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1 The short-term and creep mechanical behaviour of clayey soil-Geocomposite
2 Drainage Layer interfaces subjected to environmental loadings

3
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8
9 **Abstract:** In this paper, to investigate the impact of environmental loadings on the
10 short-term and creep mechanical characteristics of different types of clayey soil-
11 Geocomposite Drainage Layers (GDL) interfaces, a series of rapid loading and creep
12 shear tests were conducted on Mercia Mudstone Clay-GDL interfaces and Kaolin Clay-
13 GDL interfaces subjected to drying-wetting cycles, thermal cycles and elevated
14 temperature, etc, using a bespoke temperature and stress-controlled large direct shear
15 apparatus. The experimental results indicate that, compared with the original specimens,
16 the interfaces subjected to drying-wetting cycles, thermal cycles and elevated
17 temperature, have lower peak shear strength and creep shear resistance. For example,
18 under 25 kPa normal stress, the peak shear strength of original Mercia Mudstone Clay-
19 GDL interfaces and Kaolin Clay-GDL interfaces falls by 11.91 % and 10.11 %,
20 respectively, when subjected to 1 drying-wetting cycle. This can be ascribed to the
21 weakening of interlocking effects and skin friction between soil and GDL caused by
22 the softening of drainage core and geotextile fibres of GDL. The peak shear strength of
23 clayey soil-GDL interfaces subjected to one drying-wetting cycle is lower than that
24 subjected to one thermal cycle because of the reduction in the peak shear strength of
25 clayey soil above GDL during drying-wetting cycles. The impact of drying alone on

26 the decrease in the peak shear strength of clayey soil-GDL interfaces during drying
27 cycles with heating is small, and the main influence factor is the elevated temperature.

28

29 **Keywords:** Geosynthetics; Geocomposite Drainage Layers; interface shear strength;
30 creep; drying-wetting cycles; thermal cycle

31

32 **1 Introduction**

33 Geocomposite Drainage Layers (GDL) are increasingly applied in a wide range of
34 geotechnical and geoenvironmental applications, which can replace traditional
35 solutions of adopting layers of graded sand and gravel to effectively drain excess water
36 and reduce pore water pressure, improving the stability of engineering projects
37 (Bahador et al., 2013; Chinkulkijniwat et al., 2017; Jang et al., 2015; Stormont et al.,
38 2009). Especially for the GDL placed underneath cover soil above landfills, it can also
39 provide separation and reinforcement functions and perform as a capillary break to
40 prevent the migration of contaminated water and gas produced from waste materials
41 (Khire and Haydar, 2007). For the engineering projects installed with GDL, their
42 stability is mainly governed by the mechanical properties of interfaces between the
43 GDL and adjacent soil (Othman et al., 2018). Thus, assessments of the mechanical
44 characteristics for soil-GDL interfaces are vital for the application of GDL in
45 engineering projects.

46

47 In the operational phase of engineering facilities installed with GDL, the soil-GDL
48 interfaces within the facilities can experience both shear stresses and climatic loadings,
49 such as, drying-wetting cycles, thermal cycles, and elevated temperature, etc (Bouazza

50 et al., 2011; Fleureau et al., 2002; Koerner and Koerner, 2006). The environmental
51 factors have non-negligible influences on the interaction mechanism between the
52 installed GDL and adjacent soil, significantly changing the mechanical properties of the
53 soil-GDL interfaces (Othman, 2016). For example, cover soil-GDL interfaces in
54 landfills are usually exposed to elevated temperature due to exothermal reaction from
55 waste biodegradation and hydration, with temperature ranging from 30 °C to 60 °C
56 inside the landfills, decreasing the stiffness of the GDL (Abuel-Naga and Bouazza,
57 2013; Hanson et al., 2015; Jafari et al., 2014). Additionally, drying-wetting cycles and
58 thermal cycles, generated by rainfall and ambient temperature variation, also have non-
59 negligible impact on the mechanical properties of cover soil-GDL interfaces over the
60 lifespan of landfills (Hosney and Rowe, 2013). This is because, in general, the thickness
61 of cover soil for landfills is relatively small (about 0.5 m to 2 m), thus is susceptible to
62 rain water and ambient air temperature cycles through its full thickness (McCartney and
63 Zornberg, 2010). Whilst the high temperature inside landfills further accelerates the
64 evaporation of water in the cover soil-GDL interfaces during drought, promoting the
65 formation of obvious drying-wetting cycles on the cover soil-GDL interfaces during
66 climatic changes, which may cause potential safety hazards on the long-term operation
67 of landfills (Li et al., 2016).

68

69 In the existing investigations, the detrimental influences of elevated temperature and
70 drying-wetting/thermal cycles on the mechanical properties of soil and polymer
71 geosynthetics have been documented (Abuel-Naga and Bouazza, 2013; Guan et al.,
72 2010; Ishimori and Katsumi, 2012; Singh and Bouazza, 2013). For instance, due to the
73 presence of thermoplastic materials, the decrease in tensile strength and modulus of
74 polymer geosynthetics occurs in elevated temperature (Wang et al., 2016; Zhang et al.,

75 2015). Additionally, the decline in shear strength of soil was observed owing to the
76 development of cracks and structure damage for the soil subjected to drying-wetting
77 cycles (Guney et al., 2007; Md et al., 2016). However, due to the limitation of
78 experimental equipment, studies about the mechanical responses of soil-geosynthetics
79 interfaces subjected to environmental factors have rarely been reported, let alone the
80 investigation of soil-GDL interfaces, because the conventional displacement-controlled
81 direct shear apparatus cannot hold constant shear stresses whilst varying other
82 parameters, such as, temperature, drying and wetting conditions, etc. to impose
83 environmental loadings on the interfaces. Besides, it is impossible for the displacement-
84 controlled direct shear apparatus to conduct creep tests on soil-geosynthetics interfaces
85 (Fox and Stark, 2015). Moreover, the displacement-controlled direct shear tests that are
86 not sufficiently representative of the real situation in engineering applications because,
87 in reality, the shear displacement of soil-geosynthetics interfaces is controlled by stress
88 rather than displacement (Frost and Karademir, 2016).

89

90 This is the second paper of two related papers. The first paper describes the bespoke
91 stress and temperature-controlled large direct shear apparatus on soil-geosynthetics
92 interfaces in detail (Chao and Fowmes, 2021). The aim of this second paper is to
93 demonstrate in depth understanding of the mechanical responses of multiple of clayey
94 soil-GDL interfaces under environmental loadings. A series of rapid loading direct
95 shear tests and creep shear tests on Mercia Mudstone Clay-GDL interfaces and Kaolin
96 Clay-GDL interfaces subjected to drying-wetting cycles, thermal cycles, and elevated
97 temperature etc, were performed using the self-designed stress and temperature-
98 controlled large direct shear apparatus, respectively. Whilst preliminary experimental
99 results of Mercia Mudstone Clay-GDL interfaces have been presented in the first paper,

100 this paper contains the full testing programme and allows the impacts of environmental
101 factors on the short-term and creep mechanical characteristics of different kinds of
102 clayey soil-GDL interfaces to be analysed.

103

104 **2 Experimental program**

105 *2.1 Experimental apparatus*

106 The bespoke temperature and stress-controlled large direct shear apparatus developed
107 consists of four primary systems: normal stress system, shear stress system, heating
108 system, and data acquisition and control system, as shown in Figure 1. The detailed
109 introduction of the apparatus can be found in Chao and Fowmes (2021) .

110

111 *2.2 Materials*

112 *2.2.1 Soil*

113 Two types of soils were adopted in this paper:(1) Kaolin Clay and (2) Mercia Mudstone
114 Clay. both derived from the UK. The Kaolin Clay and Mercia Mudstone Clay is
115 classified as medium plasticity clay (CM) and low plasticity clay (CL) according to
116 BS5930 (Dumbleton, 1981). The reason for selecting the two types of soil is to
117 investigate and compare the impacts of environmental factors on mechanical properties
118 of interfaces between GDL and clayey soils with different plasticity characteristics. The
119 results of classification tests on the soil are presented in Table 1.

120

121 *2.2.2 GDL*

122 A proprietary GDL (6S250D/NW8) was adopted in this paper. The GDL is composed
123 of a single cusped HDPE (High Density Polyethylene) drainage core with a medium
124 weight non-woven needle-punched and heat-treated staple fibre polypropylene

125 geotextile filter thermally bonded on the dimple side and a lighter geotextile on the flat
126 side. The GDL is often placed underneath the cover soil in landfills for drainage
127 application, which is inevitably influenced by drying-wetting cycles, thermal cycles
128 and elevated temperature. The properties of the GDL are shown in Table 2.

129

130 *2.3 Preliminary sample preparation*

131 Test samples were cut from a GDL roll, according to ASTM D 6072 (ASTM, 2008).
132 The samples with 350 mm in width by 480 mm in length were cut so that shearing was
133 carried out along the machine direction. GDL was clamped to the leading edge of the
134 lower box. Then the upper shear box was filled with 13.02 kg or 13.50 kg of Mercia
135 Mudstone Clay or Kaolin Clay at the optimum moisture content, 11.8 % or 20 %, in
136 three equal increments, 25 mm height of each layer, respectively. The clay was then
137 compacted adopting the light compaction method, and each layer was compacted with
138 16 blows of a tamper. The total height of the Mercia Mudstone Clay or Kaolin Clay
139 specimen above the GDL was 75 mm with density 1.93 g/cm³ or 2.00 g/cm³,
140 respectively. The gap between the upper and bottom shear boxes was adjusted to
141 maintain approximately 1 mm during testing. During the tests, the dimple side of HDPE
142 drainage core for the GDL was upward, and the pyramid-teeth penetrated into the
143 geotextile bonded on the flat side of HDPE drainage core to prevent the relative
144 movement between the GDL and the heating plate.

145

146 *2.4 Experimental procedure*

147 In the paper, both rapid loading shear tests and creep shear tests were carried out to
148 research the short-term and creep mechanical behaviour of clayey soil-GDL interfaces
149 subjected to environmental loadings, including drying-wetting cycles, thermal cycles

150 and elevated temperature, etc, respectively, using the aforementioned self-designed
151 stress and temperature-controlled large direct shear apparatus. Both the rapid loading
152 shear tests and creep shear tests were conducted on two types of interfaces: Mercia
153 Mudstone Clay-GDL interfaces and Kaolin Clay-GDL interfaces.

154

155 2.4.1 Rapid loading shear tests

156 Rapid loading shear tests show that, in the shearing process, shear load is continually
157 increased until soil-GDL interfaces fail. The normal stress ranges from 15 kPa to 50
158 kPa to simulate 0.75-2.5 m of cover soil as is typical in the UK practice. The shearing
159 was initiated after 24 hours consolidation, adding weights at a rate of 10 kg every 5
160 minutes, which was determined by trial and error. The detailed introduction of the tests
161 is as follows:

162

163 (1) Standard rapid loading shear tests: The tests were carried out under normal
164 stress of 15 kPa, 25 kPa and 50 kPa normal stress, at room temperature (22 °C).

165

166 (2) Tests under elevated temperatures: The process of the tests was almost the same
167 with the standard tests, except that the whole process of the tests was conducted
168 at an elevated temperature of 40 °C under normal stress of 15 kPa, 25 kPa and
169 50 kPa.

170

171 (3) Tests subjected to drying-wetting cycles: In the tests, after 24 hours
172 consolidation, the drying process was initiated. Water in the external shear box
173 was discharged, and the heating system was turned on to dry the interface at a
174 constant temperature of 40 °C for 24 hours. After that, the wetting process was

175 started. The heating system was turned off, and water was poured into the
176 external shear box to submerge the interface for 24 hours. This accounts for a
177 single cycle. The cycle was repeated until the required number was reached.
178 Then, the shearing process was conducted on the interface with it submerged
179 into water. In this research, tests after 0,1 and 3 drying-wetting cycles were
180 implemented under normal stresses of 15 kPa, 25 kPa and 50 kPa.

181

182 (4) Tests subjected to thermal cycle: The procedure of the tests was almost the same
183 as the tests subjected to drying-wetting cycles, except that during the drying
184 processes, the interfaces were submerged into water. In this case, tests after 1
185 thermal cycle were conducted under normal stress of 15 kPa, 25 kPa and 50 kPa,
186 respectively.

187

188 (5) Tests subjected to drying-wetting cycle without heating: The procedure of the
189 tests was almost the same as the tests subjected to drying-wetting cycles, except
190 that during the drying process, only water in the external shear box was
191 discharged and the heating system remained switched off to dry interfaces at
192 room temperature of 22 °C for 7 days. In this case, tests after one drying-wetting
193 cycle without heating was conducted under normal stress 25 kPa.

194

195 In order to research the moisture content variation of clay samples under drying-wetting
196 cycle, thermal cycle and drying cycle without heating, the moisture contents of Mercia
197 Mudstone Clay and Kaolin Clay specimens in the top shear box were measured after
198 the drying process of drying-wetting cycle, wetting process of drying-wetting cycle,
199 thermal cycle and drying cycle without heating, respectively. The measurement results

200 shown that the falling magnitudes of soil moisture content during the drying process of
201 drying-wetting cycle and drying cycle without heating, respectively, were almost the
202 same, with about 40 % and 30 % less than the moisture contents of the Mercia Mudstone
203 Clay and Kaolin Clay specimens before experiencing drying process of drying-wetting
204 cycle and drying cycle without heating, respectively. Also, it was found that the
205 moisture contents of clay samples after thermal cycle and the wetting process of drying-
206 wetting cycle were almost the same with the moisture contents of the clay samples
207 before experiencing thermal cycle and wetting process of drying-wetting cycle,
208 respectively.

209 2.4.2 Creep shear tests

210 Creep shear tests were conducted under constant normal stress of 25 kPa (representative
211 of approximately 1.25 m of cover soils) and was taken at the middle stress range of
212 those for the rapid loading tests and a value typical in the UK practice when allowing
213 for top soil and vegetation. For all the creep tests, initially, 24 hours consolidation was
214 conducted, and then weights were added to the hanger until reaching the target creep
215 shear stress. A detailed introduction of the creep tests is as follows:

216

217 (1) Creep tests subjected to drying-wetting cycles: In the tests, five different levels
218 of creep shear stress: 80 %, 70 %, 60 %, 50 %, and 40 % of the peak shear
219 strength for Kaolin Clay-GDL interfaces were adopted. The peak shear
220 strength of Kaolin Clay-GDL interfaces (10.11 kPa) was determined by the
221 standard rapid loading shear tests under 25 kPa normal stress. During the creep
222 tests, initially, the interfaces were imposed by corresponding creep shear stress
223 with being submerged into water. If the horizontal displacement of clayey soil-
224 GDL interfaces had not reached the maximum value (80 mm) after 4 days from

225 imposing the creep shear stress, drying and wetting cycles were imposed on
226 the interfaces. The drying process was conducted before the subsequent
227 wetting process. During the drying process, water in the external shear box
228 was discharged, and the heating system was turned on to dry the interfaces at
229 a constant temperature of 40 °C for 24 hours. During the wetting process, the
230 interfaces were fully submerged into water for 24 hours at the room
231 temperature (22°C). This is one drying-wetting cycle. In this research, three
232 drying-wetting cycles were conducted for each test.

233

234 (2) Creep tests subjected to thermal cycles: In the tests, two different creep shear
235 stress levels of 70 % and 80 % of the peak shear strength for Kaolin Clay-GDL
236 interfaces were adopted. The procedure of the creep tests subjected to thermal
237 cycles was almost the same with the creep tests subjected to drying-wetting
238 cycles, except that, unlike the drying cycles, during the heating cycles, the
239 interfaces were heated to 40 °C whilst being submerged into water. In this
240 research, three thermal cycles were conducted for each test.

241

242 (3) Creep tests subjected to drying-wetting cycles without heating: In the tests, the
243 creep shear stress level 60 % of the peak shear strength for Kaolin Clay-GDL
244 interfaces were adopted. The procedure of the creep tests subjected to drying-
245 wetting cycles without heating was almost the same with the creep tests during
246 drying-wetting cycles with heating, except that during the drying cycle without
247 heating, only water in the external shear box was discharged, and the heating
248 system was kept off to dry the interfaces at the room temperature of 22 °C for
249 7 days. In this case, one drying-wetting cycle without heating was carried out

250 for each test.

251

252 **3 Results and analysis**

253 *3.1 Rapid loading shear tests*

254 3.1.1 Impacts of temperature

255 Relationship curves between horizontal displacement of Kaolin Clay -GDL interfaces
256 at different temperatures against shear stress are drawn in Figure 2. The corresponding
257 curves of Mercia Mudstone Clay-GDL interfaces refer Figure 10 in Chao and Fowmes
258 (2021). The detailed description of the shear displacement of Mercia Mudstone Clay-
259 GDL interfaces under different temperature also refers to the first paper of the two-
260 paper set (Chao and Fowmes, 2021)

261

262 Based on Figure 2, similar to Mercia Mudstone Clay-GDL interfaces, the horizontal
263 displacement of Kaolin Clay-GDL interfaces at elevated temperature is higher than that
264 at room temperature. Moreover, as with Mercia Mudstone Clay-GDL interfaces, with
265 the rise of temperature, the peak shear strength of Kaolin Clay-GDL interfaces
266 decreases, and the decreasing magnitude under low normal stress is larger than that
267 under high normal stress. However, the falling amplitude of Kaolin Clay-GDL
268 interfaces was lower than that of Mercia Mudstone Clay-GDL interfaces. For example,
269 under 50 kPa normal stress, for Kaolin Clay-GDL interfaces, with the rise in
270 temperature, the peak shear strength falls by 2.13 %. Meanwhile, for Mercia Mudstone
271 Clay-GDL interfaces, the value is 5.49 %. Furthermore, similar to Mercia Mudstone
272 Clay-GDL interfaces, the peak shear strength of Kaolin Clay-GDL interfaces at
273 elevated temperature is more sensitive to the rise in normal stress than those at room
274 temperature. For instance, when normal stress is increased from 15 kPa to 50 kPa, the

275 peak shear strength of Kaolin Clay-GDL interfaces at room temperature increases by
276 135.10 %. Meanwhile, for the specimens at elevated temperature, the value is 436.30 %.

277

278 3.1.2 Impacts of drying-wetting cycles

279 The relationship curves between horizontal displacement of Mercia Mudstone Clay/
280 Kaolin Clay-GDL interfaces subjected to drying-wetting cycles against shear stress are
281 drawn in Figure 3.

282

283 Based on Figure 3 (a), the horizontal displacement of Mercia Mudstone Clay-GDL
284 interfaces with a high number of drying-wetting cycles is higher than those with a low
285 number. More specifically, the difference between them increases gradually with the
286 increase in shear stress. Taking the specimens under 50 kPa normal stress as an example,
287 when the shear stress is 1.52 kN/m^2 , the horizontal displacement for the specimen
288 subjected to 3 drying-wetting cycles is 37.14 % and 81.75 % higher than those of
289 specimens subjected to 1 and 0 cycle, respectively. In comparison, when shear stress is
290 2.21 kN/m^2 , these values are 58.62 % and 97.54 %, respectively. Moreover, during
291 drying-wetting cycles, the peak shear strength of the specimens gradually decreases.
292 The extent of this decline under low normal stress is larger than that under high normal
293 stress. This is presented in Figure 4 (a). For example, under 25 kPa normal stress, the
294 peak shear strength of original Mercia Mudstone Clay-GDL interfaces falls by 11.91 %
295 and 38.55 % when subjected to 1 and 3 drying-wetting cycles, respectively. In
296 comparison, under 50 kPa normal stress, these values are 5.83 % and 8.45 % when
297 subjected to 1 and 3 cycles, respectively. Furthermore, the impact of normal stress on
298 the peak shear strength of the specimens subjected to drying-wetting cycles is larger
299 than that of the original specimens. For instance, when normal stress is increased from

300 15 kPa to 50 kPa, the peak shear strength of the original specimens increases by 181 %,
301 whilst for the specimens subjected to 3 cycles, the values is 523 % .

302

303 Based on Figure 3 (b), similar to Mercia Mudstone Clay-GDL interfaces, the horizontal
304 displacement of Kaolin Clay-GDL interfaces with a high number of drying-wetting
305 cycles is higher than those of a low number. However, unlike Mercia Mudstone Clay-
306 GDL interfaces, the difference between the horizontal displacement of Kaolin Clay-
307 GDL interfaces with a high number of drying-wetting cycles and those with a low
308 number does not rise markedly with the increase in shear stress. Taking the specimens
309 under 50 kPa normal stress as an example, when shear stress is 0.90 kN/m^2 , the
310 horizontal displacement for the specimen subjected to 3 drying-wetting cycles is 1.14 %
311 and 1.5 % higher than those subjected to 1 and 0 cycle, respectively. In comparison,
312 when shear stress is 1.32 kN/m^2 , these values are 1.62 % and 1.94 %, respectively.
313 Moreover, as with Mercia Mudstone Clay-GDL interfaces, the peak shear strength of
314 Kaolin Clay-GDL interfaces decrease gradually during drying-wetting cycles. The
315 extent of this decrease under low normal stress is larger than that of under high normal
316 stress, as shown in Figure 4 (b). However, compared to Mercia Mudstone Clay-GDL
317 interfaces, the falling amplitude of Kaolin Clay-GDL interfaces is lower. For example,
318 under 25 kPa normal stress, the peak shear strength of original Kaolin Clay-GDL
319 interfaces falls by 10.11 % and 13.33 % after 1 and 3 drying-wetting cycles,
320 respectively. In comparison, for Mercia Mudstone Clay-GDL interfaces, these values
321 are 11.91 % and 38.55 % after 1 and 3 cycles, respectively. Furthermore, similar to
322 Mercia Mudstone Clay-GDL interfaces, the peak shear strength of Kaolin Clay-GDL
323 interfaces subjected to drying-wetting cycles is more sensitive to the rise in normal
324 stress than that of original specimens.

325

326 3.1.3 Impacts of thermal cycle

327 Relationship curves between horizontal displacement of Mercia Mudstone Clay/ Kaolin
328 Clay -GDL interfaces during thermal cycles against shear stress are drawn in Figure 5.

329

330 Based on Figure 5 (a), the horizontal displacement of Mercia Mudstone Clay-GDL
331 interfaces subjected to 1 thermal cycle is higher than that of the original specimens but
332 lower than those subjected to 1 drying-wetting cycle. Moreover, during the thermal
333 cycle, the decline in peak shear strength was observed. The decreasing amplitudes are
334 lower than those during 1 drying-wetting cycle, respectively, as shown in Figure 3. For
335 instance, under 25 kPa normal stress, after 1 thermal cycle, the peak shear strength of
336 Mercia Mudstone Clay-GDL interfaces falls by 7.85 %. Whilst after 1 drying-wetting
337 cycle, the percentage is 11.91 %.

338

339 Based on Figure 5 (b), similar to Mercia Mudstone Clay-GDL interfaces, the horizontal
340 displacement of Kaolin Clay-GDL interface subjected to 1 thermal cycle is lower than
341 those subjected to 1 drying-wetting cycle and higher than that of the original specimens.
342 Moreover, as with Mercia Mudstone Clay-GDL interfaces, during the thermal cycle,
343 the decreasing amplitude of peak shear strength for Kaolin Clay-GDL interfaces is
344 lower than that during 1 drying-wetting cycle. This is presented in Figure 4. However,
345 the decreasing amplitudes of Kaolin Clay-GDL interfaces during the thermal cycle are
346 lower than those of Mercia Mudstone Clay-GDL interfaces. For instance, under 50 kPa
347 normal stress, for Kaolin Clay-GDL interfaces, the peak shear strength reduces by
348 1.42 %, whilst for Mercia Mudstone Clay-GDL interfaces, the number is 4.43 %.

349

350 3.1.4 Impacts of drying-wetting cycle without heating

351 Relationship curves between horizontal displacement of Mercia Mudstone Clay/ Kaolin
352 Clay -GDL interfaces during drying-wetting cycle without heating against shear stress
353 are drawn in Figure 6.

354

355 Based on Figure 6 (a), the horizontal displacement of Mercia Mudstone Clay-GDL
356 interfaces subjected to 1 drying-wetting cycle without heating is higher than that of the
357 original specimen but lower than those subjected to 1 thermal cycle. Moreover,
358 compared to the original specimen, the decrease in peak shear strength of the specimen
359 subjected to 1 drying-wetting cycle without heating was observed. However, the
360 decreasing amplitudes are lower than those that are subjected to 1 drying-wetting cycle
361 with heating and 1 thermal cycle, respectively. For instance, under 25 kPa normal stress,
362 after 1 thermal cycle, the peak shear strength of Mercia Mudstone Clay-GDL interfaces
363 falls by 7.85 %. Meanwhile, after 1 drying-wetting cycle without heating, the value is
364 3.74 %. This indicates that the impacts of drying alone on the peak shear strength of
365 Mercia Mudstone Clay-GDL interfaces is small, which is lower than those of sole
366 heating and drying with heating, respectively.

367

368 Based on Figure 6 (b), similar to Mercia Mudstone Clay-GDL interfaces, the horizontal
369 displacement of Kaolin Clay-GDL interfaces subjected to 1 drying-wetting cycle
370 without heating is higher than that of the original specimen but lower than those
371 subjected to 1 thermal cycle. Moreover, as with Mercia Mudstone Clay-GDL interfaces,
372 compared with the original specimen, the decrease in peak shear strength of the Kaolin
373 Clay-GDL interface subjected to 1 drying-wetting cycle without heating was observed.
374 However, the decreasing amplitudes are lower than those of the specimens subjected to

375 1 drying-wetting cycle with heating and 1 thermal cycle, respectively. This indicates
376 that the impacts of drying alone on the peak shear strength of Kaolin Clay-GDL
377 interfaces is small, which is lower than those of sole heating and drying with heating,
378 respectively. Additionally, the decreasing amplitudes of peak shear strength of Kaolin
379 Clay-GDL interfaces during drying-wetting cycle without heating are lower than those
380 of Mercia Mudstone Clay-GDL interfaces, respectively. For instance, under 25 kPa
381 normal stress, for Kaolin Clay-GDL interfaces, the peak shear strength reduces by 3.5 %,
382 whilst, for Mercia Mudstone Clay-GDL interfaces, the figure is 3.74 %.

383

384 *3.2 Creep shear tests*

385 3.2.1 Impacts of creep shear level

386 Figure 7 presents the creep shear displacement of Kaolin Clay-GDL interfaces during
387 the whole test. The corresponding curves of Mercia Mudstone Clay-GDL interfaces
388 refer Figure 13 in Chao and Fowmes (2021). The detailed description of the creep
389 deformation of Mercia Mudstone Clay-GDL interfaces under different creep shear
390 stress levels also refers to the first paper of the two-paper set (Chao and Fowmes, 2021).

391

392 Based on Figure 7, similar to Mercia Mudstone Clay-GDL interfaces, the level of creep
393 shear stress has significant impacts on the creep shear deformation of Kaolin Clay-GDL
394 interfaces. The horizontal displacement of Kaolin Clay-GDL interfaces under a high
395 creep shear stress level is higher than those under a low shear stress level. Especially
396 for the Kaolin Clay-GDL interface under 80 % creep shear stress level, the sample fails
397 before the beginning of drying-wetting cycles. In comparison, the Mercia Mudstone
398 Clay-GDL interface remains stable under the 90 % creep shear stress level before the
399 beginning of drying-wetting cycles. When the creep shear stress level is lower than or

400 equal to 70 %, the interfaces become stable after the primary creep stage. Additionally,
401 as with Mercia Mudstone Clay-GDL interfaces, the influence of drying-wetting cycles
402 on the creep displacement of Kaolin Clay-GDL interfaces are large. The impacts are
403 more evident for interfaces under a high creep shear stress level than those under a low
404 creep shear stress level. For example, during the first drying cycle, the horizontal
405 displacement of the interface under 40 % creep shear stress level rises around 0.6 mm,
406 whilst that under 60 % creep shear stress level rises about 2.5 mm. Especially for the
407 interface under 70 % creep shear stress level, it comes to failure caused by the first
408 drying cycle. In comparison, for Mercia Mudstone Clay-GDL interfaces, failure does
409 not occur during the drying-wetting cycles when the creep shear stress level is less than
410 or equal to 70 %.

411

412 3.2.2 Impacts of drying-wetting cycles

413 To further analyse the impact of drying-wetting cycles on creep deformation of the
414 interfaces, taking the beginning time of the first drying cycle as the 0 minute and the
415 horizontal displacement at the beginning of the first drying cycle as 0 mm, curves about
416 horizontal displacement of Kaolin Clay-GDL interfaces under 60 %, 50 % and 40 %
417 creep shear stress levels in elapsed time are drawn in Figure 8. The corresponding
418 curves of Mercia Mudstone Clay-GDL interfaces under 70 %, 60 % and 50 % creep
419 shear stress levels refer Figure 15 in Chao and Fowmes (2021). The detailed description
420 of the creep deformation of Mercia Mudstone Clay-GDL interfaces during drying-
421 wetting cycles also refers to Chao and Fowmes (2021) .

422

423 Based on Figure 8, as with Mercia Mudstone Clay-GDL interfaces, the first drying
424 cycle and wetting cycle have the highest influence over the horizontal displacement of

425 Kaolin Clay-GDL interfaces compared with the following drying and wetting cycles,
426 respectively. Taking the Kaolin Clay-GDL interface under 60 % creep shear stress level
427 as an example, the horizontal displacement rises by 1.5 mm and 1.4 mm during the first
428 drying and first wetting cycle, respectively. Meanwhile, during the third drying cycle
429 and wetting cycle, the value is 0.6 mm and 0.3 mm, respectively. Additionally, as with
430 Mercia Mudstone Clay-GDL interfaces, the impact of drying cycles on the horizontal
431 displacement of Kaolin Clay-GDL interfaces is larger than that of wetting cycles.
432 However, compared to Mercia Mudstone Clay-GDL interfaces, wetting cycles have
433 greater impacts on the creep deformation of Kaolin Clay-GDL interfaces. For the drying
434 cycles, the opposite phenomenon is observed. For instance, under 50 % creep shear
435 stress level, the horizontal displacement of Kaolin Clay-GDL interfaces increases about
436 2 mm during the first drying cycle, whereas this is 4.6 mm for Mercia Mudstone Clay-
437 GDL interfaces. In comparison, during the first wetting cycle, the horizontal
438 displacement of Mercia Mudstone Clay-GDL interfaces and Kaolin Clay-GDL
439 interfaces rises by 0.34 mm and 1.37 mm, respectively.

440

441 3.2.3 Impacts of thermal cycles

442 The experimental results of the creep tests on Kaolin Clay-GDL interfaces subjected to
443 thermal cycles and the creep tests subjected to drying-wetting cycles under the same
444 creep shear stress level are plotted in Figure 9. The corresponding curves of Mercia
445 Mudstone Clay-GDL interfaces during thermal cycles refer Figure 16 in Chao and
446 Fowmes (2021). In order to further determine that, during the drying cycles, the
447 increase in creep shear displacement of Clayey soil-GDL interfaces is due to the
448 combined impacts of elevated temperature and drying or the individual impact of the
449 two factors, taking the beginning time of the first drying/thermal cycle as the 0 minute

450 and the horizontal displacement at the beginning of the first drying/thermal cycle as 0
451 mm, the horizontal displacement of Kaolin Clay-GDL interfaces subjected to thermal
452 cycles and subjected to drying-wetting cycles under 60 % creep shear stress level in
453 elapsed time was drawn in Figure 10, respectively. The corresponding curves of Mercia
454 Mudstone Clay-GDL interfaces under 70 %, creep shear stress levels refer Figure 17 in
455 Chao and Fowmes (2021). The detailed description of the creep deformation of Mercia
456 Mudstone Clay-GDL interfaces during thermal cycles also refers to Chao and Fowmes
457 (2021).

458

459 Based on Figure 9, similar to Mercia Mudstone Clay-GDL interfaces, the horizontal
460 displacement of Kaolin Clay-GDL interfaces increases markedly during the first
461 thermal cycle. Especially for the Kaolin Clay-GDL interface under 70 % creep shear
462 stress level, failure occurs in the first thermal cycle. However, for the Mercia Mudstone
463 Clay-GDL interface at the same creep shear stress level, failure does not occur during
464 the first thermal cycle. Regarding the Kaolin Clay-GDL interface under 60 % creep
465 shear stress level, the first thermal cycle has the highest influence on the horizontal
466 displacement. For example, during the first thermal cycle, the horizontal displacement
467 rises by around 2.9 mm, whereas during the third thermal cycle, this is about 1 mm.
468 This demonstrates that elevated temperature is an important factor to result in the rise
469 in the horizontal displacement of Kaolin Clay-GDL interfaces during creep deformation.

470

471 Based on Figure 10, similar to Mercia Mudstone Clay-GDL interfaces, the rise in
472 horizontal displacement of Kaolin Clay-GDL interfaces during the thermal cycles is
473 always higher than those during the drying cycles. This can be attributed to the fact that
474 during thermal cycles, the Kaolin Clay-GDL interfaces were submerged in water. This

475 softened the overlaying clay sample to provide more lubrication between Kaolin Clay
476 particles and Kaolin Clay - GDL interfaces, respectively, reducing the shear resistance
477 of Kaolin Clay-GDL interfaces. In comparison, during the drying cycles, the overlaying
478 clay sample was unsaturated. This led to the generation of suction in soil to enhance the
479 shear resistance of Kaolin Clay-GDL interfaces. For example, during the first thermal
480 cycle, the horizontal displacement rises by 2.9 mm, which is around 1.4 mm higher than
481 that during the first drying cycle.

482

483 3.2.4 Impacts of drying cycles without heating

484 The experimental results of the creep tests on Kaolin Clay-GDL interfaces subjected to
485 drying-wetting cycle without heating under the creep shear stress level of 60 % and the
486 corresponding creep tests subjected to drying-wetting cycles and thermal cycles under
487 the same creep shear stress level were plotted in Figure 11. The corresponding curves
488 of Mercia Mudstone Clay-GDL interfaces under 70 %, creep shear stress levels refer
489 Figure 18 in Chao and Fowmes (2021). In order to further determine that, during drying
490 cycles with heating, the increase in creep shear displacement of Clayey soil-GDL
491 interfaces is due to the combined impacts of elevated temperature and drying, or
492 individual impacts of the two factors, taking the beginning time of the first drying cycle
493 without heating, drying cycle with heating and thermal cycle as the 0 minute,
494 respectively, and the horizontal displacement at the beginning of the first drying cycle
495 without heating, drying cycle with heating and the thermal cycle as 0 mm, the horizontal
496 displacement of Kaolin Clay-GDL interfaces subjected to drying-wetting cycle without
497 heating under the creep shear stress level of 60 % and the creep tests subjected to
498 drying-wetting cycles with heating and thermal cycles under the same creep shear stress
499 level in elapsed time was drawn in Figure 12. The corresponding curves of Mercia

500 Mudstone Clay-GDL interfaces under 70 %, creep shear stress levels refer Figure 17 in
501 Chao and Fowmes (2021). The detailed description of the creep deformation of Mercia
502 Mudstone Clay-GDL interfaces during drying-wetting cycle without heating also refers
503 to Chao and Fowmes (2021).

504

505 Based on Figure 11, as with Mercia Mudstone Clay-GDL interfaces, for the Kaolin
506 Clay-GDL interface subjected to drying-wetting cycle without heating, its horizontal
507 displacement keeps stable during the drying cycle without heating. Variation in the
508 horizontal displacement of the interfaces during the drying cycles with heating and
509 during the heating processes of thermal cycles is significantly higher than that during
510 the drying cycle without heating.

511

512 Based on Figure 12, similar to Mercia Mudstone Clay-GDL interfaces, the rise in
513 horizontal displacement of Kaolin Clay-GDL interfaces during the drying cycle without
514 heating is significantly lower than those during the drying cycles with heating and the
515 heating processes of thermal cycles. This can be related to the same mechanism as that
516 for Mercia Mudstone Clay-GDL interfaces. Regarding the specific variation amplitude
517 of horizontal displacement, the horizontal displacement rises by 0.3 mm during the
518 drying cycle without heating, whilst this increase during the first heating process of
519 thermal cycles and the first drying cycle with heating is 3.0 mm and 1.6 mm,
520 respectively. This indicates that the impacts of drying alone on the rise in horizontal
521 displacement of Kaolin Clay-GDL interfaces during drying cycles is marginal and that
522 the main influence factor is elevated temperature.

523

524 **4 Discussion**

525 The peak shear strength and creep shear resistance of clayey soil-GDL interfaces is
526 mobilised from two components: the skin friction between fibres of geotextile bonded
527 on the drainage core of GDL and soil, and the interlocking effects between soil and
528 cusplate elements on the drainage core of GDL (Bacas et al., 2015). In the first paper of
529 the two paper-set (Chao and Fowmes, 2021), the decrease in peak shear strength and
530 creep shear resistance of clayey soil-GDL interfaces at elevated temperature is ascribed
531 to that, due to the presence of thermo-softening plastic materials, the stiffness (modulus)
532 of HDPE drainage core and fibres of geotextiles bonded on the drainage core decreases
533 at elevated temperature, which results in the softening of cusplate elements on the
534 drainage core and the fibres of geotextiles (Hanson et al., 2015). The softening cusplate
535 elements are easier to compress. This reduces the penetrating depth of the cusplate
536 elements into soil, as they are easier to deform during the shearing process, weakening
537 the interlocking effects between soil and GDL. Meanwhile, the softening fibres are
538 easier to align during the shearing process to decrease the skin friction between soil and
539 GDL.

540

541 In rapid loading shear tests, for the interfaces subjected to drying-wetting cycles and
542 thermal cycles, in shearing process, when the temperature of interfaces decreases to the
543 normal level again, although an increase can occur in the stiffness of drainage core, the
544 compressive deformation of the cusplate elements on the drainage core caused by
545 elevated temperature cannot recover fully (Karademir, 2011). It results in the small
546 penetrating depth of the cusplate elements into soil, weakening the interlocking effects
547 between soil and GDL.

548

549 It is noteworthy to mention that, actually, the temperature-related environmental

550 loadings, including elevated temperature, drying-wetting cycles and thermal cycles,
551 have two contradictory effects on the mechanical characteristics of interfaces. More
552 specifically, as aforementioned, the elevated temperature can cause the softening of
553 drainage core and geotextile fibre of GDL to weaken the interlocking effects and skin
554 friction between soil and GDL, resulting in the decrease in the peak shear strength and
555 creep shear resistance of interfaces. On the other hand, at elevated temperature, the
556 softening drainage core and geotextile fibre are easier to be compressed under normal
557 stress to result in larger contact area between soil and GDL than that at normal
558 temperature to rise the skin friction, leading in the increase in the peak shear strength
559 and creep shear resistance of interfaces. Overall, the detrimental effects of elevated
560 temperature on the peak shear strength and creep shear resistance of interfaces are
561 higher than the enhancing effects. Thus, when the interfaces are subjected to
562 temperature-related environmental loadings, including elevated temperature, drying-
563 wetting cycles and thermal cycles, the peak shear strength and creep shear resistance of
564 interfaces decreases.

565

566 The higher sensitivity of peak shear strength of interfaces to the temperature-related
567 environmental loadings, including elevated temperature, drying-wetting cycles and
568 thermal cycles, under low normal stress than those under high normal stress can be
569 attributed to the aforementioned two contradictory effects of elevated temperature on
570 the mechanical properties of interfaces. Under high normal stress, the rising contact
571 area between soil and GDL due to the softening drainage core and geotextile fibre
572 caused by elevated temperature is higher than that under low normal stress. The higher
573 rising magnitude of contact area between soil and GDL can provide larger skin friction
574 to improve the enhancing effects of elevated temperature on the peak shear strength and

575 creep shear resistance of interfaces, which can offset more detrimental effects of
576 elevated temperature on the mechanical properties of interfaces to reduce the decreasing
577 magnitude of peak shear strength and creep shear resistance of interfaces when
578 subjected to the temperature-related environmental loadings. Thus, under high normal
579 stress, the peak shear strength of interfaces is less sensitive to the temperature-related
580 environmental loadings than that under low normal stress.

581

582 To further analyse the interaction mechanism, consolidated undrained triaxial shear
583 tests were conducted on the prepared Mercia Mudstone Clay and Kaolin Clay
584 specimens subjected to the same process of drying-wetting cycles on clayey soil-GDL
585 interfaces by being submerged into water for 24 hours to wet and placed in 40 °C
586 temperature for 24 hours to dry. The obtained peak shear strength of the soil specimens
587 were drawn in Figure 13 .Based on Figure 13, for both of Mercia Mudstone Clay and
588 Kaolin Clay specimens, their peak shear strength reduces consistently during drying-
589 wetting cycles, Thus, in rapid loading shear tests, when clayey soil-GDL interfaces
590 were subjected to drying-wetting cycles, the reducing shear strength of clayey soil
591 above GDL further weakens the interlocking effects between clayey soil and GDL,
592 resulting in the larger decreasing amplitude of shear resistance for the interfaces
593 subjected to one drying-wetting cycle than those subjected to one thermal cycle to
594 cause the peak shear strength of the interfaces subjected to one drying-wetting cycle
595 being lower than that subjected to one thermal cycle.

596

597 The reason that, in rapid loading shear tests, the peak shear strength of clayey soil-GDL
598 interfaces subjected to a drying-wetting cycle without heating is slightly lower than that
599 of original specimens but significantly higher than the interfaces subjected to drying-

600 wetting cycles and thermal cycles, respectively, can be attributed to the fact that, in the
601 absence of elevated temperatures, the stiffness of the drainage core and geotextile fibres
602 of the interfaces subjected to drying-wetting cycles without heating is identical to that
603 of original specimens during the tests. The aforementioned softening of the drainage
604 core and weakening of the interlocking effects between clayey soil and GDL caused by
605 the decrease in stiffness of the GDL drainage core does not occur in clayey soil-GDL
606 interfaces subjected to drying-wetting cycle without heating. Only the impacts of
607 drying-wetting cycles alone, which are mentioned in above paragraph are imposed on
608 the short-term mechanical properties of clayey soil-GDL interfaces. This also indicates
609 that the impacts of a drying-wetting cycle alone on the decrease in peak shear strength
610 of clayey soil-GDL interfaces during drying-wetting cycles with heating is marginal,
611 with the main influence factor being elevated temperature.

612

613 Another aspect which should be noted is that Mercia Mudstone Clay-GDL interfaces
614 have higher peak shear strength and can keep stable under larger creep shear stress level
615 than that of Kaolin Clay-GDL interfaces, which can be attributed to the stronger
616 interlocking effects of Mercia Mudstone Clay-GDL interfaces than that of Kaolin-GDL
617 interfaces, resulting from the larger peak shear strength of Mercia Mudstone Clay than
618 that of Kaolin Clay. This is presented in Figure 13.

619

620 The larger influence of temperature-related environmental loadings, including elevated
621 temperature, drying-wetting cycles and thermal cycles on the mechanical properties of
622 Mercia Mudstone Clay-GDL interfaces than that of Kaolin Clay-GDL interfaces can be
623 explained by the following content. As aforementioned, elevated temperature has two
624 contradictory effects on the mechanical properties of interfaces. At elevated

625 temperature, the enhancing effect of elevated temperature on the mechanical properties
626 of interfaces is that the softening drainage core and geotextile fibre can result in larger
627 contact area between soil and GDL to increase the skin friction, resulting in higher peak
628 shear strength and creep shear resistance of interfaces. Since Kaolin Clay is more sticky
629 than Mercia Mudstone Clay, with the same rising contact area, Kaolin Clay can stick to
630 the surface of GDL more strongly to provide higher skin friction between Kaolin Clay
631 and GDL than that between Mercia Mudstone Clay and GDL, resulting in larger
632 enhancing effects of elevated temperature on the peak shear strength and creep shear
633 resistance of Kaolin Clay-GDL interfaces than that of Mercia Mudstone Clay-GDL
634 interfaces. The higher enhancing effects of elevated temperature on the mechanical
635 properties of interfaces can offset more the detrimental effects of elevated temperature
636 to reduce the decreasing magnitude of peak shear strength and creep shear resistance of
637 interfaces when subjected to temperature-related environmental loadings. Thus, the
638 decreasing extent of peak shear strength and increasing extent of creep horizontal
639 displacement for Mercia Mudstone Clay-GDL interfaces are greater than those of
640 Kaolin Clay-GDL interfaces under the impacts of the temperature-related
641 environmental factors, respectively.

642

643 The higher influence of drying-wetting cycle without heating on the mechanical
644 properties of Mercia Mudstone Clay-GDL interfaces than that of Kaolin Clay-GDL
645 interfaces can be contributed to the greater reducing magnitude of peak shear strength
646 of Mercia Mudstone Clay during drying-wetting cycles than that of Kaolin Clay, as
647 presented in Figure 13. The greater reducing magnitude of peak shear strength for soil
648 can cause the larger decreasing magnitude of interlocking effects between soil and GDL
649 to result in the larger decreasing magnitude of peak shear strength and creep shear

650 resistance of interfaces. Therefore, during drying-wetting cycle without heating, the
651 decreasing extent of peak shear strength and increasing extent of creep horizontal
652 displacement for Mercia Mudstone Clay-GDL interfaces are higher than those of
653 Kaolin Clay-GDL interfaces, respectively.

654

655 **5 Conclusion**

656 In this paper, a series of rapid loading shear tests and creep shear tests were conducted
657 on different kinds of clayey soil-GDL interfaces subjected to environmental loadings
658 using the self-designed temperature and stress-controlled large direct shear apparatus.
659 Based on the experimental results, the impacts of drying-wetting cycles, thermal cycles
660 and elevated temperature, etc. on the short-term and creep mechanical characteristics
661 of different kinds of clayey soil-GDL interfaces were investigated. The main
662 conclusions are summarised as follows:

663

664 (1) Under low normal stress, the peak shear strength of clayey soil-GDL interfaces
665 is more sensitive to drying-wetting cycles and elevated temperature than those
666 under high normal stress. This can be attributed to that, under high normal stress,
667 the rising contact area between soil and GDL due to the softening drainage core
668 and geotextile fibre caused by elevated temperature is higher than that under
669 low normal stress, which can provide larger skin friction to improve the
670 enhancing effects of elevated temperature on the peak shear strength and creep
671 shear resistance of interfaces to offset more detrimental effects of elevated
672 temperature, resulting in the reduction of the decreasing magnitude of peak
673 shear strength and creep shear resistance of interfaces when subjected to the
674 temperature-related environmental loadings.

675

676 (2) Compared with the original specimens, the interfaces subjected to drying-
677 wetting cycles, thermal cycles and elevated temperature, have lower peak shear
678 strength and creep shear resistance, For example, under 25 kPa normal stress,
679 the peak shear strength of original Mercia Mudstone Clay-GDL interfaces falls
680 by 38.55 % and 13.33%, respectively, when subjected to 3 drying-wetting
681 cycles. This can be ascribed to the weakening of interlocking effects and skin
682 friction between soil and GDL caused by the softening of drainage core and
683 geotextile fibers of GDL and the decline in the peak shear strength of soil.

684

685 (3) Owing to the larger peak shear strength of Mercia Mudstone Clay than that of
686 Kaolin Clay, the peak shear strength and creep shear resistance of Mercia
687 Mudstone Clay-GDL interfaces is higher than that of Kaolin Clay-GDL
688 interfaces. Additionally, the larger detrimental influence of temperature-related
689 environmental loadings on the peak shear strength and creep shear resistance of
690 Mercia Mudstone Clay-GDL interfaces than those of Kaolin Clay-GDL
691 interfaces can be attributed to that the enhancing effects of elevated temperature
692 on the mechanical properties of Kaolin Clay-GDL interfaces are higher than
693 those of Mercia Mudstone Clay-GDL interfaces to offset more the detrimental
694 effects of elevated temperature, resulting in the reduction of the decreasing
695 magnitude of peak shear strength and creep shear resistance of Kaolin Clay-
696 GDL interfaces when subjected to temperature-related environmental loadings.

697

698 (4) The peak shear strength of the clayey soil-GDL interfaces subjected to one
699 drying-wetting cycle is lower than that subjected to one thermal cycle because

700 of the reduction in the peak shear strength of clayey soil above GDL during
701 drying-wetting cycles.

702
703 (5) The rise in creep displacement of the clayey soil-GDL interfaces during thermal
704 cycles is higher than that during drying cycle with heating because during
705 thermal cycles, the interfaces were submerged by water to soften the overlaying
706 soil to reduce the shear resistance between soil and GDL.

707
708 (6) The decreasing magnitude of peak shear strength and increasing magnitude of
709 creep displacement for the interfaces subjected to drying-wetting cycle without
710 heating is significantly lower than that subjected to drying cycle with heating
711 /thermal cycle, respectively. It indicates that the impacts of drying alone on the
712 decrease in the peak shear strength and creep shear resistance of clayey soil-
713 GDL interfaces during drying cycles with heating is small, and the main
714 influence factor is the elevated temperature.

715

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718

719 **6 Reference**

720 Abuel-Naga, H.M., Bouazza, A., 2013. Thermomechanical behavior of saturated geosynthetic
721 clay liners. *Journal of geotechnical and geoenvironmental engineering* 139, 539-547.

722 ASTM, 2008. Standard practice for obtaining samples of geosynthetic clay liners.

723 Bacas, B., Cañizal, J., Konietzky, H., 2015. Frictional behaviour of three critical geosynthetic
724 interfaces. *Geosynthetics International* 22, 355-365.

725 Bahador, M., Evans, T., Gabr, M., 2013. Modeling effect of geocomposite drainage layers on
726 moisture distribution and plastic deformation of road sections. *Journal of geotechnical and*
727 *geoenvironmental engineering* 139, 1407-1418.

728 Bouazza, A., Nahlawi, H., Aylward, M., 2011. In situ temperature monitoring in an organic-
729 waste landfill cell. *Journal of geotechnical and geoenvironmental engineering* 137, 1286-1289.

730 Chao, Z., Fowmes, G., 2021. Modified stress and temperature-controlled direct shear apparatus
731 on soil-geosynthetics interfaces. *Geotextiles and Geomembranes*.

732 Chinkulkijniwat, A., Horpibulsuk, S., Bui Van, D., Udomchai, A., Goodary, R., Arulrajah, A.,
733 2017. Influential factors affecting drainage design considerations for mechanical stabilised
734 earth walls using geocomposites. *Geosynthetics International* 24, 224-241.

735 Dumbleton, M., 1981. The British soil classification system for engineering purposes: Its
736 development and relation to other comparable systems[Final Report].

737 Fleureau, J.-M., Verbrugge, J.-C., Huergo, P.J., Correia, A.G., Kheirbek-Saoud, S., 2002.
738 Aspects of the behaviour of compacted clayey soils on drying and wetting paths. *Canadian*
739 *geotechnical journal* 39, 1341-1357.

740 Fox, P.J., Stark, T.D., 2015. State-of-the-art report: GCL shear strength and its measurement-
741 ten-year update. *Geosynthetics International* 22, 3-47.

742 Frost, J., Karademir, T., 2016. Shear-induced changes in smooth geomembrane surface
743 topography at different ambient temperatures. *Geosynthetics International* 23, 113-128.

744 Guan, G.S., Rahardjo, H., Choon, L.E., 2010. Shear strength equations for unsaturated soil
745 under drying and wetting. *Journal of Geotechnical and Geoenvironmental Engineering* 136,
746 594-606.

747 Guney, Y., Sari, D., Cetin, M., Tuncan, M., 2007. Impact of cyclic wetting-drying on swelling
748 behavior of lime-stabilized soil. *Building and environment* 42, 681-688.

749 Hanson, J., Chrysovergis, T., Yesiller, N., Manheim, D., 2015. Temperature and moisture
750 effects on GCL and textured geomembrane interface shear strength. *Geosynthetics International*
751 22, 110-124.

752 Hosney, M., Rowe, R.K., 2013. Changes in geosynthetic clay liner (GCL) properties after 2
753 years in a cover over arsenic-rich tailings. *Canadian Geotechnical Journal* 50, 326-342.

754 Ishimori, H., Katsumi, T., 2012. Temperature effects on the swelling capacity and barrier
755 performance of geosynthetic clay liners permeated with sodium chloride solutions. *Geotextiles*
756 *and Geomembranes* 33, 25-33.

757 Jafari, N.H., Stark, T.D., Rowe, R.K., 2014. Service life of HDPE geomembranes subjected to
758 elevated temperatures. *Journal of Hazardous, Toxic, and Radioactive Waste* 18, 16-26.

759 Jang, Y.-S., Kim, B., Lee, J.-W., 2015. Evaluation of discharge capacity of geosynthetic drains
760 for potential use in tunnels. *Geotextiles and Geomembranes* 43, 228-239.

761 Karademir, T., 2011. Elevated temperature effects on interface shear behavior. *Georgia Institute*
762 *of Technology*.

763 Khire, M.V., Haydar, M.M., 2007. Leachate recirculation in bioreactor landfills using
764 geocomposite drainage material. *Journal of geotechnical and geoenvironmental engineering*

765 133, 166-174.

766 Koerner, G., Koerner, R., 2006. Long-term temperature monitoring of geomembranes at dry
767 and wet landfills. *Geotextiles and Geomembranes* 24, 72-77.

768 Li, J., Li, L., Chen, R., Li, D., 2016. Cracking and vertical preferential flow through landfill
769 clay liners. *Engineering Geology* 206, 33-41.

770 McCartney, J.S., Zornberg, J.G., 2010. Effects of infiltration and evaporation on geosynthetic
771 capillary barrier performance. *Canadian Geotechnical Journal* 47, 1201-1213.

772 Md, S.H., Ling-wei, K., Song, Y., 2016. Effect of drying-wetting cycles on saturated shear
773 strength of undisturbed residual soils. *American Journal of Civil Engineering* 4, 143-150.

774 Othman, M., 2016. Interface behaviour and stability of geocomposite drain/soil systems.
775 Loughborough University.

776 Othman, M., Frost, M., Dixon, N., 2018. Stability performance and interface shear strength of
777 geocomposite drain/soil systems, *AIP Conference Proceedings*. AIP Publishing LLC, p. 020049.

778 Singh, R.M., Bouazza, A., 2013. Thermal conductivity of geosynthetics. *Geotextiles and*
779 *Geomembranes* 39, 1-8.

780 Stormont, J.C., Henry, K., Roberson, R., 2009. Geocomposite capillary barrier drain for
781 limiting moisture changes in pavements: Product application. Final Rep., Contract No. NCHRP
782 113.

783 Wang, D.-Y., Tang, C.-S., Cui, Y.-J., Shi, B., Li, J., 2016. Effects of wetting–drying cycles on
784 soil strength profile of a silty clay in micro-penetrometer tests. *Engineering Geology* 206, 60-
785 70.

786 Zhang, B., Zhang, J., Sun, G., 2015. Deformation and shear strength of rockfill materials
787 composed of soft siltstones subjected to stress, cyclical drying/wetting and temperature
788 variations. *Engineering Geology* 190, 87-97.

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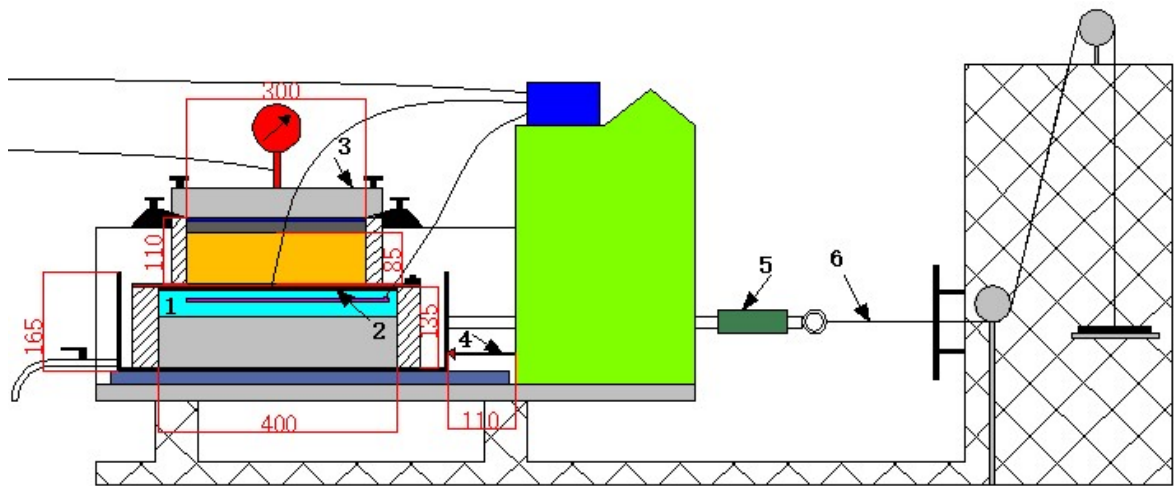
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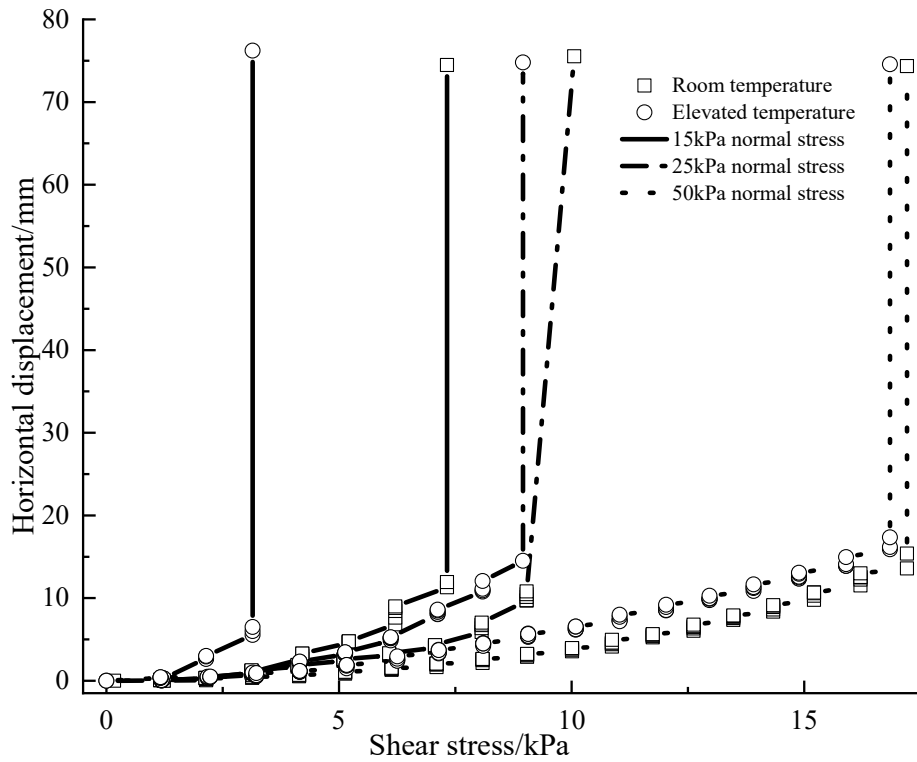
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804 1. Aluminium heating plate 2. Pyramid teeth gripping plate 3. Air pressure bladder 4.
805 Horizontal movement transducer 5. Load cell 6. Steel wire

806

Figure 1 The schematic diagram of the developed apparatus

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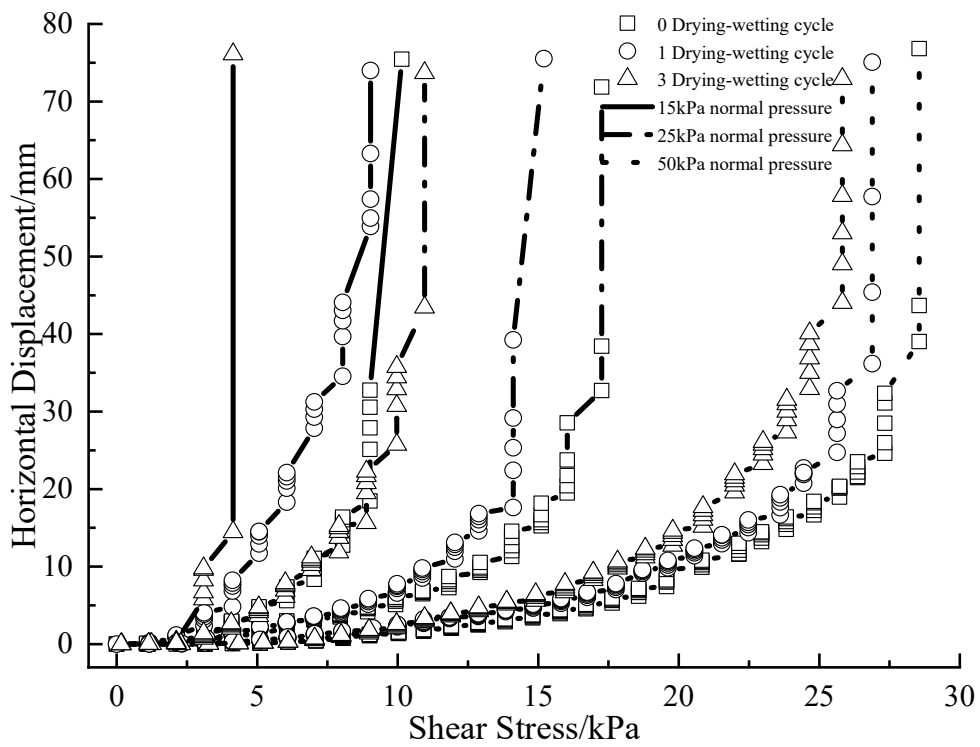
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809 Figure 2 Shear stress-horizontal displacement curves of Kaolin Clay-GDL interfaces

810

at different temperatures

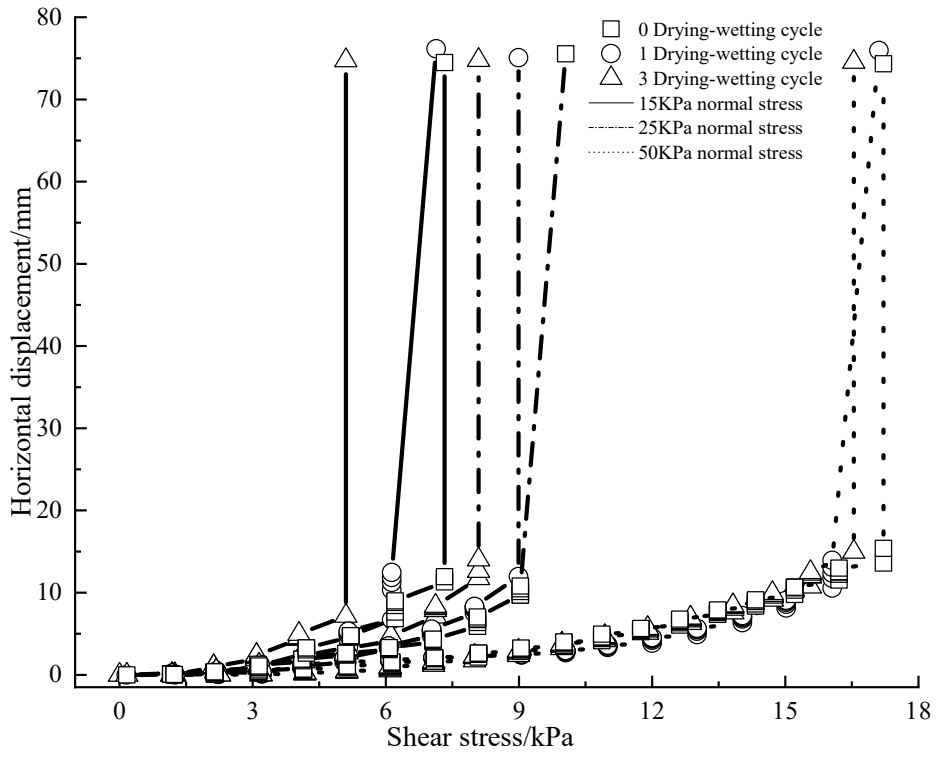
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(a)Kaolin Clay-GDL interfaces



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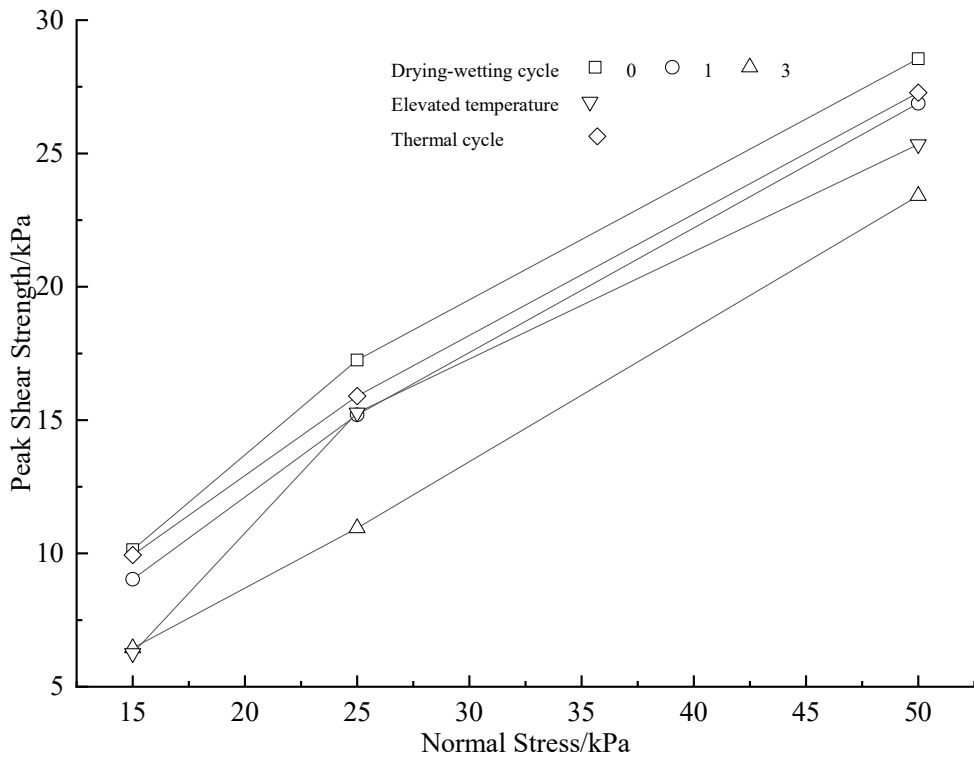
(b) Mercia Mudstone Clay-GDL interfaces

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Figure 3 Tests on interfaces subjected to different drying-wetting cycles

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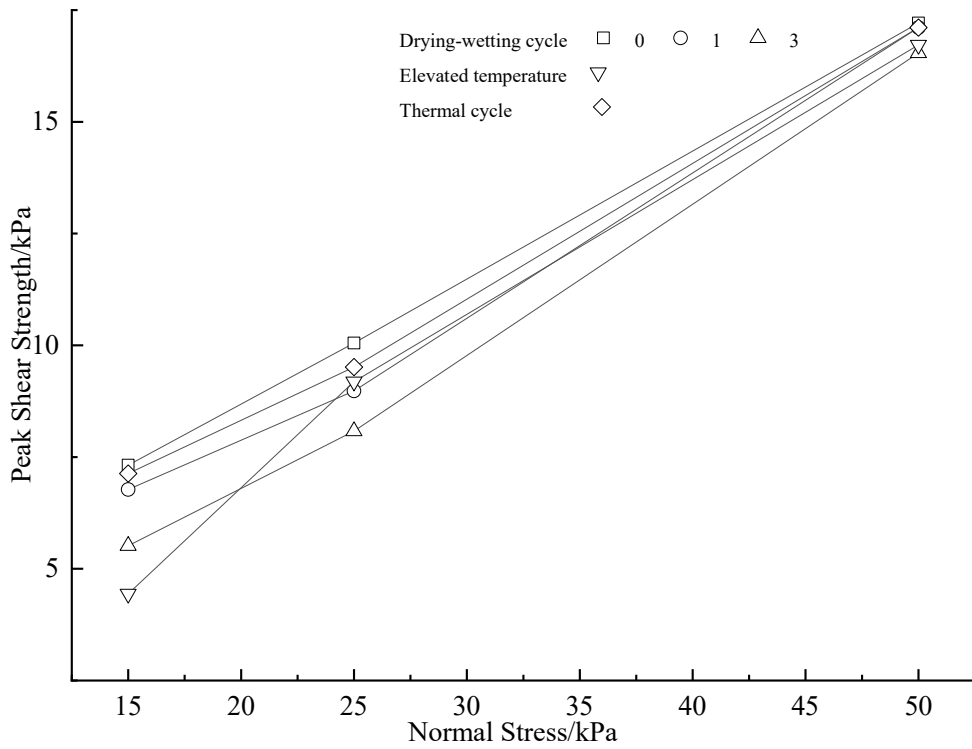
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(a) Mercia Mudstone Clay-GDL interfaces

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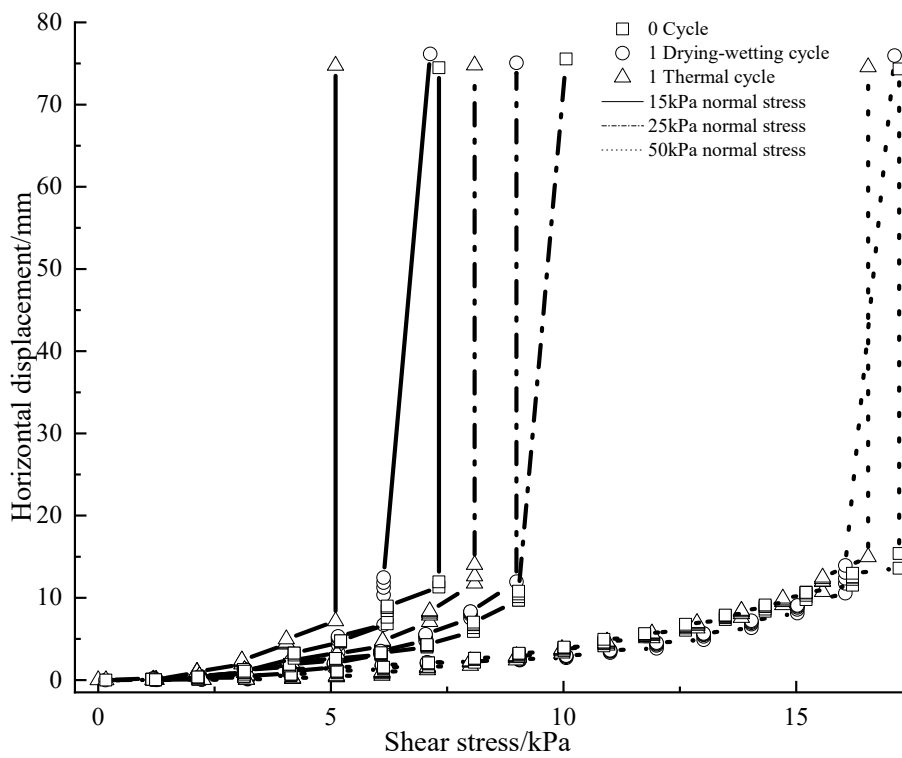
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(b) Kaolin Clay-GDL interfaces

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Figure 4 The peak shear strength of clayey soil-GDL interfaces

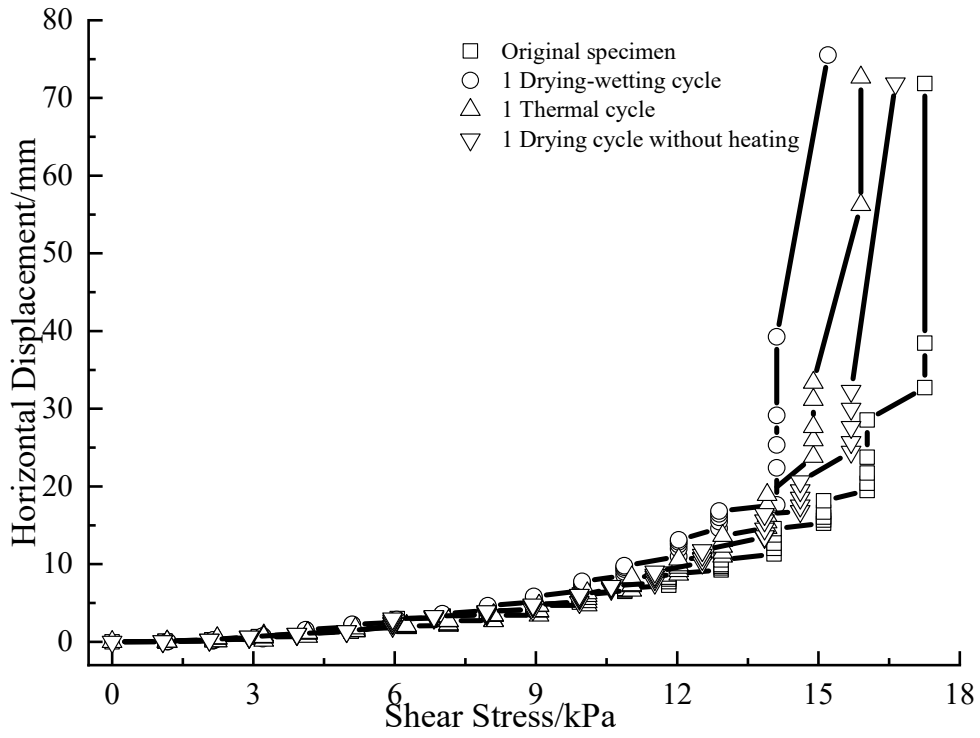
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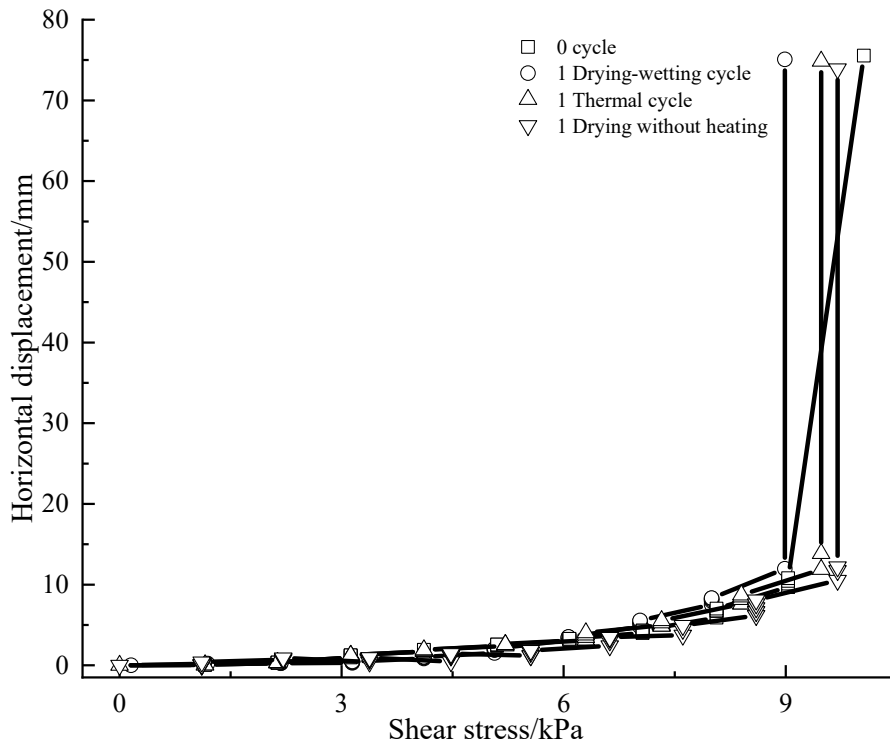
Figure 5 Shear stress-horizontal displacement curves of Kaolin Clay-GDL interfaces



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(a) Mercia Mudstone Clay-GDL interfaces



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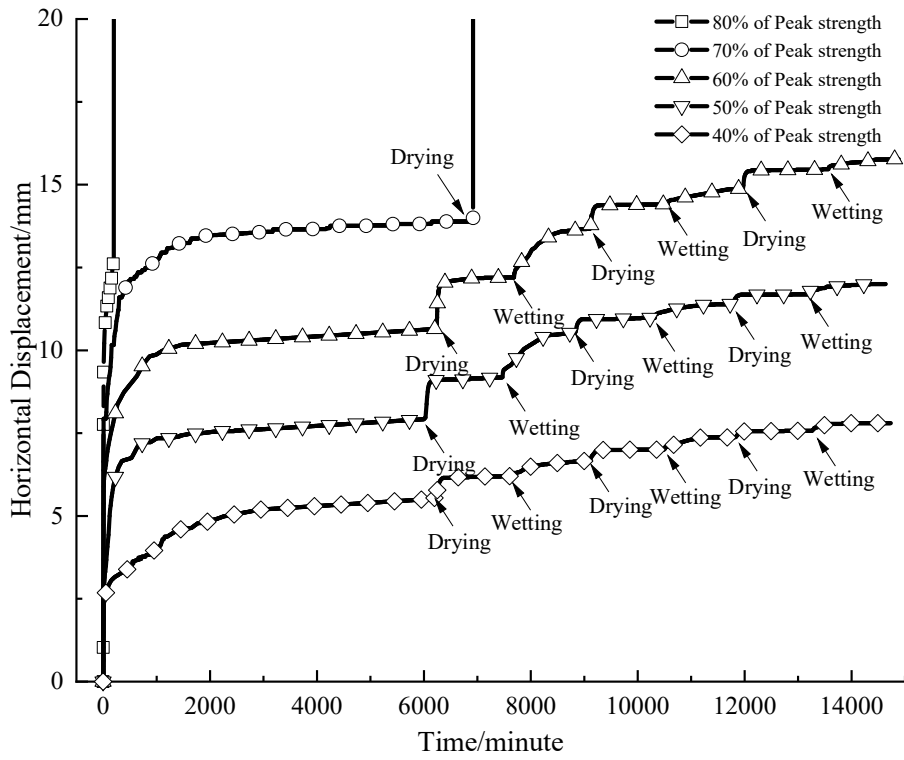
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(b) Kaolin Clay-GDL interfaces

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Figure 6 Tests on interfaces subjected to drying cycle without heating under 25 kPa

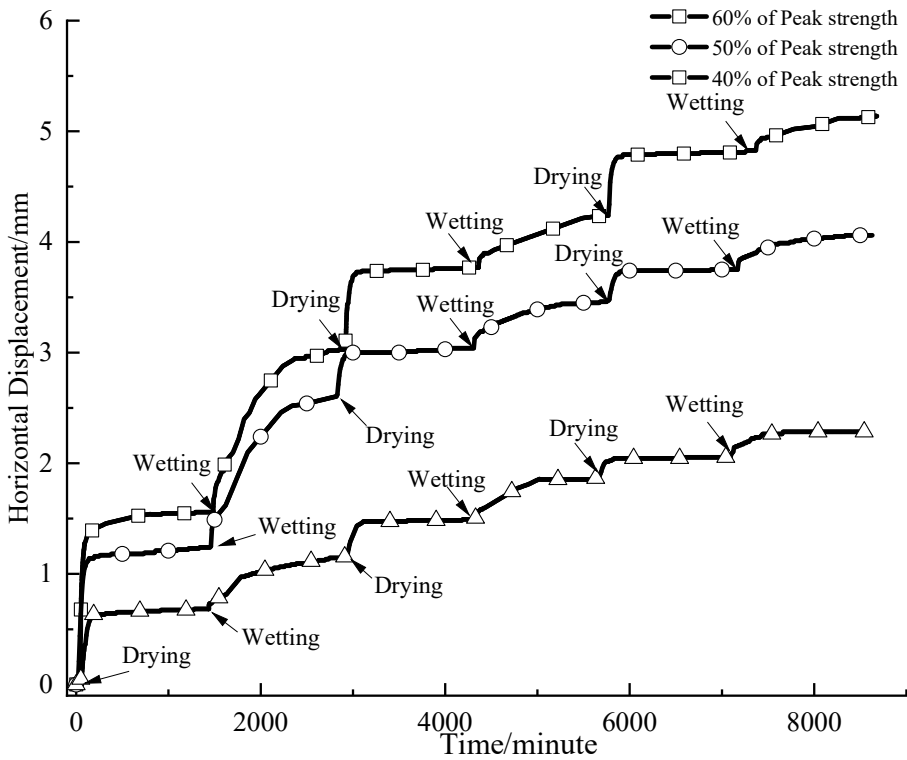
normal stress



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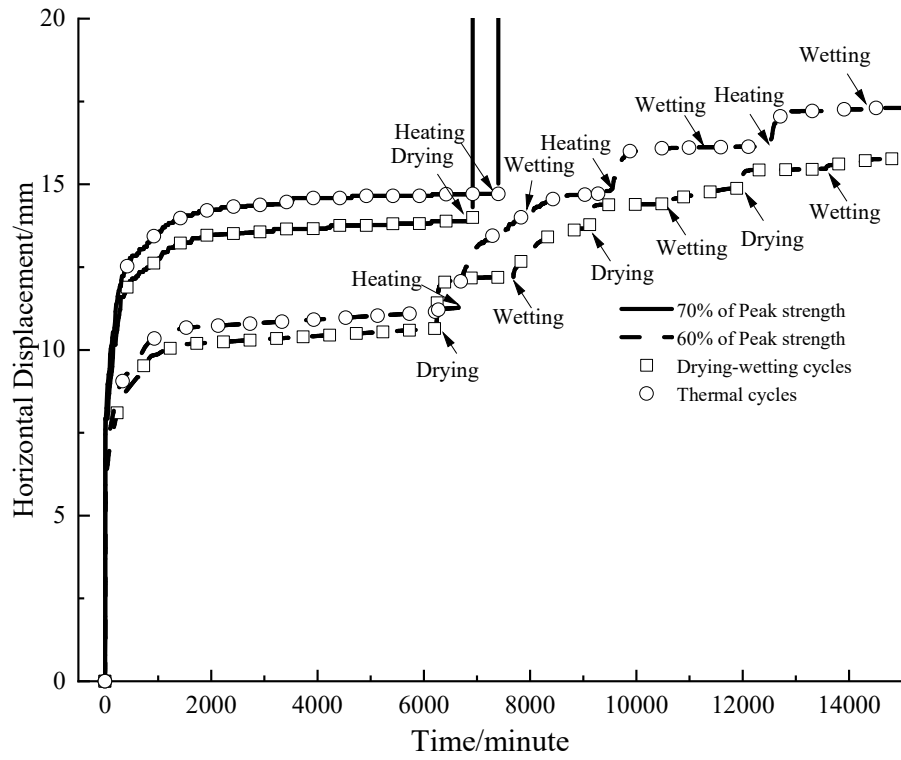
834 Figure 7 The shear creep deformation of Kaolin Clay-GDL interfaces during the
835 whole test

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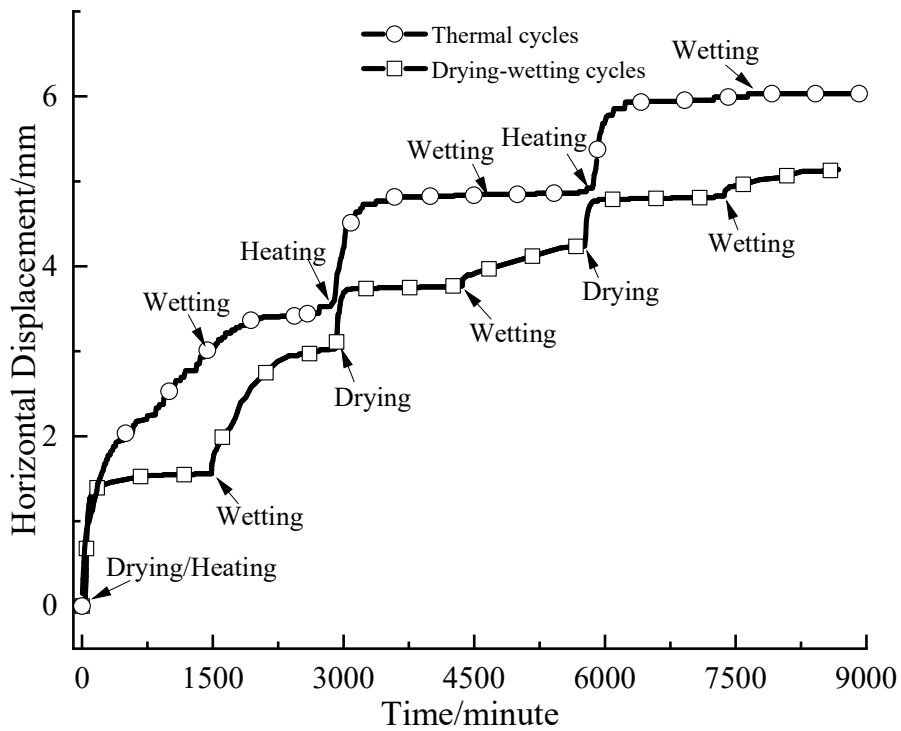
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838 Figure 8 The creep shear displacement of Kaolin Clay-GDL interfaces during drying-
 839 wetting cycles



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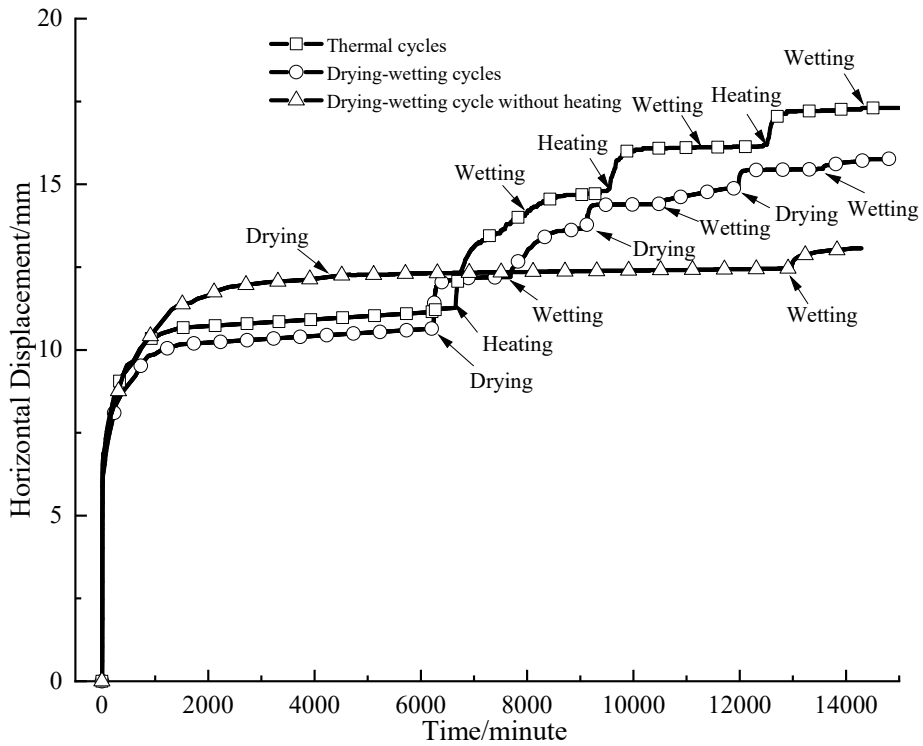
841 Figure 9 The influence of thermal cycles on creep behaviour of Kaolin Clay-
 842 GDL interfaces during the whole tests



843

844 Figure 10 The impacts of thermal cycles on creep deformation of Kaolin Clay-GDL

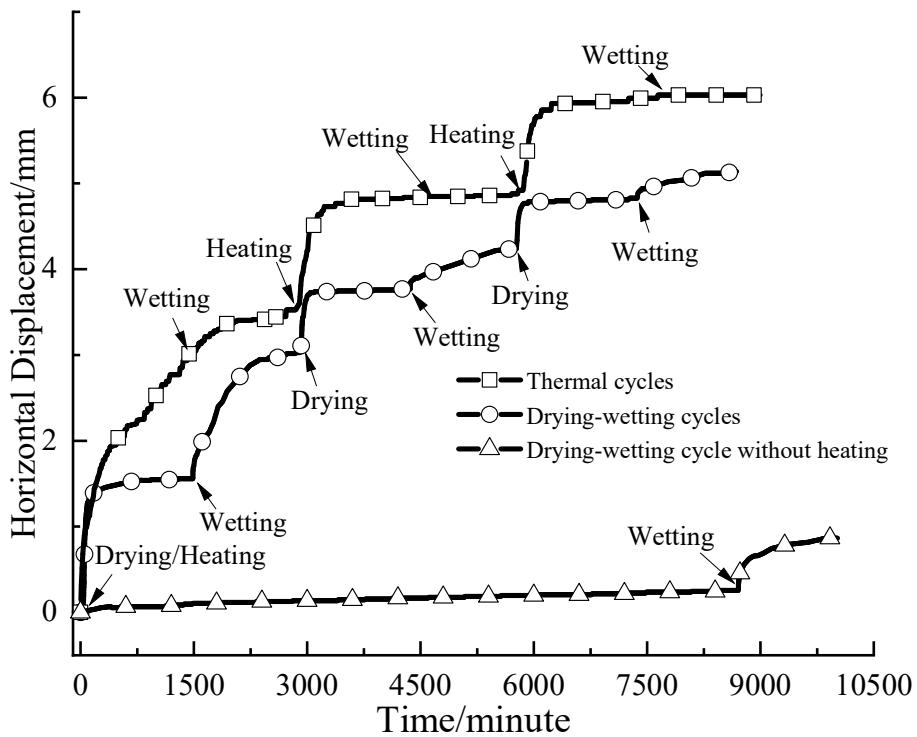
845 interfaces during drying-wetting/thermal cycles



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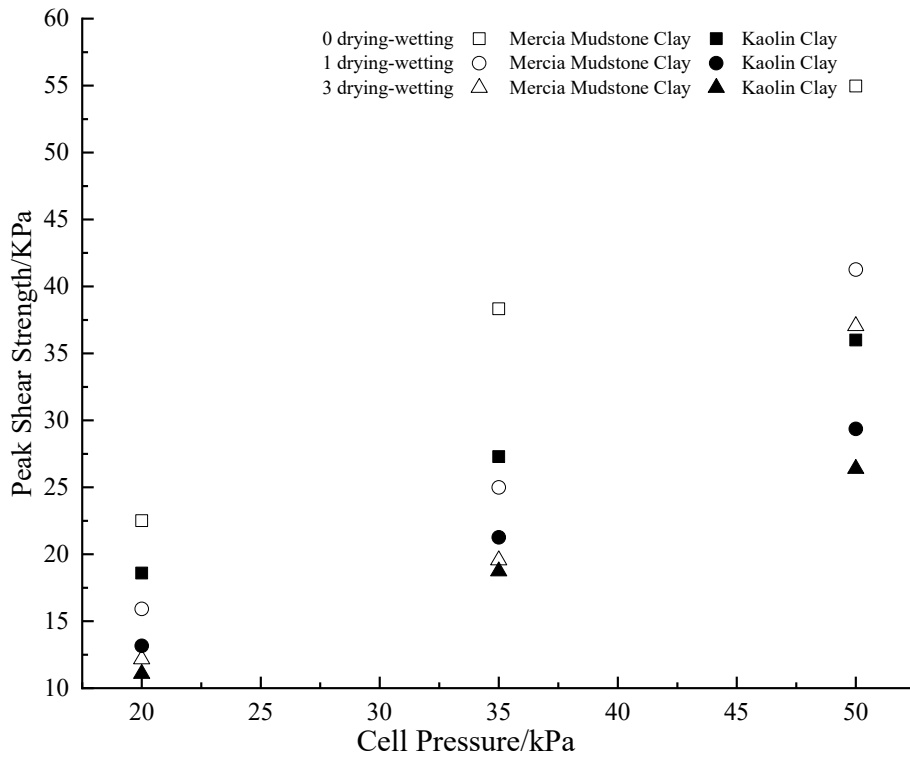
847 Figure 11 The influence of drying-wetting cycle without heating on creep behaviour

848 of Kaolin Clay-GDL interfaces during the whole tests



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850 Figure 12 The impacts of drying-wetting cycle without heating on creep deformation
 851 of Kaolin Clay-GDL interfaces during drying-wetting/thermal cycles



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 853 Figure 13 The peak shear strength of soil specimens

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 855 Table 1 The basic properties of soil specimens

Properties			Kaolin Clay	Mercia Mudstone Clay
Liquid limit (%)			47	33.63
Plastic limit (%)			26.58	17.42
Plasticity index (%)			20.42	16.23
Maximum dry density (g/cm ³)			2.0	1.93
Optimum water content (%)			20	11.76
Saturated water content (%)			56.36	68.43
Triaxially consolidated undrained shear	Cell Pressure (kPa)	20	18.59	24.12
		35	27.29	39.72
		50	35.99	55.32

strength (kPa)				
Percentage passing (%)	Sieve size (mm)	5.6	100	100
		4	100	99.68
		2	100	84.79
		1	100	52.36
		0.1	100	6.26
		0.05	92	2.39

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Table.2 The properties of Geocomposite Drainage Layer

GDL properties	GDL
Thickness of drainage core at 2kPa (mm)	6
Drainage core type	Single direction cusped core
Mass per unit area (g/m ²)	840
Tensile strength of machine direction (kN/m)	22
Elongation at peak of machine direction (%)	45
CBR puncture resistance (N)	3750

Geotextile properties	Bonded on the dimple side	Bonded on the flat side
Thickness at 2kPa (mm)	1.75	1.2
Tensile strength of machine direction (kN/m)	20	9.5
Pore size 090 (μm)	70	120
CBR puncture resistance (N)	3400	1600
Dynamic perforation cone drop (mm)	17	32

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