Thermo-Mechanical Behavior of Reinforced Concretes for Energy Piles

Wei Huang[1], Wei Xiang[2(✉)], and Jin Luo[1]

[1] Faculty of Engineering, China University of Geosciences (Wuhan), Wuhan, China
{huangwei,jinluo}@cug.edu.cn

[2] Three Gorges Research Center for Geo-hazards, China University of Geosciences (Wuhan), Wuhan, China
xiangwei@cug.edu.cn

Abstract. Energy pile is a ground source heat pump technology that couples foundation pile with ground heat exchangers for geothermal energy exploitation. However, the thermally induced contraction and expansion of the concrete affect the heat transfer performance and sustainable operation of the energy piles. In order to minimize these effects, a set of concrete samples was tested by deploying heating-recovery-cooling-recovery cycle. Three different concrete samples including plain concrete, polypropylene reinforced and steel fiber reinforced concretes are prepared. Temperature and stain development of the concrete samples were continuously recorded during the testing process. The results show that heating expansion and cooling contraction are both reduced for steel fiber reinforced concrete. For polypropylene fiber reinforced concretes, only the heating expansion is reduced but the contraction is larger than the plain concrete. Finally, the content of steel fiber of 1.3% is optimized to minimize the thermally induced mechanical effects on steel fiber reinforced concrete for energy piles.

Keywords: Energy pile · Thermo-mechanical behavior
Fiber reinforced concrete · Strain

1 Introduction

The energy pile is a renewable geothermal energy coupled pile foundations as ground heat exchangers [1]. Compering with the traditional borehole heat exchangers, the energy piles are known to be cost economically. Energy piles put heat exchanges into the foundations and save the cost of drilling and area to install borehole. Pahud put the u-type heat exchanger into the concrete piles and applied the concrete piles as foundation of Munich airport building [2]. Since 21 century, energy piles installed widely in the developed countries and were being an important research topic [3–5]. It was the first time that energy piles were used in Tianjin China in 2004.

With reference of experiences on projects at home and abroad, the operating of energy piles is a complicated thermal-mechanical process. the expansion and shrinkage of the plies material affects long-term running and the safety of buildings due to energy

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piles operate in cooling and heating thermal load for different seasons, Laloui tested the energy piles in the Swiss federal Institute of Technology in Lausanne, the length of energy piles was set for 15 m, the diameter was set for 117 cm, when temperature difference between the energy piles and ground approached to 15 °C, additional temperature stress was measured to be 2 MPa and the deformation on the top of piles was 4 mm [6]. P Bourne-Webb, BL Amatya researched the energy piles at the Lambeth Academy in London, the length and diameter of energy were set to 23 m and 55 cm, when energy piles heated to 28 °C, thermal load was measured to 500 kN, what's more, the expansion of energy piles was about 2 mm [7, 8]. AD Donna developed a 3-dimensional finite model and simulated the deformation of energy piles after seasonal thermal storage operation, the energy piles heated to 40 °C, the expansion was 4 mm [9].

In conclusion, additional temperature stress affects long-term running and the safety of buildings during seasonal thermal storage operation [10, 11]. To deal with problem above, this paper aims to investigate thermal-mechanical behavior of grouting concretes, polypropylene and steel fiber reinforced concretes in energy piles, and find the optimal proportion of energy piles.

2 Material and Test Program

2.1 Materials

Samples are made by ordinary Portland cement, the maximum size of coarse aggregate size is about 5 mm. the length of steel fiber is 10 mm, cross sectional area is measured to be 1 mm × 0.8 mm, respectively, the length of polypropylene is 8 mm. Concrete mix proportion listed in Table 1 is obtained by The Design Regulations Of Mix Ratio Of Ordinary Concrete (JGJ55-2011), the sample is Cylindrical and the diameter and height of sample are 50 mm and 100 mm, respectively. According to thermal conductivity experiment, the maximum thermal conductivity is measured to be 2.44 W/m · K in the concrete with content of the steel fiber of 1.3%, the optimal content of steel fiber and polypropylene is set to be 1.3% and 0.7% respectively. All samples named C1 C2 C3.

Table 1. Mix proportion of pile material sample

Sample number	Water cement ratio	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Content of steel fiber (%)	Content of polypropylene fiber (%)
C1	0.55	381	210	668	1240	1.3	0
C2	0.55	381	210	668	1240	0	0.7
C3	0.55	381	210	668	1240	0	0

2.2 Test Program

To investigate the thermal-mechanical characteristics of reinforced grouting concretes in energy piles. As shown in Figs. 1, 2, 3 and 4, we have developed 815 rock mechanic test system, heating panel, cooling system. The test steps divide into heating, recovery,

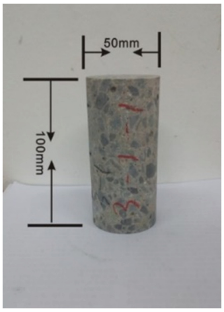

Fig. 1. Cylindrical sample

Fig. 2. 815 rock mechanic test system

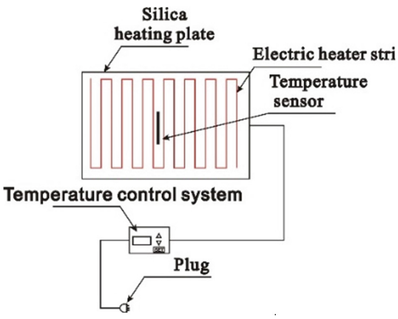

Fig. 3. Heating panel

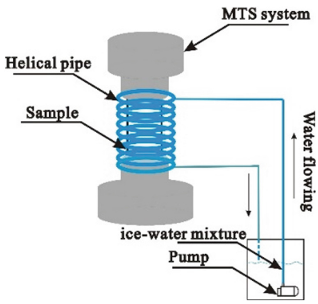

Fig. 4. Cooling system

cooling, recovery stages and simulate energy piles operation during seasonal thermal storage. The samples were set into MTS system with the heating panel, the MTS system provided the axial stress 28 kN and kept stable for 20 min, firstly, in the heating stage, the heating panel was set to 55 °C, and kept stable for 30 min. Then, stopped heating and recovered to the indoor temperature for 60 min, cooling system kept the temperature to 0 °C at next cooling stage. Finally, recovered to the indoor temperature for 60 min. In terms of monitor, MTS system kept the axial stress stable and stored the stain of each samples per second throughout the experiment, meanwhile. The stain of samples developed with time was obtained.

3 Results

As shown in Fig. 5, comparing with the plain concrete C3, steel fiber reinforced concrete samples C1 reduced the strain of the heating expansion and cooling shrinkage, and polypropylene fiber reinforced concrete samples C2 reduced the strain of the heating expansion but increased the strain of cooling shrinkage. Respectively, that means steel fiber added into plain concrete can improve the both compressive strength

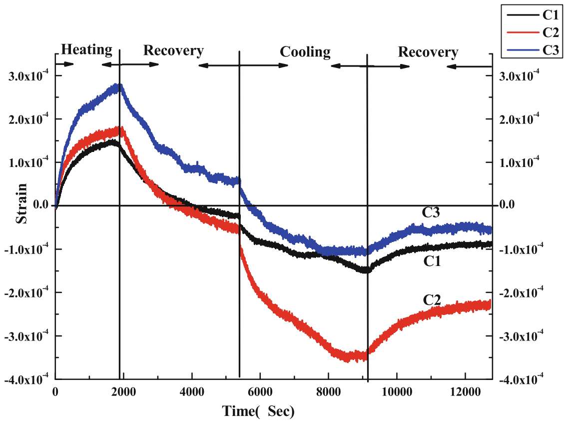

Fig. 5. Strain development of three different reinforced samples with four stages.

and tensile strength of concrete, however, polypropylene fiber added into plain concrete can only increase the tensile strength but reduce the compressive strength of concrete.

Table 2 shows that strain of the both steel fiber and polypropylene fiber reinforced concrete was reduced by adapting heating loads, comparing with plain concrete C3, steel fiber reinforced concrete sample C1 reduced about 49.6% and polypropylene fiber reinforced concrete sample C2 reduced about 38.1% in heating stage, meanwhile, in the cooling stage, the strain of steel fiber reinforced concrete sample C1 was reduced about 28.8% but polypropylene fiber reinforced concrete sample C2 increased about 81.9%.

Table 2. Strains development of fiber reinforced sample with four stages

Specimen number	Stain			
	Heating	Recovery	Cooling	Recovery
C1	1.44×10^4	1.71×10^4	-1.14×10^{-4}	0.65×10^{-4}
C2	1.75×10^4	-2.05×10^4	-2.91×10^4	1.17×10^{-4}
C3	2.78×10^4	-2.22×10^4	-1.60×10^4	0.50×10^{-4}

4 Conclusions

The results show that the maximum thermal conductivity is measured to be $2.44\ \mathrm{W/m \cdot K}$ in the concrete with content of the steel fiber of 1.3%. The strain of the both steel fiber and polypropylene fiber reinforced concrete is reduced by adapting heating loads, steel fiber reinforced concrete reduces about 49.6% and polypropylene fiber reinforced concrete reduces about 38.1%. Furthermore, heating expansion and cooling shrinkage strain are both reduced for steel fiber reinforced concrete during the heating and cooling load cycles testing, but polypropylene fiber reinforced concretes increase cooling shrinkage strain. Comparison of the three different pile concretes, steel fiber reinforced concrete is suggested to be a suitable material for the grouting of energy piles and the optimal proportion of steel fiber is 1.3%.

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