applying high levels of compressive stress to the specimen. Utilizing a w/c below 0.30 and adding 10% silica fume in the high-performance concrete mixture was found to prevent the carbonation shrinkage from taking place [71]. Adding some admixtures for high strength concrete has shown a positive impact on controlling types of shrinkage. The use of shrinkage reducing admixtures such as (polyoxyalkylene alkyl ether) effectively lowers the measured drying and plastic shrinkage value [8, 72]. As well, the autogenous shrinkage of high strength concrete was dropped using superabsorbent polymer. Whereas, incorporation of ground granulated blast furnace slag to internally cured high strength concrete exhibited higher autogenous shrinkage and increased with the increase of slag content [73].

5.4. Fiber Reinforced Concrete

Fibers are usually used in concrete to control cracking, and studies showed that fiber-reinforced mixes exhibited lower early age autogenous shrinkage compared to the control one. The early age autogenous shrinkage deformations decreased by using fiber of 0.38% by volume. Polypropylene fibers showed better behavior than hooked-end steel fibers in terms of early-age autogenous shrinkage. Fibers used in white cement concrete had a slight effect in terms of early-age autogenous shrinkage in comparison with other cement mixes, which have shown better effect [74]. Adding steel fibers decreases the free shrinkage of the conventional concrete beam by up to 30% for controlled curing conditions while it decreases the shrinkage at the lower half of the beam by about 30% in the case of uncontrolled curing conditions [75]. The drying shrinkage was reduced by the granulometric correction of dune sand and the inclusion of fibers. In general, the effect of introducing fibers on the shrinkage strain is inconstant. Adding fibers to concrete has a slight effect on its shrinkage if a meager aspect ratio of the fibers is used in the mixture [76]. The high-volume fraction of fibers reduces the drying shrinkage in concrete [60]. The drying and plastic shrinkage can be reduced by 1/3 when 0.4% polypropylene fibers are incorporated in the concrete mixture. The increase of fiber volume fraction decreases the total crack area, number of cracks, and maximum crack width.[77-79]. The inclusion of 0.3% of flax fiber (percentage by volume) showed a reduction in total cracks as 99.5% and 98.5% of maximum crack width in comparison to normal concrete. No considerable effect of fiber length was noticed on unrestrained plastic shrinkage strain or the cracking behavior [80]. The basalt fiber concrete with fiber ratio of 0.1% and length to diameter ratio between 800 and fiber ratio of 0.1% exhibited the best performance against plastic shrinkage and drying shrinkage [81]. Using polyethylene terephthalate fibers up to 0.25% by volume decrease the plastic shrinkage while using more than 0.25% has a slight effect on reducing the plastic shrinkage [82]. Moreover, the use of carbon nanotubes in concrete resulted in decreasing early shrinkage by 54% and long-term shrinkage by 15%. The low w/c ratio and high carbon nanotubes content led to the lowest reduction in the total shrinkage value [83].

5.5. Superabsorbent Polymer Concrete

The use of superabsorbent polymers (SAPs) has many unique characteristics and utilized widely in several applications, not only concrete technology, where it is used to improve the performance and long-term durability of concrete. Studies have shown that superabsorbent polymers impacted the shrinkage properties of concrete, especially with deducted internal curing water. Using pre-absorbed superabsorbent polymer resulted in decreasing the total shrinkage of concrete significantly. Furthermore, the inclusion of a superabsorbent polymer enhanced the carbonation resistance dramatically. While the pre-absorbed superabsorbent polymer deducted internal curing water from mixing water is added, the carbonation resistance improved considerably [84]. The autogenous shrinkage was decreased with the addition of superabsorbent polymer [85-87].

5.6. Recycled Polymers and Rubberized Concrete

Due to its environmental impact, the use of recycled wastes in construction has increased, but the use of some recycled polymers such as polyurethane wastes, which is a polymer composed of organic units joined by carbamate, has some negative impacts as drying shrinkage seems to increase when polyurethane waste content increase. However, with the use of other recycled polymers like polyvinyl chloride, aggregate drying shrinkage is reduced as the polyvinyl chloride volume increase, and when 15% of polyvinyl chloride aggregate were used, 50% of drying shrinkage was decreased [82]. Moreover, the addition of styrene-butadiene polymer in concrete showed no plastic shrinkage cracking. Furthermore, styrene-butadiene polymeric is used to resolve the shrinkage cracking caused by the rapid hydration heat produced by rapid hardening cement as it exhibited small length changes due to the low w/c ratio used. Besides, it has undergone lower shrinkage levels, effectively reduced cracking, as concluded by Won et al. [88]. For rubberized concrete, which is usually used for applications such as highways also in buildings as an earthquake shock-wave absorber by mixing recycled rubber crumb with concrete. The drying shrinkage of rubberized concrete was found to be influenced by the number of rubber particles in the concrete mixture with the more the rubber replacement ratio, the higher the measured drying shrinkage is expected. This observation is similar to the general behavior of

rubberized concrete in which the rubber contents have a negative influence on the mechanical properties of the produced concrete [89, 90]. These reductions are mainly attributed to the fact that rubber aggregates are weaker and more flexible than the natural ones [91]. On the other hand, pre-treating the rubber particles by NaOH solution resulted in a reduction in drying shrinkage [92, 93]. In addition, when less than 4 mm crumb rubber aggregate is used, the strain capacity is improved, resulting in increasing free shrinkage. This is attributed to the low stiffness aggregate introduced by rubber particles, which means less internal restraint and thus results in a more considerable change in the length due to the increase in shrinkage. Self-compacting rubberized concrete was found to provide better performance in terms of shrinkage as compared to the control mixture. Utilizing waste rubber particles was observed to improve the deformability of the mixture under pre-failure loads and to result in a lesser shrinkage [94]. The use of styrene-butadiene rubber with the copolymer (ethylene-vinyl acetate) in concrete resulted in a reduction of drying shrinkage as the polymer-cement ratio is increased [95].

5.7. Geopolymer Concrete

Geopolymer concrete is a new type of concrete that has zero Portland cement content. Geopolymer concrete can utilize several abandoned materials to create a strong binder that has superior properties as compared to ordinary cement concrete [96-98]. Geopolymer concrete uses an alkaline solution as an activating solution that largely influences its properties, including shrinkage [99, 100]. The drying shrinkage of fly ash-based geopolymer concrete exhibits deficient value as compared to ordinary concrete [101]. This fact occurs from the smaller pores size of the geopolymer binder, which tends to increase the resistance to diffusion, and a longer time is required for drying [102]. Contrary to this, some researchers have reported that the drying shrinkage of slag-based geopolymer concrete was higher than ordinary concrete [103]. Indeed, the shrinkage behavior of geopolymer concrete is not a function of the aluminosilicate source only but also the properties of the alkaline solution used. It was reported that the higher concentration of the sodium hydroxide solution resulted in a higher autogenous shrinkage while it reduced the drying shrinkage values. Sodium silicate content showed less effect on the drying and autogenous shrinkage values [104].

6. Conclusion

This review paper summarizes the findings of more than 100 research studies published over the last 30 years on different types of concrete and the factors influencing the shrinkage properties of concrete. In general, several studies showed that shrinkage in concrete starts at an early age. It goes through different stages over time, depending on the shrinkage properties of concrete that are affected by many factors, including the humidity, w/c ratio, type of coarse aggregate, shape, and hardness of aggregates, use of supplementary cementitious materials, and curing conditions. Shrinkage cracking is closely related to water loss in the paste, where the drying condition and limiting the amount of paste is controlled by w/c ratio (0.4-0.5), a proper curing technique, and chemical admixtures. Whereas, for higher strength concrete when w/c is around 0.3, plastic shrinkage is the primary concern as well as autogenous shrinkage and the use of shrinkage reducing admixtures such as (polyoxyalkylene alkyl ether). On the other hand, fiber reinforcement is considered as a useful technique for reducing and limiting the development of plastic shrinkage since it enhances the tensile creep and delays the cracking of concrete. The aggregates that are used in the production of concrete have different impacts on shrinkage properties based not only on the type of the aggregates but also on its shape and hardness. Besides, larger-sized aggregate absorbs lower water and hence shows a reduced shrinkage. Moreover, recycled aggregate from polymers as polystyrene and tire rubbers revealed a negative effect and increased the plastic shrinkage. In contrast, polymeric binders such as polyvinyl chloride aggregate, styrene-butadiene polymer, and geopolymer binders enhanced concrete characteristics and prevented shrinkage. The usage of superabsorbent polymers improved the performance and long-term durability of concrete. Notably, the pre-absorbed superabsorbent polymer that was decreased the total shrinkage of concrete. Another important factor that affects the shrinkage properties of concrete is the inclusion of supplementary cementitious materials such as fly ash, slag, and limestone powder. Generally, the short-term shrinkage was observed to be higher in the case of concrete with silica fume. In contrast, the higher the percentage of replacement of ordinary cement with limestone powder provides better results in resisting the long-term shrinkage.

7. Conflicts of Interest

The authors declare no conflict of interest.

8. References

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