

Improvement the Properties of High Strength Fly Ash Based Geopolymer Concrete by Using Cement

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Abstract. Geopolymer concrete was introduced to decrease the consumption of Portland cement, reduce the emission of CO₂ and produce alternative binders by applying by-products materials such as fly ash. This study the effect of steel fiber on the fresh and hardened properties of geopolymer concrete and also aimed to improve the properties of this type of concrete by replacing the fly ash by Portland cement by 5, 10, 15, 20 and 25% by weight. The results demonstrated that the use of steel fiber leads to improve compressive, splitting tensile and flexural strengths and reduce the flowability and drying shrinkage. The results also showed that the compressive strength of geopolymer concrete increased with increasing the replacement level up to 25%, the increase reached to 40.24 and 34.66% at 7 and 28 days respectively. Splitting tensile strength and flexural strength also increased with the replacement level of fly ash by cement. The results also revealed that the drying shrinkage of fly ash geopolymer concrete increased with cement replacement level.

1. Introduction

Production of cement is associated with the emission of a great quantity of CO₂ [1]. The quantity of CO₂ released is about one ton for each ton cement clinker. Therefore, it is represented pivotal to find alternative low CO₂ emission binders for concrete to diminish its carbon emission and the evolution of alternative binders by applying by-products materials is one of the present strategies [2].

Geopolymer concrete is a latent material for structural application as an alternative to Portland cement concrete. It can play an important role in green concrete technology by removing cement and employing various by-product waste materials such as fly ash [3]. The main constituents of geopolymer are the source materials and the alkaline solutions. The first must be rich in silicon and aluminium [1]. Using of fly ash as an aluminosilicate source material has been considered for making geopolymer concrete owing to its vast availability, high silica and alumina contents and low water demand [2,3]. Some investigators tried to develop the reactivity of fly ash in alkaline environment by adding some calcium comprising materials [4,5]. The addition of calcium oxide (CaO) forms hydrated products like calcium silicate hydrates [6,7]. Increase in strength and reduction in setting time was detected with increasing the CaO content [8]. The most widely recognized alkaline solution utilized in geopolymerisation is a mixture of sodium hydroxide and sodium silicate [9,10]. There are too limited studies tried to use Portland cement with fly ash geopolymer concrete. This work aimed to study the effect of steel fiber on fly ash geopolymer concrete and produce high strength geopolymer concrete by replacing the fly ash by cement to improve the properties of geopolymer concrete.

2. Materials



Low calcium type F fly ash according to ASTM C 618 [11] with ordinary Portland cement OPC from Tasluja factory conforming to the Iraqi specification No.5 /1984 [12] were used as source material in this study. The chemical compositions and some physical properties of FA and OPC are presented in table (1). A mixture of sodium silicate and sodium hydroxide solutions were utilized as alkaline liquid. Al-Ekhadir natural sand with a specific gravity of 2.65 and passing from the sieve 2.36 mm was used as a fine aggregate. The desired workability of the mixtures was achieved by utilizing type F polycarboxylate-based superplasticizer (SP) conforming to ASTM C494 [13]. The steel fibers utilized in this work were straight steel fibers used to provide fiber reinforcement. The properties of straight steel fiber given by the manufacturer are listed in table (2).

Table 1. Chemical analysis of fly ash and cement*

Oxide	Fly ash	Cement
SiO ₂	59.56	20.18
Al ₂ O ₃	29.33	5.00
Fe ₂ O ₃	3.36	3.60
CaO	2.20	62.21
MgO	0.66	2.31
SO ₃	0.67	1.44
Na ₂ O	0.21	----
K ₂ O	2.24	----
L.O.I	2.77	3.29

* Chemical composition was accomplished by National Center for Construction Laboratories and Researches (NCCLR).

Table 2. Properties of Straight Steel Fiber **

Description	Straight Steel Fiber
Diameter	0.2 mm
Length	13 mm
Aspect ratio (l/d)	65
Relative density	7800 kg / m ³
Ultimate tensile strength	2600 MPa
Modulus of Elasticity	200000MPa

**According to the industrialist (The Chemical Company BASF)

2.1 Mix proportions

The mix proportioning studied in the experimental program is shown in table (3). A total of 7 concrete mixtures with a total binder content of 1000 kg/m³. One of the mixes without steel fiber and the other 6 mixes containing a constant volume fraction of 1.5% micro steel fiber. The replacement level of cement was varied from 0 to 25% of the fly ash content. The alkaline solution were prepared by mixing the solutions of sodium silicate and sodium hydroxide and allowing the blend for a period of 24 hours. The sodium silicate solution (Na₂SiO₃) to Sodium Hydroxide (NaOH) ratio by mass of 2.5 was used. A commercially available pellet form of sodium hydroxide with 98% purity was used. The solids are dissolved in water to produce a solution with 12 M.

2.2 Casting, sample preparation, and curing conditions

Geopolymer mixes were mixed by using a high speed mixer that could mix with a speed up to 470 rpm. At first, dry powders and fine aggregates were mixed together at low speed of 100 rpm for 3 min. Then the alkaline liquid were added to the dry powders and the mixture was remixed for another 3 min. with the same speed. The SP were added to the mix and the mixing was persistent at high speed

for 3 min. Finally, the micro steel fibers were appended to the mix and mixed with the same speed for 2 min. Thereafter the fresh concretes were poured into the molds and compacted using a vibrating table. Then the samples were covered with polyethylene sheets and preserved in the molds for 24 h at ambient temperature of 22 ± 2 °C. After 24 h from casting the concrete samples were demoulded and cured in oven at 75 °C for 24 h.

Table 3. Mix proportions of geopolymer concrete.

Mix	Fly ash kg/m ³	Cement kg/m ³	WG kg/m ³	NaOH kg/m ³	SP%	Steel fiber kg/m ³	Fine aggregate kg/m ³
R	714.286	0.000	204.082	81.633	1.5	0	1258.912
M0	714.286	0.000	204.082	81.633	1.5	117.750	1219.162
M5	678.571	35.714	204.082	81.633	1.5	117.750	1231.180
M10	642.857	71.429	204.082	81.633	1.5	117.750	1243.198
M15	607.143	107.143	204.082	81.633	1.5	117.750	1255.216
M20	571.429	142.857	204.082	81.633	1.5	117.750	1267.235
M25	535.714	178.571	204.082	81.633	1.5	117.750	1279.253

2.3 Testing procedures

2.3.1 Evaluating of flow diameter

The flow of geopolymer concrete was measured using the workability test recommended by ASTM C1437 [14]. After pouring fresh mixture to the mini cone, the cone was raised straight upwards to permit free flow for the fresh geopolymer concrete on the plate. The flow value was estimated by taking the average of two measured diameters.

2.3.2 Compressive strength test

Compressive strength test was performed on 50 mm cubes with a rating load of 0.9 kN/s according to ASTM C109 [15]. This test was conducted by taking the average of three samples at the ages of 7 and 28 days.

2.3.3 Splitting tensile Strength test

Splitting tensile strength test was evaluated according to ASTM C4 96 [16] by taking the average of three of 100×150 mm cylindrical samples for each mix at 7 and 28 days, with rating load of 0.2 kN/s.

2.3.4 Flexural strength test

Flexural strength test was performed on 100×100×500 mm prisms according to ASTM C 78 [17]. This test was conducted by taking the average of three samples at the ages of 7 and 28 days.

2.3.5 Drying shrinkage test

This test was accomplished according to ASTM C 596-01[18] and ASTM C 157/C 157M-08[19].



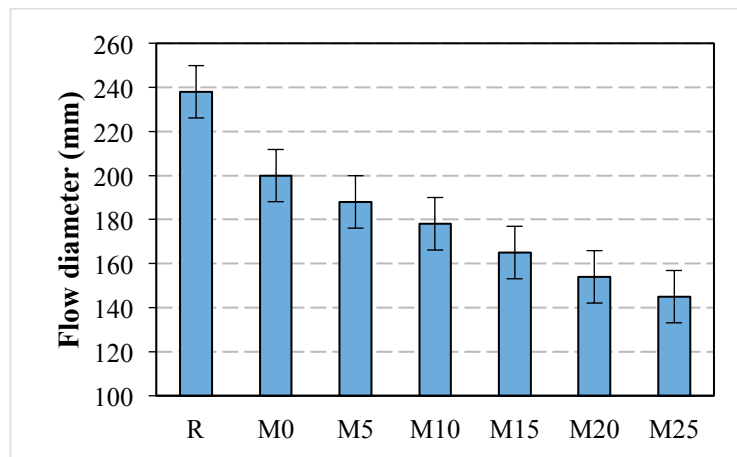
Figure 1. Apparatus and a specimen during shrinkage test.

3. Results and discussion

3.1 Flow diameter

The flow results of all mixes showed in figure 2. The results showed that the mix reference mix without steel fiber gives higher flow diameter than the same mix containing 1.5% steel fiber. The increasing in flow diameter was 19%. This is because of restrict the flow of the geopolymer concrete due to use steel fiber and to high cohesive forces between the fibers and geopolymer concrete matrix the relative slump flow ability linearly decreases [20].

The results also revealed that the flow diameter reduced with increasing the cement replacement level up to 25% of the weight of cement. This is due to spherical shape of fly ash particles which is helps to improve the workability [1] compared with irregular shape of cement particles. The decreasing were 6, 11, 17.5, 23 and 27.5% for 5, 10, 15, 20 and 25% of cement replacement level respectively.

**Figure 2.** Flow diameter of geopolymer concrete.

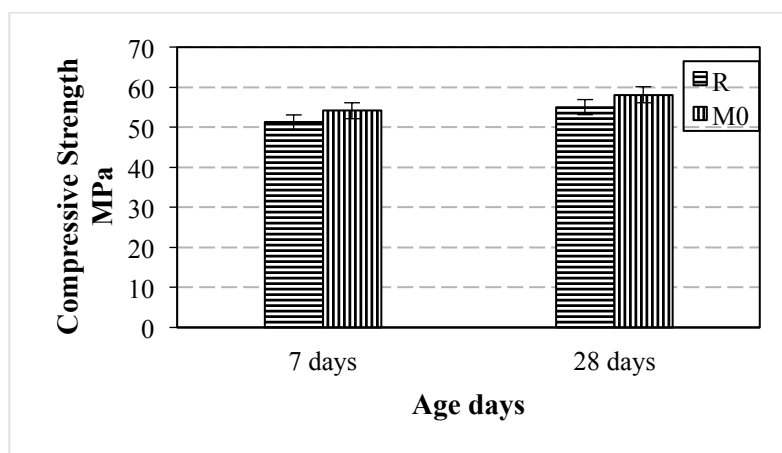
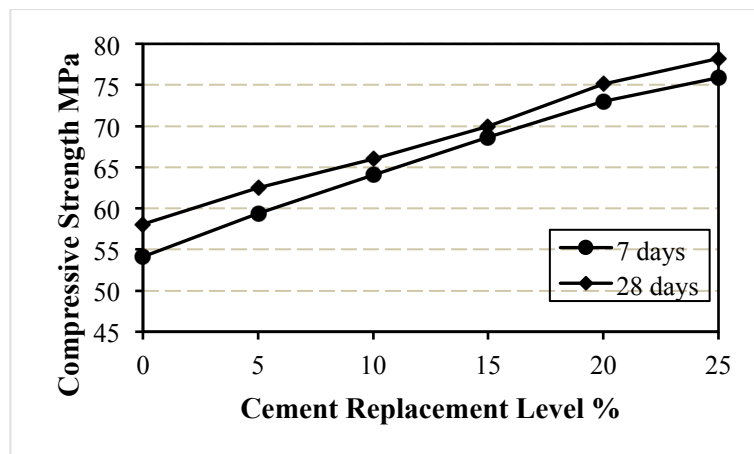
3.2 Compressive strength

The compressive strength results demonstrated that the incorporation of steel fiber leads to increase the compressive strength of geopolymer concrete about 5.6 and 5.5% at 7 and 28 days respectively as shown in figure 3. This is may be because that the steel fibers effectively delay the formation and propagation of cracks when the concrete is subjected to compressive stresses, and it prevents a sudden explosive failure of the specimens [21].

The results indicated that it can produced fly ash geopolymer concrete with compressive strength reached to 54.12 and 58.08 MPa at 7 and 28 days respectively. The results also revealed that the compressive strength of geopolymer concrete increased with increasing the replacement level of fly ash by cement up to 25%. This is due to the existence of calcium oxide (CaO) [22], because increasing the CaO content leads to decrease the microstructure porosity and increased the compressive strength [23]. The increasing in compressive strength were 9.76, 18.29, 26.83, 34.94 and 40.24% at 7 days and 7.58, 13.64, 20.45, 29.36 and 34.66% at 28 days for 5, 10, 15, 20 and 25% replacement level of cement respectively, as shown in figure 4. The results also indicated that for the same mix, the strength gain was very low. This is due to use high curing temperature of 75 °C. The strength gain ranged between 1.7 to 7.3%.

Table 4. Compressive strength of geopolymer concrete.

Mix symbol	Compressive strength MPa	
	7 days	28 days
R	51.24	55.06
M0	54.12	58.08
M5	59.4	62.48
M10	64.02	66.00
M15	68.64	69.96
M20	73.029	75.13
M25	75.9	78.21

**Figure 3.** Effect of steel fiber on compressive strength of geopolymer concrete.**Figure 4.** Compressive strength of geopolymer concrete.

3.3 Splitting tensile strength

The splitting tensile strength results demonstrated that the steel fiber leads to increase the splitting tensile strength of geopolymer concrete about 55.5 and 52.8% at 7 and 28 days respectively as shown in figure 5. This increase because of the steel fibers effectively delay the formation and prevalence of cracks when the concrete is subjected to tensile stresses, and it prevents a sudden failure of the specimens [21].

The results presented in figure 6 indicated that the tensile strength of geopolymer concrete increased with increasing the replacement level of fly ash by cement up to 25%. The increasing in tensile strength were 9.76, 18.29, 26.1, 31.22 and 36.34 % at 7 days and 9.88, 20, 25.18, 30.82 and 36.47% at 28 days for 5, 10, 15, 20 and 25% replacement level of cement respectively. This increase is due to decrease the microstructure porosity and increased the splitting tensile strength.

Table 5. Splitting tensile strength of geopolymer concrete.

Mix symbol	Splitting tensile strength MPa	
	7 days	28 days
R	2.9	3.06
M0	4.51	4.675
M5	4.95	5.137
M10	5.335	5.61
M15	5.687	5.852
M20	5.918	6.116
M25	6.149	6.38

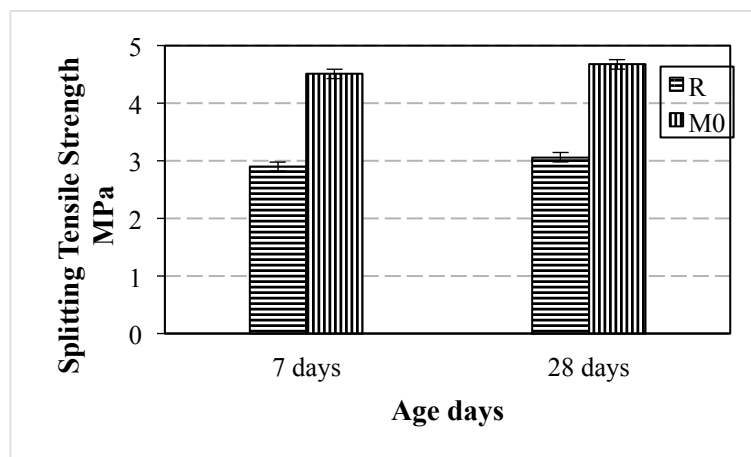


Figure 5. Effect of steel fiber on splitting tensile strength of geopolymer concrete.

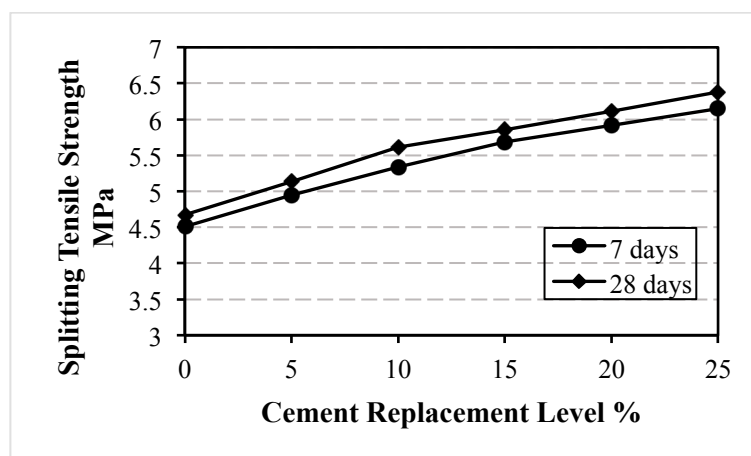


Figure 6. Splitting tensile strength of geopolymer concrete.

3.4 Flexural strength

The results of the flexural strength indicated that the steel fiber leads to increase the flexural strength of geopolymer concrete to 45.5 and 43.4% at 7 and 28 days respectively as shown in figure 7. The progressive effect of fiber on flexural strength is more significant than compressive strength. This because of increasing the ductility of geopolymer concrete.

The results showed in figure 8 indicated that the flexural strength of geopolymer concrete increment with increasing the replacement level of fly ash by cement up to 25%. The increment in flexural strength were 10.42, 19.17, 27.08, 32.29 and 38.33 % at 7 days and 9.76, 19.52, 25.1, 31.47 and 36.65% at 28 days for 5, 10, 15, 20 and 25% replacement level of cement respectively.

Table 6. Flexural strength of geopolymer concrete.

Mix symbol	Flexural strength MPa	
	7 days	28 days
R	3.3	3.5
M0	4.8	5.02
M5	5.3	5.51
M10	5.72	6
M15	6.1	6.28
M20	6.35	6.6
M25	6.64	6.86

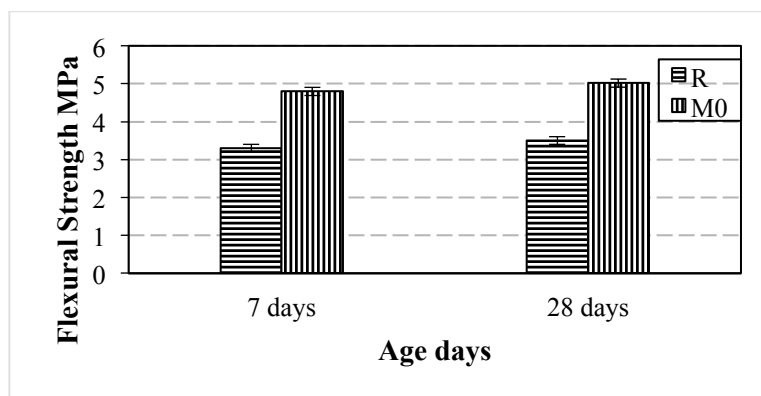


Figure 7. Effect of steel fiber on flexural strength of geopolymer concrete.

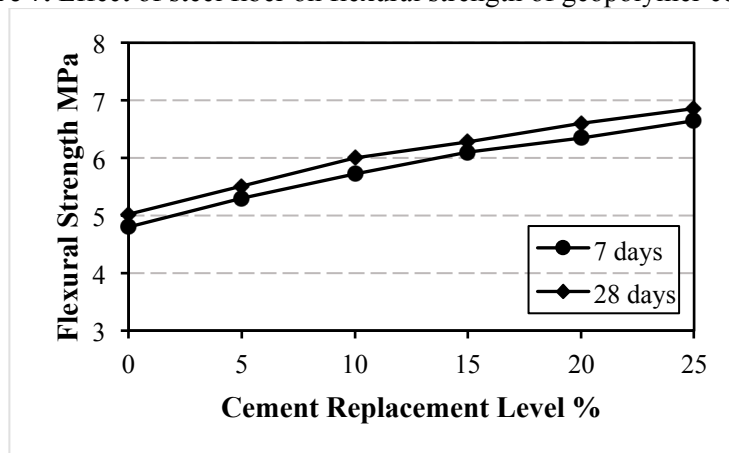


Figure 8. Flexural strength of geopolymer concrete.

3.5 Drying shrinkage

The drying shrinkage results indicated that the steel fiber leads to decrease the drying shrinkage of geopolymer concrete reached to 12.9% at 3 days and 6% at 45 days as shown in figure 9. This reduction in shrinkage may be due to that the steel fiber restrict the geopolymer concrete and leads to reduce the drying shrinkage.

The results presented in figure 10 showed that the drying shrinkage of fly ash geopolymer concrete increased with increasing the age and cement replacement level at all test ages. The increasing in drying shrinkage was 2.73, 6.01, 10.93, 19.13 and 25.68 at 3 days and 0.69, 1.9, 3.1, 5.17 and 6.9 at 45 days for 5, 10, 15, 20 and 25% replacement level of cement respectively. The increasing in drying shrinkage may be due to that the cement have higher shrinkage compared with fly ash. The results also revealed that the difference in drying shrinkage between the control mix containing only fly ash and the other mixes containing up to 25% of cement were reduced with age.

Table 7. Drying shrinkage of geopolymer concrete.

Mix	Drying Shrinkage Strain $\times 10^{-6}$					
	3 days	10 days	17 days	25 days	35 days	45 days
R	-210	-317	-442	-532	-568	-609
M0	-183	-287	-412	-502	-540	-580
M5	-188	-309	-422	-507	-553	-584
M10	-194	-315	-448	-522	-555	-591
M15	-203	-323	-461	-528	-567	-598
M20	-218	-337	-480	-537	-570	-610
M25	-230	-350	-490	-548	-582	-620

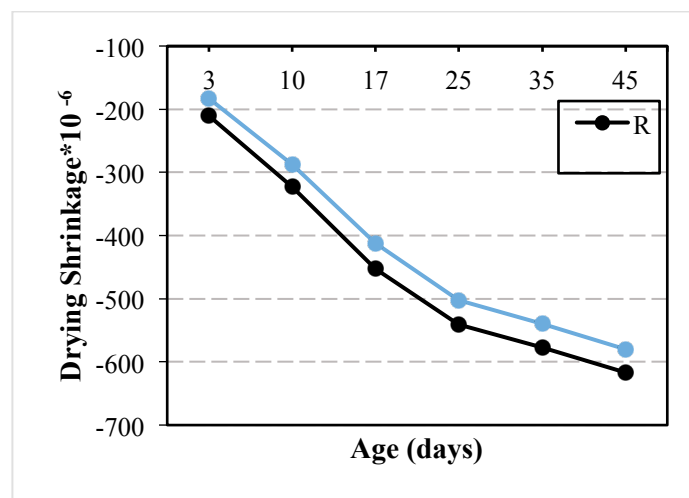


Figure 9. Effect of steel fiber on drying shrinkage of geopolymer concrete.

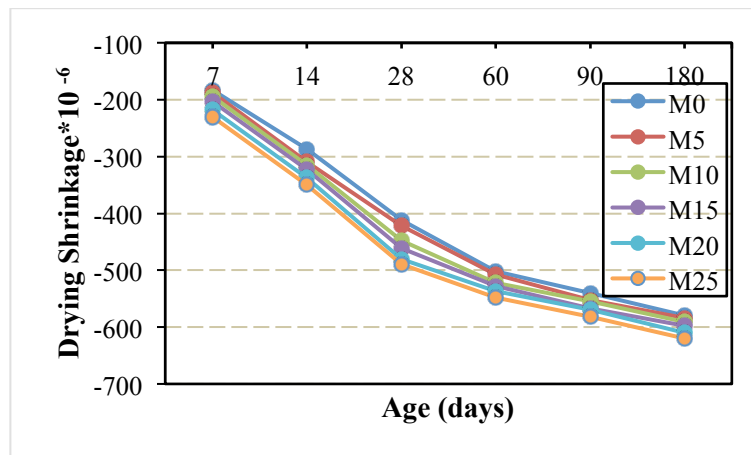


Figure 10. Drying shrinkage of geopolymer concrete.

4. Conclusions

From the results of this work it can be found that for the same amount of superplasticizer the workability of geopolymer concrete reduced with increased the cement content and using 1.5% steel fiber lead to restrict the flowability of geopolymer concrete. Using steel fiber leads to increase the compressive, splitting tensile and flexural strengths of geopolymer concrete. The results revealed that the increase in splitting tensile strength and flexural strength due to use steel fiber was more than the increasing in compressive strength. Geopolymer concrete can be produced with compressive strength reached to 75.9 and 78.21 N/mm² at 7 and 28 days respectively by replacing the fly ash by Portland cement up to 25% by weight and it also showed very low strength gain due to using high curing temperature (75 °C). Splitting tensile and flexural strengths increased with increasing the replacement level of fly ash by cement. Drying shrinkage of fly ash based geopolymer concrete increased with increasing cement content and reduced with steel fiber.

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