CHAPTER 1

INTRODUCTION

1.1 Overview

Concrete is the most commonly used structural materials in civil engineering. For some important modern structures, such as high-rise buildings, large-span bridges, dams, and so on, severe vibration and significant internal damage may be caused by dynamic loading from different sources, such as a strong wind or earthquake. This will pose a great threat to the safety of the structures. To solve these problems, intelligent structures including health monitoring and active vibration control of structures have been developed. However, the traditional smart materials, such as piezoelectric ceramic, shape memory alloys, and piezoelectric polymer, may not be applicable in civil engineering due to the distinct differences in the properties between the smart materials and the concrete structures [1-12]. Furthermore, the piezoelectric ceramic such as lead zirconate titanate (PZT) exhibit high acoustic impedance ($\approx 21.2 \times 10^6$ kg/m^{2}s) compared to that of concrete ($\approx 6.90\text{-}11.23 \times 10^6$ kg/m^{2}s) [13-14].

Some factors during the hydration of cement such as variations in relative humidity or temperature and chemical reactions, will cause shrinkage or expansion of concrete. Such mismatching would not only degrade the energy transfer between the traditional smart materials and the host concrete, but also cause considerable lost of the signal transmission [1]. Therefore, some kinds of smart structure materials should be developed to meet the requirement of the civil engineering main structure material, concrete. Moreover, the smart structural composites have been developed for multifunctional structural materials which can perform functions such as structural vibration control, shielding bridge safety, heavy instrument monitoring, highway barrier sensor and energy harvesting.

Recently, piezoelectric-cement based composites were developed and proved to be promising materials for sensors and actuators in the field of civil engineering [1-11]. The most advantage of the composites over the traditional piezoelectric materials is that they have better compatibility and advantage of tuning their acoustic impedance to match the host structure material, i.e., concrete [2-3]. Li et al. [1] first developed a 0-3 PZT-white Portland cement composite in 2002. Their research indicates that, when the 40-50% PZT composites, the acoustic impedance of the 0-3 composite can match that of concrete, as opposed to PZT.

Recently, piezoelectric cement-based 1-3 composites was proposed by Lam et al. [7] and the 1-3 types lead piezoelectric composites were fabricated by dice-and-fill method. The 1-3 piezoelectric-cement based composites also showed that the piezoelectric properties of the composite were better than those of 0-3 cement-based piezoelectric composite but 0-3 connectivity composites can be more easily fabricated in complicated shapes than other forms of composites. In addition, Xu *et al.* [12] also studied the fabrication and properties of piezoelectric composites designed for process monitoring of cement hydration reaction in 2012. The 2-2 type piezoelectric composites had higher piezoelectric coefficient, while 1-3 type piezoelectric composites had higher piezoelectric voltage factor. Lead-based piezoelectric ceramic such as PZT has been used with cement to form piezoelectric cement based composites [1-3], but PZT ceramic cause pollution and environmental problems due to lead oxide toxicity [15, 16]. Therefore, it is desirable to produce environmental friendly non lead piezoelectric ceramic with equivalent properties, which could be used as an alternative to lead based ceramics.

It is well-known that barium titanate ($BaTiO_3$; BT) ceramic is one of the most widely studied non lead piezoelectric materials [16-22]. Moreover, the modifed barium titanate (such as barium zirconate titanate; BZT) is an effective way to improve the material performance in electroceramics. BT-based ceramics find applications in many modern disciplines such as automatics, micromanipulation, measuring techniques, medical diagnostics (i.e. multilayer capacitors, actuators, sensor, transducers, and ultrasound imaging) [17]. It has been well documented that small amounts of impurity ions can dramatically modify the properties of BT materials in general [18].

Barium zirconate titanate ($BaTi_{1-x}Zr_xO_3$) ceramics were extensively investigated and show promising piezoelectric/electrostrictive properties [19]. The $BaTi_{1-x}Zr_xO_3$ ceramics at x = 0.05 showed good piezoelectric properties [20-21], low temperature poling and low curie temperature. These properties are good for piezoelectric-cement based composites and easy to poling. So, modified barium titanate ceramics are of interest for applications in the field of environmental protection. The type of smart materials suitable for applications in civil engineering structures should have good piezoelectric properties as well as good compatibility to concrete and be environmental friendly such as non lead composites. According to the research of Newnham *et al* [23], piezoelectric composite can be classified into 10 categories. The research of the piezoelectric composite mainly concentrates on these connection types, such as 0-3, 1-3, and 2-2 [1-12]. It is understandable that 0-3 connectivity piezoelectric composites can be more easily fabricated in complicated shapes than other forms of composites [1-6]. The 1-3 and 2-2 connectivity piezoelectric composite on the other hand, can give better piezoelectric and electromechanical properties compared with 0-3 connectivity piezoelectric composite [7-12]. Therefore, the dielectric and piezoelectric properties of modified barium titanate-Portland cement composites with 0-3, 1-3 and 2-2 connectivity are investigated for smart structural composites.

1.2 Objectives of this work

In this study, the fabrication, dielectric, piezoelectric, acoustic impedance, thermal expansion and microstructure properties of modified barium titanate-Portland cement composites with 0-3, 1-3 and 2-2 connectivity were investigated.

The objectives of this study are as follows:

- To investigate the dielectric and piezoelectric properties of 0-3 connectivity modified barium titanate-Portland cement composites.
- To investigate the dielectric and piezoelectric properties of 1-3 connectivity modified barium titanate-Portland cement composites.
- To investigate the dielectric and piezoelectric properties of 2-2 parallel connectivity modified barium titanate-Portland cement composites.

1.3 Methodology and Analyses

The experimental part of the work consists of the initial preparation of lead-free piezoelectric ceramic (Barium zirconate titanate; BZT). The 0-3 piezoelectric-cement based composites were fabricated by normal mixing, pressing and curing method. The 1-3 and 2-2 piezoelectric-cement based composites were fabricated by the dice-and-fill method. Dielectric properties (using LCR-meter), piezoelectric properties (using d_{33} meter and impedance meter), acoustic impedance (using ultrasonic thickness meter) and thermal expansion (using LVDT dilatometer) were investigated. For the thermal expansion, measurements were carried out on 0-3 piezoelectric-cement based composites. The microstructure of the composites was investigated using scanning electron microscopy (SEM) and energy dispersive X-ray spectrometry (EDX) analysis. The research plan, methodology and scope are represented in the flowchart (Fig 3.1 in chapter 3 experimental procedure). The summary of overall work can be seen as follows:

- Literature review
- Preparation of lead-free piezoelectric ceramic
- The 0-3 piezoelectric-cement based composites fabrication by the normal mixing, pressing and curing method
- The 1-3 and 2-2 piezoelectric-cement based composites fabrication by the dice-and-fill method
- Measurements: dielectric properties, piezoelectric properties, acoustic impedance, thermal expansion and microstructure
- Measuring instrument: LCR-meter, d_{33} meter, impedance meter, ultrasonic thickness meter, LVDT dilatometer, SEM and EDX