

University of Wollongong

Research Online

Faculty of Engineering and Information
Sciences - Papers: Part B

Faculty of Engineering and Information
Sciences

2017

Influence of geogrid on the drying shrinkage performance of concrete pavements

Abbas Sahib Abd-Ali Al-Hedad

University of Wollongong, asaa774@uowmail.edu.au

Ebony Bambridge

University of Wollongong, ekb960@uowmail.edu.au

Muhammad N. S Hadi

University of Wollongong, mhadi@uow.edu.au

Follow this and additional works at: <https://ro.uow.edu.au/eispapers1>



Part of the [Engineering Commons](#), and the [Science and Technology Studies Commons](#)

Recommended Citation

Al-Hedad, Abbas Sahib Abd-Ali; Bambridge, Ebony; and Hadi, Muhammad N. S, "Influence of geogrid on the drying shrinkage performance of concrete pavements" (2017). *Faculty of Engineering and Information Sciences - Papers: Part B*. 61.

<https://ro.uow.edu.au/eispapers1/61>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Influence of geogrid on the drying shrinkage performance of concrete pavements

Abstract

The aim of this study is to investigate the effect of geogrid on the drying shrinkage behaviour of concrete pavements. For this purpose, two categories of concrete specimens were prepared and tested by drying them within the controlled environmental conditions, for 56 days. The first category of specimens included casting and testing nine concrete prism specimens having dimensions of 75 x 75 x 280 mm. These specimens were divided into three groups. The first group included three unreinforced concrete prism specimens and taken as references. The second group consisted of three concrete prism specimens reinforced with a single biaxial geogrid layer located at 20 mm from the top of specimen. The last three specimens (third group) were reinforced with a biaxial geogrid layer placed at 37.5 mm from the top of specimen. The second category of specimens, which was suggested in this study to simulate the behaviour of concrete pavements, consisted of preparing and testing six concrete slab specimens. They had dimensions of 30 x 280 x 280 mm. The specimens of this category were divided into two groups. The first group included three unreinforced concrete slab specimens (References). The second group included three concrete slab specimens reinforced with a single biaxial geogrid layer placed at 15 mm from the top of specimen. The changes in the length of the prisms and the changes in the area of the slabs were measured and evaluated. Test results obtained illustrate that, under the controlled drying conditions, the geogrid can slightly reduce the drying shrinkage strains of the concrete pavements.

Keywords

concrete, pavements, geogrid, performance, influence, shrinkage, drying

Disciplines

Engineering | Science and Technology Studies

Publication Details

Al-Hedad, A., Bambridge, E. & Hadi, M. N. S. (2017). Influence of geogrid on the drying shrinkage performance of concrete pavements. *Construction and Building Materials*, 146 165-174.

Influence of Geogrid on the Drying Shrinkage Performance of Concrete Pavements

Abbas S. A. Al-Hedad¹, Ebony Bambridge², and Muhammad N. S. Hadi³

¹*PhD Candidate, School of CME Engineering, University. of Wollongong, Wollongong, NSW 2522, Australia. E-mail: asaa774@uowmail.edu.au*

²*School of CME Engineering, University. of Wollongong, Wollongong, NSW 2522, Australia. E-mail: ekb960@uowmail.edu.au*

³*Associate Professor, School of CME Engineering, University. of Wollongong, Wollongong, NSW 2522, Australia (corresponding author). E-mail: mhadi@uow.edu.au*

Abstract

The aim of this study is to investigate the effect of geogrid on the drying shrinkage behaviour of concrete pavements. For this purpose, two categories of concrete specimens were prepared and tested by drying them within the controlled environmental conditions, for 56 days. The first category of specimens included casting and testing nine concrete prism specimens having dimensions of $75 \times 75 \times 280$ mm. These specimens were divided into three groups. The first group included three unreinforced concrete prism specimens and taken as references. The second group consisted of three concrete prism specimens reinforced with a single biaxial geogrid layer located at 20 mm from the top of specimen. The last three specimens (third group) were reinforced with a biaxial geogrid layer placed at 37.5 mm from the top of specimen. The second category of specimens, which was suggested in this study to simulate the behaviour of concrete pavements, consisted of preparing and testing six concrete slab specimens. They had dimensions of $30 \times 280 \times 280$ mm. The specimens of this category were divided into two groups. The first group included three unreinforced concrete slab specimens (References). The second group included three concrete slab specimens reinforced with a

25 single biaxial geogrid layer placed at 15 mm from the top of specimen. The changes in the
26 length of the prisms and the changes in the area of the slabs were measured and evaluated.
27 Test results obtained illustrate that, under the controlled drying conditions, the geogrid can
28 slightly reduce the drying shrinkage strains of the concrete pavements.

29 **Author keywords:** Concrete prism specimens; Concrete slab specimens; Controlled drying
30 conditions; Biaxial geogrid; Drying shrinkage strains

31 **1. Introduction**

32 The early age behaviour of Portland cement concrete (PCC) pavements is significantly
33 influenced by weather conditions. This is because the PCC pavements possess a large surface
34 area exposed to the effect of climate changes. Temperature and relative humidity have a
35 combined effect on the PCC pavements, especially in the drier environments or when the
36 curing conditions of concrete being inadequate. This leads to an increase in the rate of the
37 evaporation of concrete mix water, and therefore, the PCC pavement would be more likely to
38 shrink.

39 High temperature of the concrete surface makes the concrete to lose the moisture gradually
40 through the surface. The pore water moves towards the surface through the pore network [1].
41 This results in variable moisture content in space and time. In addition, the value of
42 temperature between the top and bottom of the slab will be different. When the rate of
43 evaporation exceeds the rate of pore water movement towards the surface, the concrete will
44 start to shrink, which is called the drying shrinkage.

45 The drying shrinkage can be defined as the reduction in the concrete volume due to the
46 influence of environmental conditions [2]. This reduction may be considered a critical
47 situation for concrete pavements and may significantly affect the performance and lifetime of

48 concrete roads. Sometimes the drying shrinkage leads to a generation of excessive thermal
49 strains and stresses in the concrete, in turn, mostly leading to cracking of concrete pavements.
50 The concrete cracking may result in reducing the effective design stress used in the pavements
51 by up to 50% [1].

52 Several studies were conducted to examine the effect of temperature and relative humidity on
53 the behaviour of concrete pavements during the early-age of their service life. For example,
54 Asbahan and Vandebossche [3], Zhang et al. [4], and Kim et al. [5] investigated the response
55 of jointed plain concrete pavement subjected to environmental effects. They concluded that
56 the slab curvature which resulted from the effect of temperature and relative humidity
57 influences the locations and magnitude of the critical stresses in the concrete pavement. In
58 turn, the performance of the pavement for the long term will be affected. The authors also
59 reported that the slab curvature, which resulted from the daily fluctuations of temperature or
60 from reversible drying shrinkage, is not significantly reduced when using dowel and tie bars.

61 Zhang et al. [6] theoretically studied the drying shrinkage behaviour of normal strength
62 concrete and developed a micromechanical model using the finite element method. The
63 model was derived based on the capillary tension created in the capillary pores of the concrete
64 and considered the interior humidity as a driving parameter. The authors recommended that
65 the model can be used to predict the shrinkage-induced strains of concrete at a different time
66 and different positions. In general, these studies emphasized that the environmental loads can
67 be critical factors in the deformation of concrete pavements and, thus, on the long-term
68 performance of the pavement.

69 Several previous studies tried to address the effect of shrinkage deformation on the concrete
70 using different reinforcement materials. Shao and Mirmiran [7] investigated the role of fibre-

71 reinforced polymer (FRP) grids and rods on the drying shrinkage deformation of concrete
72 pavements. They illustrated that the FRP grids could be used instead of steel reinforcement in
73 restraining the shrinkage deformation and could be placed closer to the surface. But the cost
74 of construction using the FRP reinforcement is in the rise.

75 Fibre reinforcement such as steel, polypropylene and synthetic fibres was used to restrain the
76 shrinkage deformation of concrete. Jafarifar et al. [1]; and Ahamed et al. [8] studied the
77 drying shrinkage behaviour of concrete pavements reinforced with recycled steel fibres. They
78 concluded that the shrinkage strains of concrete reinforced with the steel fibres was lower
79 than that of plain mixes. Using fibres to mitigate the shrinkage deformation of concrete
80 pavements can be source of problems when mixing the concrete or in the workability of the
81 concrete, especially at the high fibre percentages.

82 Bentz and Weiss [9], Güneysi et al. [10]; Wei et al. [11]; and Kim and Chun [12] investigated
83 the effect of pre-wetted lightweight fine and coarse aggregates as an internal curing technique
84 on the autogenous and drying shrinkage behaviour of concrete. Although the use of this
85 technique could mitigate the shrinkage deformation of cured concrete, the rate of shrinkage
86 development was faster than the control concrete. Also, the early strength and the modulus of
87 elasticity of the concrete were reduced.

88 Geogrid, which is basically used to strengthen the weak soils, has been recently utilised as a
89 reinforcement layer for Portland cement concrete elements. This is because they have several
90 structural characteristics such as a high tensile strength and corrosion resistance [13-15]. Siva
91 and Agarwal [16-18] and Wang et al. [19] investigated the performance of concrete prismatic
92 and cylindrical specimens strengthened with the geogrid. These investigations demonstrated
93 that the flexural, compressive, and shear strength of concrete could be improved, as well as,

94 the cracking resistance of concrete specimens could be increased. However, using geogrid
95 products for reinforcing the Portland cement concrete elements are a new direction. So,
96 additional research studies to find out more benefits for geogrid applications are required. In
97 this study, the biaxial geogrid was used as a restraining layer of drying shrinkage for concrete
98 prism and slab specimens.

99 **2. Objective of study**

100 The purpose of this study is to investigate the effect of geogrid on the drying shrinkage
101 behaviour of concrete pavements by drying the specimens within controlled environmental
102 conditions, at a temperature of $23 \pm 3^\circ \text{C}$ and Relative Humidity (RH) of $60 \pm 10\%$. Two
103 categories of normal strength concrete specimens were prepared and tested. They were prism
104 and slab specimens having dimensions of $75 \times 75 \times 280 \text{ mm}$ and $30 \times 280 \times 280 \text{ mm}$,
105 respectively.

106 **3. Properties of biaxial geogrid**

107 The biaxial geogrid was used as a drying shrinkage restraining layer. This is because the
108 arrangement of biaxial geogrid ribs and roughness of nodes' surface can provide an
109 appropriate bond between the geogrid layer and the surrounding concrete [20].

110 The biaxial geogrid used in this study is manufactured from polypropylene composite
111 materials [21]. It had square openings with inner dimensions of $38 \times 38 \text{ mm}$, as shown in
112 Figure 1. The ribs of the biaxial geogrid used were interconnected together at one point called
113 node (junction). They had a cross section area of $2 \times 3 \text{ mm}$ measured by a digital vernier
114 calliper gauge.

115 The mechanical properties of the biaxial geogrid were determined using the standard of
116 American Society for Testing and Materials (ASTM) D6637/D6637M-15 [22]. The Single
117 Geogrid Rib (SGR) sample was adopted in this test. In total, five SGRs were prepared and
118 tested under a tensile force at a rate of 8 mm/min, as shown in Fig. 2(a). The instron tensile
119 testing machine that has a capacity of 10000 N was used to test the geogrid samples. All tests
120 were conducted at the High Bay Laboratory of the School of Civil, Mining and
121 Environmental Engineering, University of Wollongong (UOW), Australia.

122 Each biaxial geogrid sample was selected from the batch and prepared according to the
123 requirements of ASTM D6637/D6637M-15 [22]. All samples consisted of four junctions in
124 order to provide the minimum required length and were free from any surface defects. The
125 average length of geogrid samples, which is defined as the length of geogrid rib measured
126 between the ends of the testing machine clamps and called initial gauge length, was 200 mm,
127 as shown in Fig. 2(b). The testing was stopped when the geogrid rib was ruptured (Fig. 2(c)).

128 Table 1 lists the physical and mechanical properties of the tested biaxial geogrid samples. The
129 tensile strength of the samples ranged between 1222 N to 1467 N with the corresponding
130 elongation of 57 to 109 mm. These results satisfy with the requirements of ASTM
131 D6637/D6637M-15 [22]. The average tensile strength and elongation of samples were 1341 N
132 and 81 mm, respectively. Fig. 3 shows the tensile strength versus the corresponding strains of
133 the five biaxial geogrid samples.

134 A wide tolerance before accept or reject the test results of geosynthetic products (geogrid is
135 one of these products) is permitted by ASTM D6637/D6637M-15 [22]. This is because these
136 products are extensively affected by environmental conditions of the laboratory and
137 characteristics of tested geogrid samples. However, from Figure 3, it can be seen that there are

138 differences in the results of the tensile strengths and elongations of the biaxial geogrid
139 samples. These differences are acceptable according to the limitations of ASTM
140 D6637/D6637M-15 [22].

141 **4. Experimental program**

142 *4.1 Preparation of specimens*

143 Table 2 provides details of the experimental program adopted in this study. Two categories of
144 concrete specimens were prepared and tested. The first category of specimens that was
145 prepared according to Australian Standards (AS) 1012.8.4 [23] included casting and testing
146 nine concrete prism specimens with dimensions of $75 \times 75 \times 280$ mm. These specimens were
147 divided into three groups. The first group, which is labelled Group UP, included three
148 unreinforced concrete prism specimens and taken as references. The second group consisted
149 of three concrete prism specimens reinforced with a single biaxial geogrid layer located at 20
150 mm from the top of specimen and is named Group GP20. The last three of concrete prism
151 specimens were reinforced with a biaxial geogrid layer placed at 37.5 mm from the top of
152 specimen (middle of thickness) and is labelled Group GP37.5.

153 The second category of specimens, which is suggested in this study to mimic as much as
154 possible the behaviour of concrete pavements, consisted of preparing and testing six concrete
155 slab specimens. They had dimensions of $30 \times 280 \times 280$ mm, as listed in Table 2. The
156 specimens of this category were divided into two groups. The first group included three
157 unreinforced concrete slab specimens (References) and is labelled Group US. The second
158 group included three concrete slab specimens reinforced with a single biaxial geogrid layer

159 placed at 15 mm from the top of specimen and is named Group GS. Fig. 4 and 5 show more
160 details of the concrete prism and slab specimens.

161 The 30 mm thickness of slab specimens was selected in this study to minimize the wide
162 variation of the temperature and moisture gradients the slab surfaces and the middle of
163 thickness of the slab, which are exposed to the environmental conditions. Thus, the readings
164 of the drying shrinkage collected from the gauge studs, which were located at the middle of
165 the slab depth, can be considered as the average of results of the drying shrinkage for the
166 whole slab specimen. In addition, this value of the thickness allows achieving the movement
167 and evaporation of moisture from the slab in one direction (from the top and bottom of the
168 slab surfaces only). This case simulates to the movement and evaporation of moisture for the
169 concrete pavements [1].

170 *4.2 Preparation of moulds*

171 Nine standard metal moulds were used for moulding the prism specimens of the first
172 category, as shown in Fig. 6. They possessed inner dimensions of $75 \times 75 \times 280$ mm. For
173 each prism mould, two steel slides having dimensions of $1.5 \times 75 \times 75$ mm were cut and put
174 inside of the moulds to achieve exactly an inner length of 280 mm. In addition, gauge studs
175 made from stainless steel were used to be the reference points during collecting the test
176 readings. The dimensions of studs satisfied the requirements of AS 1012.13:2015 [24] were
177 22.5 ± 0.1 mm of length and a diameter of 6 mm. Two gauge studs were screwed into the
178 gauge stud holder, one at each of the end of the prism specimens. While, four gauge studs
179 were screwed into the gauge stud holder at each side of the slab specimens.

180 For moulding the concrete specimens of the second category, slab specimens, six timber
181 moulds were designed and prepared in this study, as shown in Fig. 7. They possessed inner
182 dimensions of $30 \times 280 \times 280$ mm. The walls of these moulds were fixed with the base using
183 16 screws. The inside of the moulds was covered with a 0.125 mm thick Vinyl sheet to keep
184 the concrete mix water and to reduce the friction force between the slab and the timber
185 moulds.

186 *4.3 Setup of specimens*

187 The dimensions of the biaxial geogrid layer embedded in the concrete specimens were lower
188 than the entire dimensions of the specimens by about 15 mm for prism specimens and 40 mm
189 for slab specimens, as shown in Fig. 8. This is because the temperature and RH gradients at
190 the edges of concrete specimens are often regular. Thus, the variation in the temperature
191 between the top and bottom of the concrete surface can be negligible [25].

192 To fix the geogrid reinforcement layer during the pouring of concrete at the required level of
193 the slab specimens, a small wire having a diameter of 0.05 mm was used at each corner of the
194 slab and removed after 24 hours from the casting.

195 All specimens were cast on the same day using ready-mixed concrete, which was supplied by
196 Hanson Company, Australia [26]. The proportion of concrete ingredients adopted to achieve
197 the normal compressive strength of concrete is listed in Table 3. The slump of concrete
198 mixture, which was mixed with a 10 mm maximum aggregate size, was 150 mm. The
199 compressive strength of the concrete, which was determined according to the test of three
200 cylinders having a 150 diameter and a 200 mm height, was 37.6 MPa at 28 days age.

201 The process of pouring of concrete inside of the moulds was conducted as follows. Firstly, all
202 moulds were cleaned and lubricated using a thin coating of mineral oil. Enough amount of
203 concrete mixture was poured into the mould and distributed equally for making the required
204 concrete cover. The poured concrete was lightly compacted using the table vibrator with a
205 frequency of 50 Hz. Then, the geogrid layer was put over the concrete cover at the specified
206 location. After that, more concrete was poured into the mould up to being filled, with the
207 compaction using a table vibrator. Finally, the surface of the poured concrete was carefully
208 levelled by the steel trowel. Fig. 9 shows the prism and slab moulds cast with the concrete.

209 **5. Testing of specimens**

210 In this study, the experimental tests conducted on the concrete specimens were achieved by
211 curing and drying these specimens within the controlled environmental conditions. Australian
212 Standards (AS) 1012.8.4 [23] was adopted to conduct these tests. All specimens were
213 assembled at the same location during the whole of the curing and drying time of the
214 specimens. This is to guarantee that all specimens would be exposed to the same
215 environmental conditions.

216 The process of curing was conducted during two main stages before the specimens were
217 dried. The first stage was performed by placing the specimens inside an environmentally
218 controlled chamber, with RH of 95% or more, as shown in Figure 10. This stage continued for
219 24 hours from the casting of the specimens. The controlled chamber used in this stage was
220 installed with two humidifiers that release a water spray. This is to ensure that the percentage
221 of RH inside the chamber remained at 95% or more. To monitor the temperature and RH
222 inside the chamber, two digital measuring devices were installed for this purpose.

223 The second curing stage of the specimens started after 24 hours from the casting of the
224 specimens. It was conducted by submerging the specimens in the water saturated with lime.
225 This stage continued for six days with a temperature of $23 \pm 3^\circ \text{C}$. Figure 11 shows the two
226 containers that included the specimens and filled with lime saturated water.

227 A drying stage of the specimens, which is the stage that the specimens will start to dry and
228 shrink, started after seven days from the casting of the specimens. At this stage, the specimens
229 were placed in a drying chamber, within the temperature and RH of $23 \pm 3^\circ \text{C}$ and $60 \pm 10\%$,
230 respectively. Fig. 12 shows the drying chamber.

231 The drying chamber, which is a fridge modified for this study to keep the temperature and RH
232 within the required level, was installed with an air heater connected with a timer to keep the
233 temperature at $23 \pm 3^\circ \text{C}$. Also, an air fan having a 96 mm diameter was supplied to create air
234 circulation around the specimens. A high accuracy sensor of RH was installed inside the
235 drying chamber to measure the RH during the drying period. To further control the RH,
236 especially at the early age of concrete, one kilogram of silica gel particles was prepared and
237 spread inside the drying chamber. This stage continued for 56 days from the casting of the
238 specimens.

239 **6. Experimental results and discussion**

240 Nine concrete prisms and six of concrete slabs were tested by drying them in the controlled
241 environmental conditions, at a temperature of $23 \pm 3^\circ \text{C}$ and RH of $60 \pm 10\%$.

242 The changes in the length, in one direction, of prisms and the changes in the area, in two
243 directions, of slabs were measured over the drying time. Test readings of drying shrinkage of
244 the specimens were collected at the total drying period of 7, 14, 21, 28, and 56 days. All
245 results calculated herein were the average of five readings taken for each specimen for each

246 group, which includes three specimens. These results were determined using the vertical
247 comparator device, as shown in Fig. 13.

248 The analysis and evaluation of test results were conducted through dividing the findings into
249 four intervals, which are: 7 to 14, 14 to 21, 21 to 28, and 28 to 56 days. Fig. 14, 15 and 16 and
250 Table 3 present a summary of the experimental results.

251 *6.1 Drying Shrinkage behaviour of prism specimens*

252 The drying shrinkage behaviour of Groups UP, GP20 and GP37.5 were analysed and
253 evaluated. Fig. 14 shows the average of drying shrinkage strains versus the intervals of drying
254 shrinkage.

255 At the first interval, 7 to 14 days, the drying shrinkage strains of Groups GP20 and GP37.5
256 were greater than Group UP by about 7% and 14%, respectively. This is because the concrete
257 at this time still had a high percentage of porosities. These porosities, spread in the concrete
258 matrix, were still filled with the free water. This results in impairment of the bond between
259 the geogrid layer and the surrounding concrete. As a result, the role of the geogrid
260 reinforcement as a shrinkage restraining layer is lower. However, this situation is identical
261 with the behaviour of drying shrinkage of concrete pavements reinforced with fibre [1].

262 In the following intervals, the effect of geogrid on the shrinkage behaviour of Groups GP20
263 and GP37.5 started to be visible. This is because the concrete matrix started gaining their
264 appropriate hardness. It is due to progress in the process of the hydration of concrete. As a
265 result, the property of the bond between the geogrid layer and the concrete was increased.

266 For intervals of 14 to 56 days, the drying shrinkage strains were reduced by about 3 to 15%
267 for Group GP20 and 7 to 17% for Group GP37.5 in comparison with the reference (Group
268 UP).

269 From the same figure, Fig. 14, the drying shrinkage behaviour of Groups GP20 and GP37.5,
270 which differed in the locations of geogrid layer, was slightly different. For intervals of 7 to 14
271 and 14 to 21 days, the percentage of increase of the drying shrinkage strains of Group GP37.5
272 was 2% to 6% more than that of Group GP20. While, for the intervals of 21 to 28 and 28 to
273 56 days, the percentage of increase of the shrinkage strains for Group GP20 was 1.2% to 3%
274 more than that of Group GP37.5. This clearly reflects the influence of location of the geogrid
275 layer in the concrete specimens, which should be located as nearly as possible to the surfaces
276 exposed to drying.

277 It should be noted that the results of drying shrinkage strains of the concrete specimens
278 reinforced with the geogrid were generally lower, when compared with the unreinforced
279 concrete specimens. It can say, this is because these specimens were dried within the
280 moderate environmental conditions, at a temperature of $23 \pm 3^\circ \text{C}$ and RH of $60 \pm 10\%$. These
281 conditions gradually have a low impact on the shrinkage behaviour of concrete specimens in
282 conjunction with the progress of hardening process of the concrete.

283 *6.2 Rate of drying shrinkage of the prism specimens*

284 The rate of drying shrinkage of concrete prism specimens can be defined, for this study, as the
285 quantity measurement that aims to compare the average of drying shrinkage that occurred for
286 geogrid reinforced concrete specimens during the drying time compared to unreinforced
287 concrete specimens.

288 Fig. 15 shows results of the rate of average drying shrinkage of Groups GP20 and GP37.5
289 compared to Group UP (reference) for each interval. In this figure, the rate of average drying
290 shrinkage of Group UP was considered a fixed datum for comparison purposes and has a zero
291 value. Thus, the negative sign means that the rate of average drying shrinkage of Groups
292 GP20 and GP37.5 was greater than the reference. While the positive sign means that the rate
293 of average drying shrinkage of Groups GP20 and GP37.5 was lower than the reference.

294 It can clearly be seen that, during the interval of 7 to 14 days, the rate of drying shrinkage of
295 Groups GP20 and GP37.5 was achieved at a higher rate than the reference, about 0.0077 to
296 0.0147 mm/day, respectively. This illustrates that, when the concrete is still fresh, the geogrid
297 reinforcement may contribute in increasing the rate of drying shrinkage of concrete.

298 The rate of drying shrinkage of Groups GP20 and GP37.5 during the intervals of 14 to 21 and
299 21 to 28 became lower than the reference by about 0.0001 to 0.0014 mm/day. This
300 emphasises that the effect of geogrid reinforcement as the restraint of drying shrinkage starts
301 when the concrete had an appropriate stiffness. While at the interval of 28 to 56 days, Groups
302 GP20 and GP37.5 started to shrink at a slow rate because the specimens were dried within the
303 moderate environmental conditions.

304 *6.3 Drying Shrinkage behaviour of slab specimens*

305 The average of drying shrinkage strains of the concrete slab specimens versus the intervals of
306 drying shrinkage are shown in Fig. 16. Although the slab specimens generally reflected the
307 compatible shrinkage behaviour of concrete, the drying shrinkage strains at the interval of 14
308 to 21 were slightly different.

309 However, the geogrid reinforcement proved that it has an impact in reducing the drying
310 shrinkage strains of concrete slab specimens reinforced with the geogrid (Group GS) by about
311 7% more than the reference (Group US). This is clearly demonstrated at the interval of 7 to 14
312 days. At the end of drying period, 28 to 56 days, the results of shrinkage strains of Groups US
313 and GS were nearly equal.

314 **7. Conclusions**

315 The drying shrinkage behaviour of concrete prism and slab specimens reinforced with the
316 biaxial geogrid layer was investigated. The specimens were dried within the controlled
317 environmental conditions, at a temperature of $23 \pm 3^\circ \text{C}$ and RH of $60 \pm 10\%$.

318 The changes in the length of the prisms and the changes in the area of the slab specimens
319 were measured and evaluated. According to the findings of the test, the principal conclusions
320 can be drawn as follow:

321 1. Except of the first drying interval, 7 to 14 days, the geogrid reinforcement could reduce the
322 drying shrinkage strains of the concrete prism specimens between 0.7% to 15% more than the
323 reference.

324 2. The geogrid reinforcement could decrease the drying shrinkage strains during the early age
325 of the specimens of Group G20. While, after 21 days of the casting, the geogrid layer in both
326 Groups GP20 and GP37.5 showed nearly the same effect.

327 3. The rate of drying shrinkage of Groups GP20 and GP37.5 declined by about 2% more than
328 the unreinforced specimens during the drying duration.

329 4. For the concrete slab specimens, the geogrid reinforcement could reduce the shrinkage
330 strains by about 7 to 28% in comparison with the control specimens.

331 5. The concrete slab specimens were suggested in this study to simulate the behaviour of
332 concrete pavements in providing a wide surface area exposed to the effect of environmental
333 conditions. However, more experimental studies are required before they are adopted.

334 **Acknowledgement**

335 The authors present special acknowledgements to senior technical officers Mr Alan Grant, Mr
336 Richard Gasser, Mrs Ling (Linda) Tie and Mr Richard Berndt, and to all of the staff of the
337 High Bay Laboratory at the School of Civil, Mining, and Environmental Engineering at the
338 University of Wollongong, Australia. Also, the first author would like to thank the Ministry of
339 High Education and Scientific Research of Iraq and University of Wollongong for supporting
340 his PhD scholarship.

341

342

343

344

345

346

347 **References**

- [1] N. Jafarifar, K. Pilakoutas, T. Bennett, Moisture transport and drying shrinkage properties of steel-fibre-reinforced-concrete, *Construction and Building Materials*, 73 (2014) 41-50.
- [2] F. Pelisser, A.B.D.S.S. Neto, H.L.L. Rovere, R.C.D.A. Pinto, Effect of the addition of synthetic fibers to concrete thin slabs on plastic shrinkage cracking, *Construction and Building Materials*, 24 (2010) 2171-2176.
- [3] R.E. Asbahan, J.M. Vandenbossche, Effects of Temperature and Moisture Gradients on Slab Deformation for Jointed Plain Concrete Pavements, *Journal of Transportation Engineering*, 137 (2011) 563-570.
- [4] J. Zhang, D. Hou, Y. Han, Micromechanical modeling on autogenous and drying shrinkages of concrete, *Construction and Building Materials*, 29 (2011) 230-240.
- [5] S. Kim, K. Gopalakrishnan, H. Ceylan, A simplified approach for predicting early-age concrete pavement deformation, *J. Civ. Eng. Manage.*, 17 (2011) 27-35.
- [6] J. Zhang, H. Dongwei, S. Wei, Experimental study on the relationship between shrinkage and interior humidity of concrete at early age, *Mag Concr Res*, 62 (2010) 191-199.
- [7] Y. Shao, A. Mirmiran, Control of Plastic Shrinkage Cracking of Concrete with Carbon Fiber-Reinforced Polymer Grids, *J. Mater. Civ. Eng.*, 19 (2007) 441-444.
- [8] Z. Ahmad, A. Ibrahim, P. Tahir, Drying shrinkage characteristics of concrete reinforced with oil palm trunk fiber, *International Journal of Elegancy Science and Technology*, 2 (2010) 1441-1550.
- [9] D.P. Bentz, W.J. Weiss, Internal Curing: A 2010 State-of-the-Art Review, National Institute of Standards and Technology [NIST], (2011).
- [10] E. Güneysi, M. Gesoğlu, A. Mohamadameen, R. Alzebaree, Z. Algin, K. Mermerdaş, Enhancement of shrinkage behavior of lightweight aggregate concretes by shrinkage reducing admixture and fiber reinforcement, *Construction and Building Materials*, 54 (2014) 91-98.

- [11] Y. Wei, W. Guo, X. Zheng, Integrated Shrinkage, Relative Humidity, Strength Development, and Cracking Potential of Internally Cured Concrete Exposed to Different Drying Conditions, *Drying Technology*, (2015) 1-37.
- [12] K. Kim, S. Chun, Evaluation of Internally Cured Concrete Pavement Using Environmental Responses and Critical Stress Analysis, *Ind. J. Concr. Struct. Mater.*, 9 (2015) 463-473.
- [13] A.M. Ghaly, Flexural performance of rubberized concrete panels reinforced with polymer grid, *J. Green Build.*, 1 (2006) 101-117.
- [14] F.E. Meski, G.R. Chehab, Flexural behavior of concrete beams reinforced with different types of geogrids, *J. Mater. Civ. Eng.*, 26 (2014).
- [15] A. Arulrajah, M.A. Rahman, Evaluation of interface shear strength properties of geogrid-reinforced construction and demolition materials using a modified large-scale direct shear testing apparatus, *J. Piratheepan, M.W. Bo, M.A. Imteaz, J. Mater. Civ. Eng.*, 26 (2014) 974-982.
- [16] R. Siva Chidambaram, P. Agarwal, The confining effect of geo-grid on the mechanical properties of concrete specimens with steel fiber under compression and flexure, *Construction and Building Materials*, 71 (2014) 628-637.
- [17] R. Siva Chidambaram, P. Agarwal, Flexural and shear behavior of geo-grid confined RC beams with steel fiber reinforced concrete, *Construction and Building Materials*, 78 (2015) 271-280.
- [18] R. Siva Chidambaram, P. Agarwal, Inelastic behaviour of RC beams with steel fibre and polymer grid confinement, *Indian Concr J*, 89 (2015) 83-90.
- [19] W. Wang, M.N. Sheikh, M.N.S. Hadi, Axial compressive behaviour of concrete confined with polymer grid, *Materials and Structures*, (2015) 1-17.
- [20] X. Tang, G.R. Chehab, S. Kim, Laboratory study of geogrid reinforcement in Portland

cement concrete, 6th RILEM International Conference on Cracking in Pavements, Chicago, IL, (2008) 769-778.

[21] S. Maxwell, W. KIM, T.B. EDIL, C.H. Benson, Effectiveness of geosynthetics in stabilizing soft subgrades, Final Rep. No. 0092-45-15, Dept. of Civil and Environmental Engineering, Univ. of Wisconsin-Madison, Madison, (2005).

[22] ASTM D6637-15, Standard test method for determining tensile properties of geogrids by the single or multi-rib tensile method, American Society for Testing and Materials, West Conshohocken, PA, USA, (2015).

[23] AS 1012.8.4-2015, Methods of testing concrete; Method 8.4: Method for making and curing concrete-drying shrinkage specimens prepared in the field or in the laboratory, Standards Australia, Sydney, Australia, (2015).

[24] AS 1012.13-2015, Methods of testing concrete; Method 13: Determination of the drying shrinkage of concrete for samples prepared in the field or in the laboratory, Standards Australia, Sydney, Australia, (2015).

[25] Y. Qin, J.E. Hiller, Modeling the temperature and stress distributions in rigid pavements: Impact of Solar Radiation absorption and heat history development, KSCE Journal of Civil Engineering, 15 (2011) 1361-1371.

[26] Hanson Australia Pty Ltd, Ready Mix Concrete Supplier, Australia, Sydney, Picton (NSW)2571, 2017, <<http://www.hanson.com.au>>

[27] Grace Construction Products and Darex Packing Technologies, GCP Applied Technologies, Issues of Construction Products, Australia, Brisbane, 2016, <<file:///E:/Suggest%20reading/Shrinkage%20file/WRDA%20PN20%20adimetre.pdf>>

348

349

350 **List of Figures**

351 Fig. 1. Biaxial geogrid

352 Fig. 2. Tensile test of single biaxial geogrid sample. (a) Fixing the biaxial geogrid sample by
353 clamps with testing machine. (b) Measuring the initial gauge length. (c) Rupture failure of
354 biaxial geogrid sample

355 Fig. 3. Tensile strength versus strain of biaxial geogrid samples

356 Fig. 4. Configurations of concrete prism specimens. (a) Unreinforced concrete prism
357 specimens (UP). (b) Geogrid reinforced concrete prism specimens (GP20). (c) Geogrid
358 reinforced concrete prism specimens (GP37.5)

359 Fig. 5. Configurations of concrete slab specimens reinforced with geogrid (GS)

360 Fig. 6. Standard steel prism moulds

361 Fig. 7. Preparation of timber slab moulds. (a) Walls of slab moulds. (b) Fixing the walls with
362 the base of slab moulds. (c) Slab moulds

363 Fig. 8. Biaxial geogrid layer inside the moulds. (a) For concrete prism specimens. (b) For
364 concrete slab specimens

365 Fig. 9. Casting of concrete prism and slab specimens

366 Fig. 10. Initial curing environmental chamber of concrete specimens

367 Fig. 11. Containers of concrete specimens utilised at the standard moist curing stage

368 Fig. 12. Modified drying chamber. (a) Front view of the modified drying chamber. (b)
369 Specimens inside the modified drying chamber. (c) Environmental control tools

370 Fig. 13. Vertical comparator device

371 Fig. 14. Average of drying shrinkage strains versus intervals of readings for unreinforced and
372 geogrid reinforced concrete prism specimens

373 Fig. 15. Rate of drying shrinkage of unreinforced and geogrid reinforced concrete prism
374 specimens

375 Fig. 16. Average of drying shrinkage strains versus intervals of readings for unreinforced and
376 geogrid reinforced concrete slab specimens

377

378

379

380

381

382

383

384

385

386

387

388

389

390

391 **List of Tables**

392 Table 1. Physical and mechanical properties of biaxial geogrid samples

393 Table 2. Test matrix of experimental study

394 Table 3. Mixture proportion of concrete [27]

395 Table 4. Drying shrinkage test results

396

397

398

399

400

401

402

403

404

405

406

407

408

Table 1. Physical and mechanical properties of biaxial geogrid samples.

Test measurements	Biaxial geogrid samples				
	1	2	3	4	5
Geosynthetic products	Biaxial geogrid				
Rib pitch (mm)	38 × 38				
MidRib depth (mm)	2.0				
MidRib width (mm)	3.0				
Nodal thickness (mm)	4.0				
Initial gauge length of sample (mm)	197	203	197	197	197
Tensile strength of sample (N)	1222	1467	1322	1258	1436
Elongation of sample (mm)	57	109	79	64	96
Percentage increase of elongation (%)	29	54	40	32	49
Average of tensile strength of samples (N)	1341				
Average of elongation of samples (mm)	81				
Standard deviation of the results of tensile strength (N)	96.52				

409

410

411

412

413

414

415

416

417

418

419

420

421

422

423

424

425

426

427

428

429

430

431

432

433

434

Table 2. Test matrix of experimental study.

Specimens group	Specimen Label	Number of specimens	Specimen size (mm)	Reinforcement condition	Reinforcement material	Location ^a of geogrid (mm)
	UP	3		Unreinforced	-----	-----
Prism group	GP20	3	75×75×280	Reinforced	Biaxial geogrid	20
	GP37.5	3		Reinforced	Biaxial geogrid	37.5
	US	3		Unreinforced	-----	-----
Slab group	GS	3	30 × 280×280	Reinforced	Biaxial geogrid	15

^a : The location of biaxial geogrid layer from the top of specimen.

435

436

437

438

439

440

441

442

443

444

445

446

447

448

449

450

451

452

453

454

455

456

457

458

459

460

461

Table 3. Mixture proportion of concrete [27].

Concrete ingredients	Cement (kg/m ³) general purpose type	Fly ash (kg/m ³)	Slag (kg/m ³)	Sand (kg/m ³)	Fine Sand (kg/m ³)	Coarse aggregate (10 mm size) (kg/m ³)	Water reducing admixture-PN20* (ml/m ³)	Water (Liters/m ³)
Dosage	164.05	65.62	98.43	339.69	687.79	829.13	1476	132.09

* Admixture-PN20 is an aqueous solution of polycarboxylate polymers and hydrocarbons [27].

462

463

464

465

466

467

468

469

470

471

472

473

474

475

476

477

478

479

480

481

482

483

484

485

486

487

488

489

490

491

Table 4. Drying shrinkage test results.

Concrete prism specimens									
Group label	Age of drying time (days)					Intervals of drying shrinkage readings (days)			
	7	14	21	28	56	7 to 14	14 to 21	21 to 28	28 to 56
	Average of readings of drying shrinkage (mm)					Average of shrinkage strains (10^{-6}) (mm/mm)			
UP	6.873	6.142	5.861	5.806	6.218	2926	1124	221	1648
GP20	7.371	6.585	6.312	6.265	6.674	3142	1094	188	1636
GP37.5	7.293	6.458	6.179	6.134	6.538	3337	1117	182	1616
Concrete slab specimens									
Group label	Age of drying time (days)					Intervals of drying shrinkage readings (days)			
	7	14	21	28	56	7 to 14	14 to 21	21 to 28	28 to 56
	Average of readings of drying shrinkage in the two directions (mm)					Average of shrinkage strains in the two directions (10^{-6}) (mm/mm)			
US	7.111	6.373	6.165	6.137	6.514	2949	834	112	1508
GS	6.910	6.222	5.923	5.902	6.282	2748	1197	80	1520