Technology Status and Prospect of Conductive Concrete and Cementitious Composite Battery

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***Abstract*—In this study, cementitious composites battery which can be regarded as a new type of conductive concrete was introduced. Conductive concrete is not a new concept of concrete, and there are numerous related studies and patents. Nevertheless, it has not been much practical. It has mainly been applied to deicing and cracks detection, but there are not many applications. In recent years, research on cementitious composites battery consisting of cathode, anode, and electrolyte made by conductive concrete has been conducted by a few researchers. If the technology is developed through more research, it is expected to be used in various fields such as prevention of corrosion of reinforcing steel, the power supply of structures, storage of renewable energy, electric vehicle charging station, etc. Therefore, in this study, research trends of conductive concrete and cementitious composites battery were investigated, and the theoretical principle of cementitious composites battery was presented. Based on the results of the investigation, future research directions were proposed.**

***Index Terms*— Concrete, conductive, cementitious, battery, corrosion, electricity**

I. Introduction

Since the ‘Portland Cement’ was first invented in the early 19th century, the concrete has developed steadily and diversely. The various concrete such as lightweight concrete used to reduce the self-weight of the structure and fiber reinforced concrete to improve toughness and strength have been developed and various cement composites have been developed and used to meet specific conditions. The concrete is able to meet the very specific conditions as well as strength and durability, through these developments. The reformation and development of the concrete should generate enormous profits in the construction market since most of the construction materials consist of the concrete. In this respect, this study is interested in another new type of concrete. It is a ‘cementitious composites battery’ which is a new type of conductive concrete.

The concrete originally has a nonconductor (or insulator) property, but the conductive concrete has an opposite concept. The basic concept of a conductive concrete is to make the concrete itself a conductor by adding a conductive admixture to the concrete or mortar like carbon, graphite and so on. The conductive concrete has been used in various construction fields. In this study, the current state of conductive concrete was investigated. In addition, the development status and future perspective of the cementitious composite battery, which is based on conductive concrete, were also investigated.

II. Conductive Concrete

The conductive concrete was invented in the 1980s and has several patents in various forms around the world. The basic concept of conductive concrete is that the concrete mixed with the conductive material to form the current flow [1], [2]. For this current flow, conductive materials such as carbon particles, carbon fibers and steel fibers could be used. This conductive concrete has been mainly used for deicing and detection of crack.

A. Deicing Using Conductive Concrete

According to statistics, almost 10-15% of traffic accidents are caused by ice and snow on the road [3]. The accumulation of snow or ice on road surface can cause damage to people and property. Several methods are typically used to treat ice on pavement through winter maintenance such as natural melting by nature and transportation and chemical treatment. For the deicing, most of the highway winter maintenance techniques depend on the use of chemicals and fine aggregates. Sodium chloride is considered to be the most cost-effective product, but the use of chloride has caused corrosion of reinforcing bars and pavement and environmental pollution [4]. In the snow removal by a mechanical way, it takes a lot of labor, cost and time. In addition, there is a disadvantage that the snow is not clearly removed. This accumulated snow around the road melted and freeze again, then it causes secondary damage to the drivers.

The deicing technology with conductive concrete was developed to solve these corrosion and environmental problems. De-icing technology using conductive concrete was applied to the heating deck of Roca Spur Bridge at Nebraska for the first time in the world. The bridge construction was completed in November 2002, and the heated deck control system was completed in March 2003. In the winter storms of three days in 2004, this system made ice-free surface during the storm. The slab which was made the conductive concrete was energized for 30

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minutes. The slab temperature was kept by about 9 ℃ (16 ℉) above the ambient temperature and the slab had effectively melted the surface. This was the first practical use of the deicing system [5].

Wu et al. [4] were carried out a study of the three-phase conductive concrete with carbon fibers, steel fibers and graphite. The experiments were performed in freezer to ensure low resistance and high conductivity using the three-phase effect. As a result of the experiment, it was confirmed that the corrosion of steel fiber greatly increases the resistivity, and it was also confirmed that the adhesion of graphite and cement mortar was weak and seriously affects the concrete strength. Considering these mutual influences, three-phase composite conductive concrete suggested the mix proportion which has the optimum ratio to provide low resistance and high power. Therefore, the three-phase conductive concrete was confirmed to exhibit sufficient potential on deicing.

Zhao et al. [6] studied concrete slabs with carbon fiber heating wires, which has lower resistance and high heating temperature compared to steel wires, for deicing. The conductive concrete with carbon fiber heating wires demonstrates the ability to deicing at an ambient temperature of -25 ℃. In addition, it was confirmed that the longest time for deicing was 5 hours under different conditions such as snow thicknesses, wind scales and so on.

Gomis et al. [7] studied the current and thermal effects of cement composites using various carbon-based materials such as carbon nanofibers, carbon nanotubes, and carbon fibers. Based on the experimental results, physical equations such as the Fourier, Newton and Joule law were applied and analyzed. This parametric analysis could predict temperature rise under various conditions without further experiments.

The deicing studies using conductive concrete with various mineral admixtures have been carried out [6], [8], [9]. Recently, steel-based materials have been found to have some disadvantages such as corrosion, and research on carbon-based materials was attracting attention.

B. Detection of Crack Using Conductive Concrete

As the interest in maintenance techniques of concrete structures has been increased, the development of new diagnostic techniques is required. The strain gauges or the displacement gauges have been mainly used for the measurement of the fracture, but the accuracy of these measurement are greatly influenced by the shape of the crack in the case of the concrete. In addition, in order to measure discontinuity after loading, the initial conditions must be clearly set. The large members such as bridge are needed a lot of sensors, and it causes not only cost but also measurement error [10].

Due to the disadvantages of previous crack detection methods, conductive concrete has recently been studied as a method for detecting cracks. When cracks are generated inside the conductive concrete, carbon fiber is cut off or pull out. The resistance and current values of the conductive concrete are changed and the crack can be detected. Chen and Chung [11] studied the current flow of carbon fiber cement composites and the relationship between the load and resistance of that. In addition, Sun et al. [12] has shown that carbon fiber reinforced concrete has not only magnetic induction such as current and resistance but also temperature sensitivity characteristics in stress and strain. Chu and Chen [13] conducted the evaluation of the resistance and damage according to the carbon fiber content. For crack detection, it was confirmed that the carbon fiber content of the appropriate level should be needed.

The various researches on conductive concrete for crack detection have been carried out. However, direct assessment of real-time damage to concrete is still difficult.

III. CEMENTITIOUS COMPOSITES BATTERY

As mentioned above, the conductive concrete has been used for deicing by generating internal heat by using conductivity, or for detecting cracks by using internal resistance and current flow. This chapter introduces cementitious composites batteries which is a new type of conductive concrete.

A. Technical Theory of Cementitious Composites Battery

Conventional batteries are composed of an anode, cathode, and electrolyte. In the typical alkaline battery, the anode and cathode are composed of zinc and manganese dioxide, respectively, and the electrolyte is composed of a salt liquid solution, as shown in Fig. 1 The cementitious composites battery is applied to these general concepts of batteries (Fig. 2) The conductivity is given to the concrete, so that the anode, the cathode, and the electrolyte are all made conductive. The zinc powder and manganese dioxide powder are used as the mineral admixture in anode and cathode to have battery function [14].

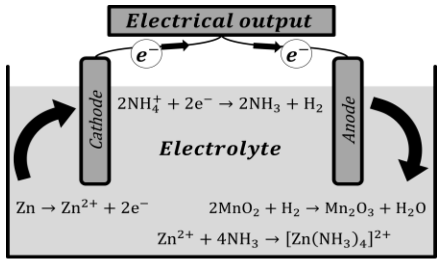

Figure 1. The typical process of alkaline batteries

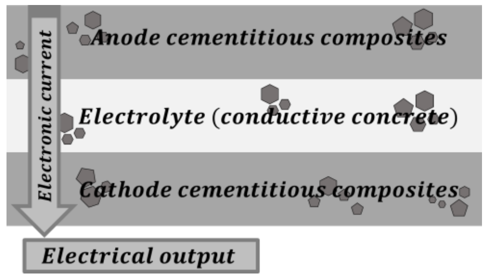

Figure 2. The basic concept of cementitious composites battery

The research on the cementitious composites battery has been conducted by a few researchers. Meng and Chung [14] experimented the cement battery considering the zinc anode and the manganese dioxide cathode. In the experiments, there were two types of electrolytes based on cement and water. The cement battery could operate as normal battery, but its battery capacity was smaller than that of a conventional alkaline battery.

Byrne et al. [15] studied the cement battery using aluminum and copper plates as anode and cathode. The experiments focused on improving the output of current. The cement battery was not high in power operation.

According to the Holmes et al. [16], the experiments were performed on can-types and sandwich type of cement batteries. The can-types cement batteries had a good usability when they were connected in series or in parallel, but the electric power was insufficient. The life-time of sandwich type cement batteries had been found to be important for moisture retention.

B. The Prevention of Rebar Corrosion

The deterioration of major facilities and buildings is noted in many countries. According to the American Road & Transportation Builders Association (ARTBA), about 10% of U.S. bridges were found to be defective in 2016 [17]. A lot of concrete bridges have been suffered structural defects due to the corrosion of reinforcements. In order to reduce social costs and protect lives, it is necessary to effectively prevent deterioration of the structure. The deterioration of reinforced concrete structures has been dominated by the corrosion of reinforcements. The corrosion process of the reinforcements is shown in Fig. 3 Impressed Current Cathodic Protection (ICCP) could be considered as one of the ways to prevent the corrosion of reinforcements. ICCP works by supplying a DC current to a submerged surface with the help of a zinc electrode combined with a metal oxide anode. However, ICCP has very low applicability because of various problems such as the economic, construction, maintenance and so on [18].

Cementitious composites batteries could prevent corrosion of reinforcing bars with a process similar to ICCP [16], as shown in Fig. 4 When the corrosion of reinforcements proceeds, the lost ions, which is from the rebar, could be filled in the flow of current of cementitious composites battery. In this process, the reinforcements could be maintained without further corrosion progress. Therefore, the cementitious composites battery will be a key technology that can save huge maintenance cost. In addition, it will be possible to predict the progress of the corrosion of the reinforcing steel by checking the current of the cementitious composite battery without confirming the corrosion of the reinforcing steel through the inside observation, which is needed huge costs and labor.

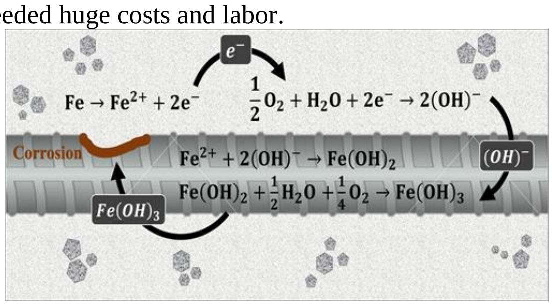

Figure 3. The mechanism of rebar corrosion

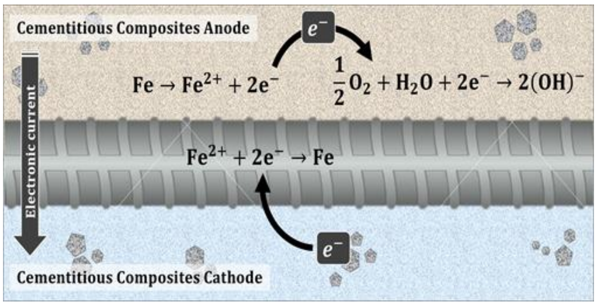

Figure 4. The mechanism of prevention of rebar corrosion using cementitious composites batteries

C. Difference between the Cementitious Composites Battery and Conventional Battery

The conventional battery is typically designed to be portable and the battery was very small and it has been designed to have a low capacity. To solve this problem, many manufacturers have continued to research and develop batteries to increase capacity, but there is a limit to increasing capacity because there are difficulties in securing small size and high capacity together. However, the cementitious composites battery could have a very large capacity. If the cementitious composites battery is applied to a building, the building itself will be the battery capacity. The cementitious composites battery can make concrete structures such as buildings, roads, bridges, etc., huge batteries.

Since the invention of batteries, there have been environmental problems associated with battery disposal. The mercury in batteries has been considered as the major problem for environmental pollution. To protect the environments, many countries have been paying attention to recycling and disposal methods of used batteries [19]. However, the cementitious composites battery does not require a special treatment facility because the discharged battery is still available as a structural material until the end of lifetime of the structure. Therefore, the cementitious composites battery does not cause additional environmental problems.

D. Applicability of Cementitious Composites Battery

The development of cementitious composites battery is expected to be available in various fields. When using as prevention of corrosion, it is expected that it will contribute significantly to extend their service life and to save a lot of maintenance costs. In addition, it is possible to supply electric power from the building itself. The cementitious composites battery is expected to supply electric power to the constant power source such as the indicator lamp and the guidance light at all times and to supply electric power in emergency situations such as power failure. If this technology is applied to huge structures such as roads and bridges, it will be possible to secure a large amount of electric energy. The securing of electrical energy could be expected to be variously utilized including the street light, the electric vehicle charging center and so on.

IV. Future Research Suggestion

Research on cementitious composite batteries is at an early stage of entry level, and even that is being done by a small number of researchers [14]-[16]. More research is needed to make cementitious composite batteries applications a reality. The following researches are suggested.

- Establishment of implementation plan of cement composite battery cell
- Development of electrolyte, anode, and cathode cementitious composite using carbon-based materials and optimization of mix proportion of cementitious composite
- Evaluation of electrical and structural performance of cementitious composite batteries by various variables including mix-design, content of carbon material, specimen size, proportion of electrolyte, anode, and cathode, etc.
- Cementitious composite batteries with secondary batteries (rechargeable batteries) function
- Reinforcing corrosion prevention of reinforced concrete structures using cementitious composite battery

V. Conclusions

In this paper, the development status of the conductive concrete was investigated. In particular, a new type of conductive concrete, cementitious composite battery, was introduced with current technology level and future research directions were proposed.

There have been a lot of studies on conductive concrete, but related studies have been somewhat stagnated. The application areas are mainly deicing and internal crack detection, but there is almost no use for other purposes than these.

In contrast, cementitious composite batteries are expected to be available in a variety of applications. First, it allows current to flow from the structural member itself constructed by cementitious composite batteries without an external power source to prevent rebar corrosion so that the lifespan of structures increases. It is also possible to provide emergency power supply in case of power failure of structures and to supply electricity to low-power devices such as emergency lights and guide lights. In addition, if the recharging function is developed, it can be used for storage of renewable energy such as sunlight, and charging station for electric vehicles. In terms of construction, it is possible to apply both cast-in-place and precast methods, and it can be applied to existing structures as well as new designed structures.

However, there are currently many challenges that need to be addressed in order for these applications to be implemented. These challenges include, for example, low battery capacity, low voltage, low current, performance as a structural material, and especially the development of rechargeable technologies. The cementitious composites battery will be a very beneficial technology when the technology is sufficiently studied and developed.

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