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Fatigue performance of ordinary concrete under discontinuous cyclic loading

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HIGHLIGHTS

- New tests were designed to study the discontinuous fatigue performance of concrete.
- Time interval promoted the development of plasticity produced by cyclic loading.
- Fatigue life of specimens in DCL tests is smaller than that from CCL tests.
- Threshold of the time interval was identified at 120 s.

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ABSTRACT

Concrete structures often serves under discontinuous fatigue loading. In this work, discontinuous fatigue tests were designed for the first time to investigate the fatigue performance of ordinary concrete under discontinuous cyclic loading. During discontinuous fatigue tests, repeated stress cycles were interrupted by no-load time intervals with different durations. Results showed that time interval could promote the development of plastic deformation produced by cyclic loading. The residual strain in a spaced cycle (*S* cycle), which follows one time interval, was significantly larger than that in a normal cycle (*N* cycle), which is not preceded by any interval. The fatigue life, which was estimated by an energy dissipative model, of the specimen used in discontinuous fatigue tests was smaller than that from conventional fatigue tests. However, the dilatancy angle stayed constant in both *S* and *N* cycles. The threshold of the time interval was identified at 120 s, with the maximum catalytic rate of 117% for the tested concrete.

1. Introduction

Compressed air energy storage (CAES) as a promising measure to regulate the imbalance of the wind power or solar power has attracted a lot of attention [1–4]. Since Alabama Electric Cooperative installed the second commercial CAES plant in McIntosh, Alabama, in 1991, there has not been any new CAES plant for more than 20 years with the issue of proper location being one of the biggest obstacles. Many scholars have studied the construction of CAES using underground lined caverns (Fig. 1) and have reported a number of interesting results [5–7].

For CAES system, various operation modes (in Fig. 2) alternately appear during its full life cycle; these are the charge mode (8 h), the discharge mode (4 h) and the idle mode (12 h) [8]. During the idle mode, the storage is subjected to a relatively small deviatoric stress (some regions will experience no deviatoric stress), which interrupts the periodic stress change. Therefore, the fatigue load acting on the surrounding rock and concrete lining is a kind of discontinuous cyclic load. Significant influence of discontinuous cyclic loading on rock has been reported and it appears to be distinct from that of the conventional fatigue load [9,10]. However, the discontinuous fatigue behavior of concrete has been rarely investigated.

In terms of fatigue performance, plastic deformation, fatigue limit strength and fatigue life are basically the essential topics of common concerns [11–13]. Over the recent years, a large amount of research on fatigue performance of concrete has been conducted [14–20]. For example, Nihad Tareq KhshainAl-Saadi et al. investigated the flexural performance of reinforced concrete beams, which are strengthened by using carbon fiber reinforced polymer, under fatigue loading. An analytical model was proposed to predict the cumulative damage-fatigue life relationship based on the stiffness of beams in loading cycles [19]. Feng Liu et al. determined the

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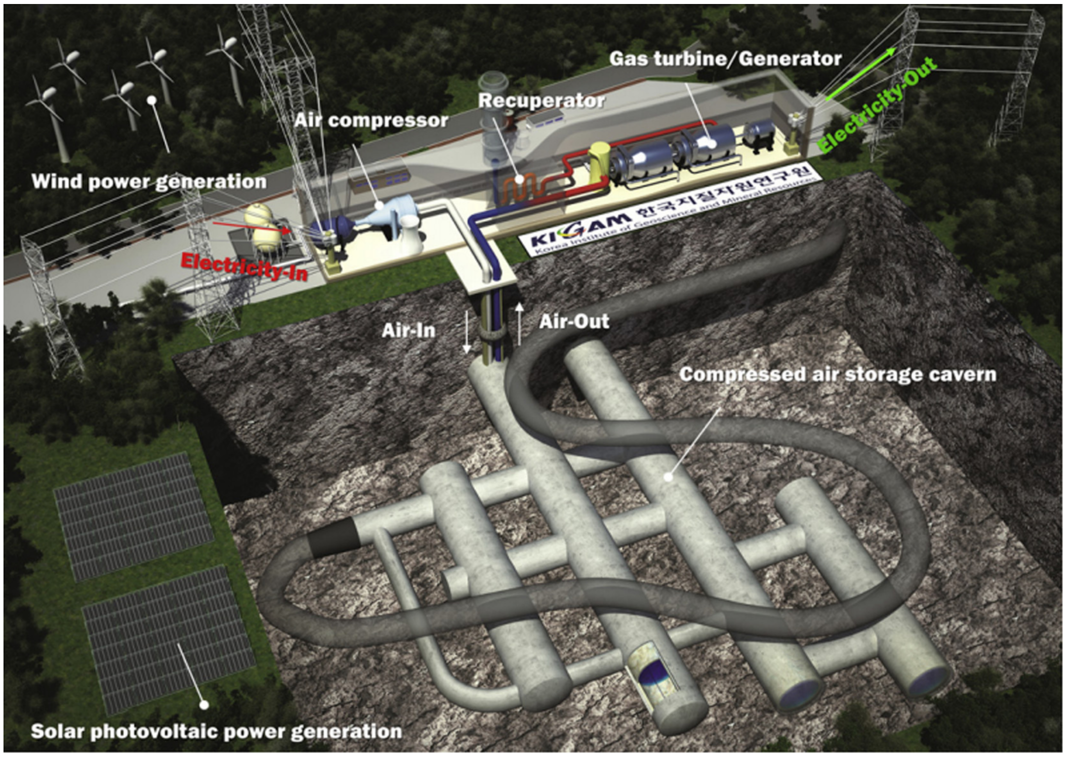

Fig. 1. Diagram of a compressed air energy storage plant using underground lined rock caverns, from Ref. [6].

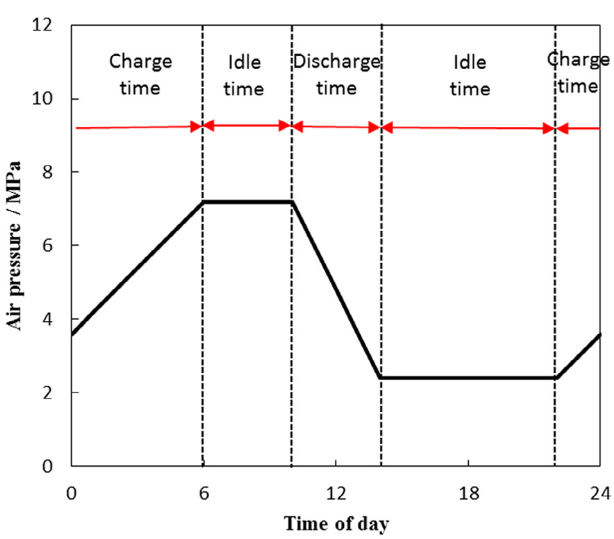

Fig. 2. Typical operation modes of a CAES plant [3].

mechanical and fatigue performance, including fatigue limit strength and fatigue life, of rubber concrete, which consisted of 0%, 5%, 10% and 15% of the selected rubber contents in terms of the fine aggregation in volume [20]. Yinhua Ma et al. studied the bending fatigue performance of cement-stabilized aggregates reinforced with polypropylene filament fiber and established the fatigue equation including fatigue strength, and fatigue life [21]. Li Song et al. examined the fatigue performance of corroded reinforced concrete beams strengthened with carbon fiber-reinforced polymer sheets in experimental and analytical studies [22]. Mahfoud Benzerzour et al. investigated the origin and magnitude of internal stresses on the interface between an overlay and an underlying reinforced-concrete slab subjected to cyclic flexural loading. Cyclic loading was found to foster that interface cracking mechanism resulting from fatigue rupture of the bond between the overlay and substrate [23]. Dong Lei et al. conducted concrete fatigue tests, and investigated the fatigue life by use of energy dissipation method [24].

Among above research, there are mainly three approaches for analyzing the fatigue failure mechanism of concrete; these methods are the phenomenological method, the fracture mechanics method and the continuum damage mechanics method [25,26]. As for the phenomenological method, the empirical equation between stress and fatigue life (known as S-N curve) is usually formulated by regression analysis. The fracture mechanics method identifies the stress intensity factor, which is related to the crack length and the stress state, by recognizing the crack initiation and propagation in the specimen. The continuum damage theory based on continuum mechanics and irreversible thermodynamics, sets up some damage variables to characterize the damage of materials, and then establishes the corresponding damage evolution equation. The phenomenological method required a mass of high-quality experimental data, since the fatigue life were scattered and distributed randomly due to the material heterogeneity; for the fracture mechanics method, complex detection equipment was indispensable for real-time monitoring of cracks development.

In this paper, the method of continuum damage mechanics was used to estimate the fatigue life and fatigue strength of ordinary concrete under discontinuous cyclic loading. Regarding the plasticity, residual strain and dilatancy angle were calculated for every stress cycle to determine the development and accumulation of plastic deformation. This paper made an initial fundamental investigation by conducting three groups of discontinuous fatigue tests and one group of conventional fatigue tests (for comparison) on ordinary concrete. The results will contribute to gain a better understanding of concrete performance under discontinuous fatigue and provide primary design parameters which better fit the actual conditions.