CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

5.1 Conclusions

Since this work was focused on the dielectric and piezoelectric properties of modified barium titanate-Portland cement composites. The following conclusions can be drawn from the experiments:

1. New environmentally friendly lead-free modified barium titanate-Portland cement composites were developed for sensor applications in smart concrete structures. The 0-3 BZT-PC composites were fabricated by normal mixing, pressing and curing method. The 1-3 and 2-2 BZT-PC composites were successfully fabricated by dice-and-fill method.

2. For 0-3 composites, the dielectric constant and piezoelectric values were found to increase with increasing ceramic particle size. The BZT of 425 μm particle size used for the ceramic particle size range tested at the same volume led to optimum piezoelectricity in the 0-3 composites. This result could be explained by the contact surfaces between cement matrix and ceramic particles.

3. The dielectric constant, electromechanical coupling coefficient, piezoelectric coefficient and piezoelectric voltage coefficient of the 0-3 BZT-PC composites were found to increase as a function of the ceramic content. For the thermal expansion of 0-3 composites, the results showed that the at $\approx$ 100°C induced shrinkage in the composites is due to a loss of some moisture and water from cement matrix in

composites. The thermal expansion coefficient value of the 0-3 composites in the range tested was found to match with concrete.

4. The dielectric constant, piezoelectric value of 1-3 and 2-2 composites obtained from the experiment were found to fit closest to that of the parallel model and the results are shown to be higher than 0-3 composites. The dielectric constant and piezoelectric values of 0-3 composites were closest to those calculated from the cube and series model. The dielectric loss of 1-3 and 2-2 composites were found to decrease with increased of ceramic content and the results are lower than 0-3 composites. The g_{33} values of the composites (for the range tested) were higher than that of pure ceramic.

5. The 2-2 BZT-PC composites had the higher dielectric constant, electromechanical coupling coefficient, piezoelectric coefficient, acoustic impedance than 1-3 composites, while 1-3 BZT-PC composites had the higher dielectric loss and piezoelectric voltage coefficient value than 2-2 composites.

6. The 0-3 composites with ≈ 30-60% BZT composites and the 1-3 composites with ≈ 30-50% BZT and the 2-2 composites ≈ 30-50% BZT were found to give the optimal ceramic content for an acoustic impedance that matches concrete.

7. From SEM micrographs of the composites, calcium silicate hydrates (the main hydration products of Portland cement) can be seen to act as the binder which binds the composites together.

8. The properties of the BZT-PC composites of this work can be compared with the basic properties of lead piezoelectric ceramic (lead zirconate titanate; PZT)-cement based composites of previous works as listed in Table 5.1. However, these

results were more likely to be affected by the techniques used and cannot be compared directly.

Table 5.1 Dielectric, piezoelectric and acoustic impedance properties of piezoelectric-cement based composites.

Materials	Vol%	ε_r (at1 kHz)	d_{33} (pC/N)	g_{33} (10^{-3}Vm/N)	Z (10^6kg/m^{2}s)	Ref
Lead piezoelectric cement-based composites						
0-3 PZT-PC	50	300	23	8.6	-	[72]
0-3 PZT-PC	50	94.2	12.5	15.0	≈10.4	[3]
0-3 PZT-PC	50	176	26	16.0	-	[74]
0-3 PZT-PC	50	≈500	≈50	≈11.3	7.4	[77]
1-3 PZT- PC	50	-	≈175	-	≈19.0	[7]
1-3 PZT- PC	54.9	1100	240	24.7	13.2	[12]
2-2 PZT- PC	53.9	1570	339	24.4	14.8	[12]
This work (modified barium titanate-Portland cement composites)						
0-3 BZT-PC	50	340	14	4.6	9.5	
1-3 BZT-PC	50	547	95	19.6	10.9	
2-2 BZT-PC	50	596	103	19.5	11.2	

5.2 Suggestions for further work

A number of interesting questions remain unanswered concerning some properties and applications of the piezoelectric-cement based composites are recommended in this part. The following suggestions are, therefore, recommended for the future work on the properties, application and design of the piezoelectric-cement based composites.

1. Further works on the variation of piezoelectric value of piezoelectric-cement based composites as a function of aging time would need to be considered.

2. Further works on another piezoelectric ceramic with high piezoelectric value are recommended.

3. Further works on the design and test of piezoelectric-cement based composites in concrete structural health monitoring are recommended.