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The Effect of Adding Fibers on Dry Shrinkage of Geopolymer Concrete

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Abstract

Despite their drastically different chemical ingredients and interactions, geopolymer concrete exhibits many of the same features as ordinary concrete. Among these properties is drying shrinkage. As in normal concrete, dry shrinkage in geopolymer concrete may cause cracking if the geopolymer concrete is bound, which affects the integrity of the structure in the future. It's important to measure drying shrinkage as soon as possible because it's the cause of early age cracking, which happens when the concrete isn't very strong. The purpose of this study is to determine how to reduce the dry shrinkage value of geopolymer concrete by using different types of fibers. Three types of fibers were used to determine their effect on the dry shrinkage of geopolymer concrete when compared with a reference mixture without the fibers. Metakaolin was used as a binder for the concrete geopolymer. As for the fibers, steel, carbon and polypropylene fibers were used in proportions of (0, 0.5, and 1%). The results showed an improvement in dryness shrinkage when adding fibers in general, with a difference in values between the different types of fibers. Steel fibers had the lowest amount of dry shrinkage. The temperature had a direct influence on the decrease in the extent of the shrinking, since the samples handled at higher temperatures had less dryness to begin with.

Keywords: Geopolymer; Fiber; Dry Shrinkage; Carbon Fiber; Metakaolin.

1. Introduction

Raw material characteristics, mixing ratios, processing methods, and other factors all influence shrinkage. Internal tension and even cracks in buildings are caused by excessive and uneven shrinkage, which affects the quality and durability of concrete [1-3]. Geopolymer concrete exhibits many of the properties of traditional concrete, although its chemical components and reactions are very different. However, only a few attempts have been made to assess the drying shrinkage of geopolymer concrete. Wallah & Rangan (2010) studied the drying of ocean-treated samples in the order of 1,500 microstrain, two to three times higher than that required for OPC-based parabolic cement [4, 5]. A thermo-thermo-treated fly ash-based geopolymer concrete has dried after 3 months. Water is not directly integrated into the geopolymer gel product, unlike Portland cement. In the geopolymer gel, only a small amount of the mixing water remains as interstitial water [6, 7]. Because MK-geopolymer pastes take a lot of water to mix, there is a lot of unbound or free water in the hardened paste that can evaporate at room temperature under low relative humidity circumstances. Despite the lack of chemically bonded water, structural stability is still required.

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Under relatively typical climatic circumstances, excessive water loss might cause severe shrinkage cracking of specimens. One explanation for geopolymer drying shrinkage and cracking might be the formation of high capillary pressures between wet and dry regions of the micropore network, which has been shown to begin crack propagation in the microstructure [8]. Also, one of the reasons for the increase in dry shrinkage is the amount of the binder and the ratio of the alkaline liquid substance to the amount of the binder [9]. There have been attempts by Bell & Kriven (2009) [10] to avoid dry shrinkage and crack proliferation by modifying the pore structure to reduce capillary porosity and control water loss during processing. It was observed that the dry shrinkage of heat treated geopolymer concrete was generally lower compared to that of heat-treated concrete at ambient conditions [11, 12]. This attribute was most likely due to the water that is released during ambient-curing, which then evaporates over time, especially within the first two weeks. Therefore, it effectively and influentially contributes to the properties of geopolymer concrete and makes it more durable [13] as well as making it a desirable option in the future when manufacturing various structural components [14].

On the other hand, Khan et al. explained the effect of curing temperature on dry shrinkage and creep of geopolymer compared to ordinary concrete consisting of Portland cement (OPC), where the increase in temperature led to less shrinkage and creep [15]. While Al-Hedad et al. (2020) found that adding reinforcement to the geopolymer concrete reduces the coefficient of thermal expansion and dry contraction compared to that without reinforcement [16]. Also, Gailitis et al. (2019) compared the shrinkage deformation between foam concrete and geopolymer concrete and found that the geopolymer shrinkage is less than that of foam concrete [17]. Many studies have addressed the effect of adding fiber to concrete. The chemical and microstructure differences between geopolymer concrete and ordinary concrete can lead to different binding properties between the matrix and the added fiber. As a result, the fibers in a geopolymer matrix may not necessarily perform the same as the fibers in a regular concrete matrix. Integrating fibers into the cementitious matrix is a well-known approach to improving the flexural properties and post peak characteristics of corresponding composites because fibers regulate crack propagation and widening under various forms of mechanical loading or shrinkage [18]. Deboning, sliding, and dragging fibers out are local processes that promote bridging action during micro and macro matrix cracking. This mechanism raises the energy requirement for the fracture to propagate [19].

Fibers of varied materials and geometric qualities, which may be classified into two categories: high modulus and low modulus, are utilized in construction [20]. Each group improves the matrix's individual properties. Metallic fibers, on the other hand, increase flexural strength due to their higher stiffness, while nonmetallic fibers, with a higher aspect ratio and surface contact area, regulate matrices' plastic shrinkage [21]. The effectiveness of fibers in geopolymer matrices is influenced by their intrinsic characteristics, fiber content, geopolymer precursors, curing conditions, and composite age [22]. The fiber/matrix interface, on the other hand, plays a critical role in the overall mechanical properties of composite structures; a strong contact interface has the ability to pass load from the matrix to fibers with high load bearing power, while fibers with inert surfaces result in weak interfacial contact, which leads to interface deboning and composite failure [23]. Because geopolymer is made mostly of water, the wettability of the reinforcement may be utilized to assess if the fibers and the matrix have a strong connection. Good wettability, which is defined by a low contact angle, aids the creation of a strong connection and the degree of efficacy of reinforcement in a geopolymer composite [24].

Noushini et al. (2016) investigated the effect of monofilament polypropylene fibers and monofilament structural polyolefin fibers on the long-term creep and shrinkage of fly ash-based geopolymer concrete and discovered that the addition of PP and PO fibers with a volume fraction of 0.5% resulted in reduced drying shrinkage and increased compression creep for fly ash-based geopolymer concrete [25].

In this study, further investigations are being conducted in order to evaluate the effect of fibers on concrete geopolymers upon initiation of the shrinkage test. The shrinkage tests started 24 hours, 3, 7, 14, 28, 56 days after casting. This drying shrinkage is a cause of premature concrete cracking, so evaluate it as soon as possible. According to the standard ASTM, or ANSI C157 [26], the curing temperatures were (35 and 75°C). This work will contribute to increasing the amount of experimental data available in the literature on the time-dependent behavior of concretions of geopolymer based on metakaolin content. This paper provides preliminary experiments on the effect of the addition of different types of fibers on the drying shrinkage of geopolymer concrete. Especially since Iraqi metakaolin is used in the production of this type of geopolymer.

2. Materials and Methods

Figure 1 shows a study flow diagram of the progress through the phases of the experiment.

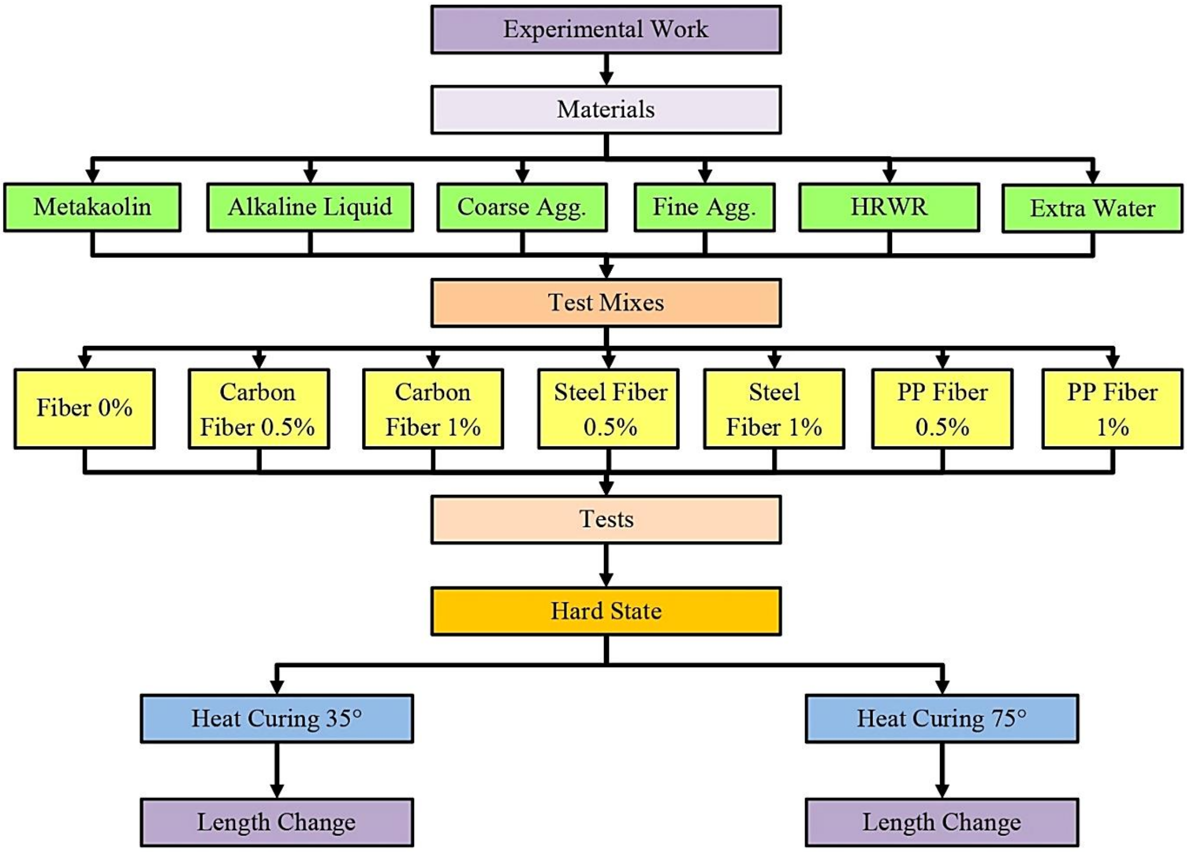

Figure 1. Details of the experimental program

2.1. Metakaolin

According to ASTM C618, the binding material in the creation of geopolymer concrete is Iraqi metakaolin. The chemical composition of metakaolin as determined by the analysis is shown in Table 1 and Figure 2, with silica oxide (SiO_2) accounting for 55.99%, aluminum oxide (Al_2O_3) for 38.32%, and iron oxide (Fe_2O_3) for 1.735%, and calcium oxide (CaO) accounting for less than 0.7%. The metakaolin utilized can be classified according to ASTM C618 based on these findings. It is primarily pozzolanic, with silicon dioxide reacting with calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (CSH) gel, which produces cementitious compounds appropriate for geopolymer application. The presence of calcium ions resulted in a rapid reaction time; As a result, the geopolymer will harden quickly and cure faster [27].

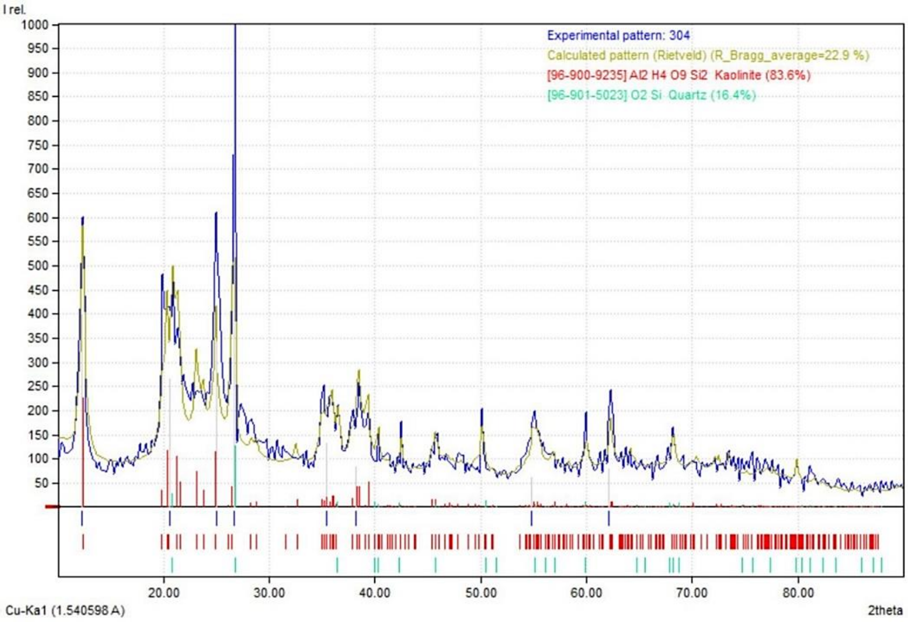

Figure 2. XRD analysis data for metakaolin

Table 1. XRD analysis data for metakaolin composition

Composition	Content (%)
SiO2	55.99
Al2O3	38.32
Fe2O3	1.735
CaO	0.671
MgO	0.19
K2O	0.5344
SO3	0.24
TiO2	2.015

2.2. Alkaline Solution

The alkaline solution is made from a mixture of a 12 molarity sodium hydroxide solution and a sodium silicate solution. To form the NaOH solution, NaOH (which is presented in flakes and pellets) granules were dissolved at 98% purity in water. Table 2 shows the properties of NaOH. In the case of sodium silicate solution, the ratio of Na_2O to SiO_2 and H_2O affects the concentration of the solution, according to Table 3.

Table 2. Properties of Sodium hydroxide

Composition	Content (%)
NaOH	98.00
Na_2CO_3	0.40
NaCl	0.15
Fe_2O_3	0.01
Na_2SO_4	200 ppm
Cu^{+2}	4 ppm
Ni^{+2}	5 ppm
SiO_2	20 ppm

Table 3. Properties of Sodium Silicate

Description	Value
Ratio of SiO_2 to Na_2O	2.4 ± 0.05
Na_2O percent by weight	13.00 – 13.60
SiO_2 percent by weight	32.00 – 33.00
Density - 20°	50 ± 0.5
Specific Gravity	1.535 – 1.550
Viscosity (CPS) 20°C	600 – 1200
pH	12.9

2.3. Fibers

The fibers used in this study are carbon, steel with hooked ends steel, and polypropylene. Table 4 and Figure 3 shows the characteristics of each.

Table 4. Properties of Fibers

Fiber Type	Specific gravity	Diameter (µm)	Tensile strength (MPa)	Modulus of Elasticity (GPa)	Average aspect ratio	Length (mm)
Carbon Fiber	1.80	10	4000	230	80	8
Steel Fiber	7.15	50	1000	200	70	35
Polypropylene Fiber	0.91	15-20	600-700	6-9	65	12

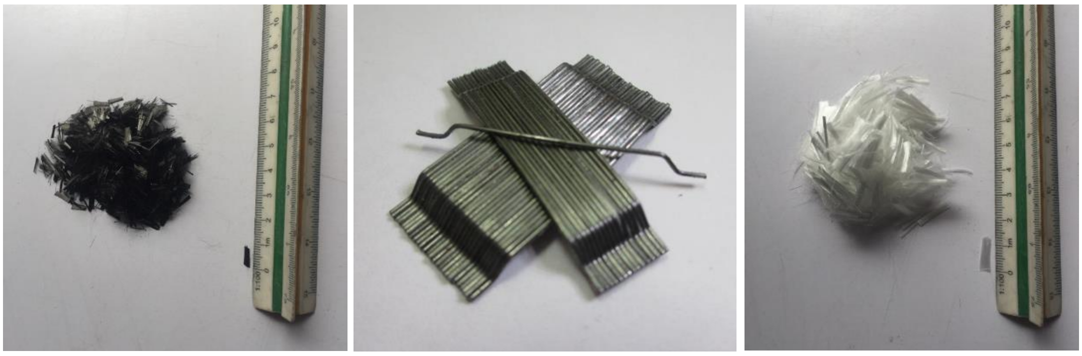

Figure 3. Carbon, steel with hooked ends and polypropylene fibers

2.4. High Range Water Reducing (HRWR)

For the production of geopolymer concrete, modified sulfated formaldehyde naphthalene condensation primer was used. KUT PLAST SP 400 HRWRA compliant with BS 5075 and ASTM C494 Type F in this study. The use of this type of HRWR results in a very high level of water reduction, and, as a result, a noticeable increase in strength can be gained along with maintaining good operability. Table 5 shows the main properties of KUT PLAST SP 400 HRWRA.

Table 5. Superplasticizer properties *

Characteristic	Depiction
Status and color	Liquid in a dark brown color
Specific gravity	1.24–1.26at 20°C
Air entrainment	⩽1%
Chloride	Nil to BS 5075
Calcium chloride	Nil
Freezing point	0° C

* According to manufacturer.

2.5. Fine Aggregate

Natural fine aggregates supplied by Samarra were used. All geopolymer concrete mixes contained fine aggregates with a maximum size of 4.75 mm and were graded into zone 2 limitations. Tables 6 and 7 were also used to classify fine aggregates that met the criteria of Iraqi Standard No. 45/1984 Zone 2 [28].

Table 6. Fine aggregates grading

Sieve size (mm)	Percentage passing	Grading limits according to Iraqi standards No. 45 / 1984 Zone 2
9.5	100	100
4.75	98	90-100
2.36	90	75-100
1.18	72	55-90
0.6	47	35-59
0.3	26	8-30
0.15	4.6	0-10

Table 7. Fine aggregate chemical and physical characteristics

Properties	Value	The criteria of Iraqi standards No. 45-1984
Specific gravity	2.60**	_
Fineness modulus	2.83*	_
Sulfate	0.23 %**	⩽ 0.5 %
Water absorption	1.9 %**	_
Bulk density	1590 kg/m3*	_
Materials finer than 0.075 mm	2.1 %*	⩽ 5 %

2.6. Coarse Aggregate

In all of the combinations, crushed gravel from Samarra was utilized as coarse aggregate. Gradient, specific gravity, sulfate concentration, absorption, and fine materials were all tested, according to Iraqi standards IQS 45/1984 [28]. Tables 8 and 9 show the grades and physical properties of the coarse aggregate which are respectively shown.

Table 8. Coarse aggregate grading

Sieve size (mm)	Percentage passing	Grading limits according to Iraqi standards IQS 45 / 1984
20	100	100
14	97	90-100
10	80.5	50-85
5	7.2	0-10
2.36	-	-

Table 9. Coarse aggregate physical characteristics and sulfate content

Physical properties	Values	The criteria of Iraqi standards IQS 45/1984
Specific gravity	2.64	_
Density	1640	_
Absorption	0.9 %	_
Fine materials that pass through a 75 µm sieve	0.08	1% Maximum
Sulfate content (%)	0.07	0.1% Maximum

3. Mixture Design and Specimen's Preparation

Seven sets of mixtures were made and tested to see how different types and amounts of fibers affected the drying shrinkage of metakaolin-based geopolymer concrete. The aggregate content, both coarse and fine, was maintained at a consistent level across totally mixes. The concentricity of NaOH was 12 Molar, sodium hydroxide to sodium silicate weight ratios equaled (1:1) also surface area of metakaolin to be (2300) m^2/kg, heat curing process was employed for these mixtures, with a temperature of 35 and 75 °C for 3 days.

Following that, the specimens are kept in the laboratory at the appropriate temperature until the time of test. Test was measured at different ages (1, 3, 7, 14, 28, and 56) days. Detailed information and mix proportions for metakaolin-based geopolymer concrete mixes are shown in Table 10.

Table 10. Mix proportions of Geopolymer concrete containing fibers

Mixes symbol	MK (kg/m^3)	Coarse agg. (kg/m^3)	Fine agg. (kg/m^3)	Steel fiber Vol. %	Carbon fiber Vol. %	PP fiber Vol. %	Alkaline solution % of MK	Extra water % of MK	HRWR (kg/m^3)
GPF0	500	1100	720	0	0	0	0.45	0.075	12
GPC1	500	1100	720	0	0.5	0	0.45	0.075	12
GPC2	500	1100	720	0	1	0	0.45	0.075	12
GPS1	500	1100	720	0	0	0	0.45	0.075	12
GPS2	500	1100	720	0.5	0	0	0.45	0.075	12
GPP1	500	1100	720	1	0	0	0.45	0.075	12
GPP2	500	1100	720	0	0	0.5	0.45	0.075	12

4. Results and Discussion

The results of the length change experiment were used to determine drying shrinkage, and the (FGPC) specimens were tested for a total of 56 days after a three-day period of heat curing (at temperatures of 35 and 75 °C). After that, the samples were placed in the laboratory at ambient temperature until the time of the tests. Figures 4 and 5 depict the relationship between all of the mixes' changing length results at various testing times at 35°C and 75°C.

The length change of all mixes was lower than that of the reference mix (GPF0), as shown in Figure 4. This might be due to the heat treatment improving the micro-structural growth and pore amendment of the geopolymer paste [29]. The shrinkage test is performed according to the ASTM C157 test method. The measurement of dry shrinkage begins (24) hours after the casting is completed.

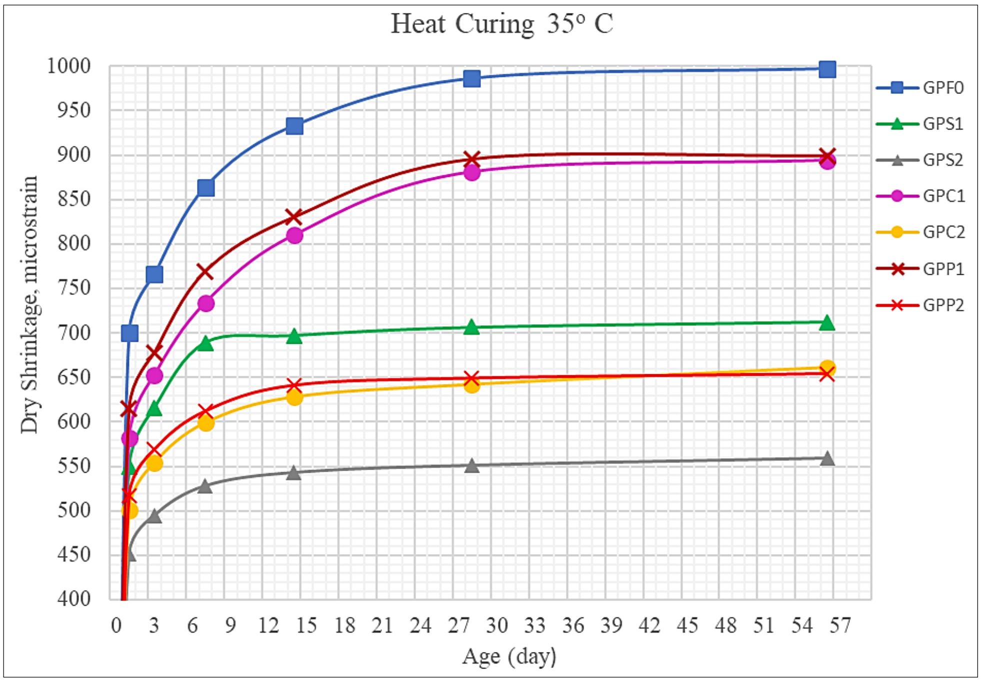

Figure 4. Relationship of Drying Shrinkage with age at 35°C

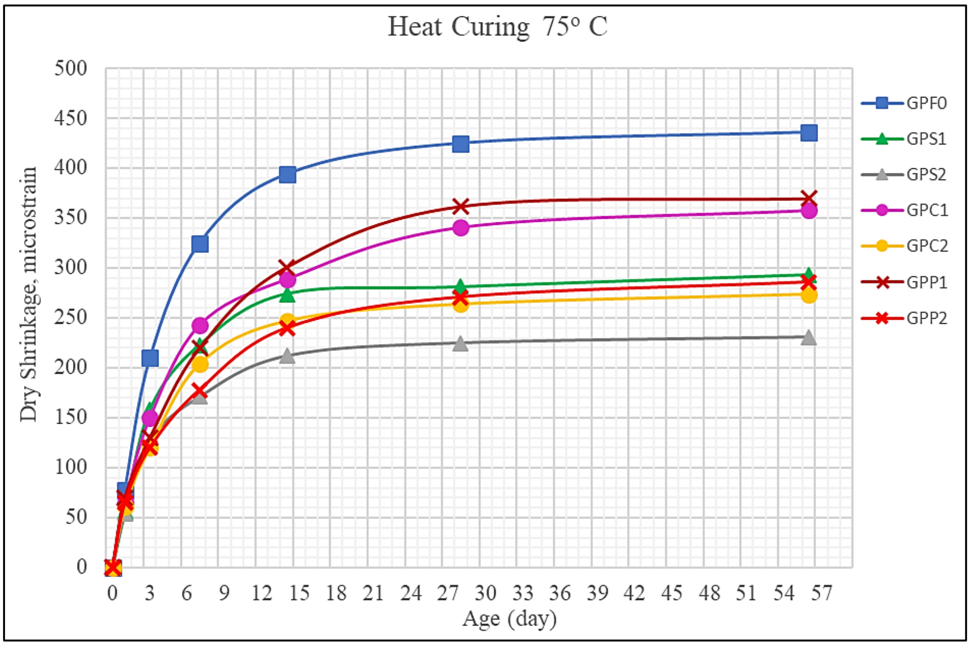

Figure 5. Relationship of Drying Shrinkage with age at 75°C

The heat cured mixes at 75°C showed much lower dry shrinkage than the heat cured samples at 35°C, as shown in Figure 5. The fact that the majority of the geopolymerisation process occurs during the heat curing phase may have contributed to the heat cured samples' reduced dry shrinkage at 75°C. Tables 11 and 12 show that all fiber reinforced GPCs had smaller shrinkage strain than the reference mix (GPF0), which did not contain any fiber. The reduction in shrinkage is likely due to the greater tensile strength of the matrix material and/or the friction bonding of fibers in the matrix [30]. Drying shrinkage in geopolymer concrete is expected to be linked to an increase in pressure applied and tensions in the structural capillary network, resulting in concrete contraction only if the concrete is regulated [31]. When compared to the reference mix, the matrix in (GPS2) containing steel fibers had a greater tensile strength than (GPF0), as assessed by an indirect tensile test. This indicates that the matrix is more durable (as shown in Table 12), resulting in less dry shrinkage and better control of micro-cracking in the steel fiber-containing matrix (GPS2). The increased length of the steel fibers, as well as the end-hooked design, allow for improved matrix-fiber interface mechanical interlocking when using steel fibers. This results in increased friction, which helps to neutralize a portion of the shrinkage energy, resulting in less shrinkage of the fiber reinforced concrete mix.

Table 11. Drying shrinkage × 10^{-6} for Heat Curing at 35°C

	Mix Symbol						
Age (Day)	**GPF0**	**GPS1**	**GPS2**	**GPC1**	**GPC2**	**GPP1**	**GPP2**
1	700	550	452	582	501	615	517
3	766	616	495	653	554	678	569
7	864	689	528	734	599	769	612
14	933	697	543	810	628	830	641
28	986	706	551	881	642	895	649
56	997	712	559	894	661	899	654

Table 12. Drying shrinkage × 10^{-6} for Heat Curing at 75°C

	Mix Symbol						
Age (Day)	**GPF0**	**GPS1**	**GPS2**	**GPC1**	**GPC2**	**GPP1**	**GPP2**
1	78	56	54	65	61	70	65
3	210	158	127	150	120	130	120
7	325	223	171	243	204	220	178
14	394	274	212	289	247	301	240
28	425	281	225	341	264	362	271
56	436	293	231	358	274	370	286

5. Conclusion

All mixes show that the dry shrinkage of metakaolin-based and heat-cured geopolymer concrete is significantly lower than that of room-temperature-cured concrete. The addition of fibers helped in developing the mechanical properties of metakaolin-based geopolymer concrete compared to non-fibrous ones. The higher the fiber content, the lower the dry shrinkage of the geopolymer concrete. Based on the tests performed and the results obtained in this study, it can be concluded that various fibers can be used as reinforcement for geopolymer concrete, as they do not cause negative effects on the mechanical properties of concrete but enhance the behavior of geopolymer concrete during dry shrinkage. The results of the tests also showed the effect of heat curing on the value and rapidity of dry shrinkage. When heat curing was increased, the dry shrinkage value was lower, because most of the geopolymerisation process takes place during the heat treatment stage, which contributed to reducing the dry shrinkage of the samples treated at high temperature. Also, the results showed that the addition of steel fibers with the end hook led to the lowest value of dry shrinkage compared to the rest of the other types of fibers. The length of the fiber and the back hook shape of the steel fiber help absorb part of the shrinkage energy, which affects the dry shrinkage value.

6. Declarations

6.1. Author Contributions

Conceptualization, Q.J.F. and M.H.K.; methodology, Q.J.F. and M.H.K.; validation, Q.J.F.; data curation, Q.J.F. and M.H.K.; writing—original draft preparation, Q.J.F.; writing—review and editing, Q.J.F. and M.H.K. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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