CONCLUSION AND SUGGESTIONS FOR FUTURE STUDY

5.1 Conclusion

Based on reviews on past literature and the present experimental study on both mortar and concrete with and without addition of microorganisms the following conclusions are made.

1. Addition of *Shewanella* species [(*S. alga u 91544*)-sequence assigned by RDP], facultative anaerobic iron reducing microorganisms obtained from the hot spring of Bakreshwar, west Bengal, India have a positive role on the compressive strength of mortar and concrete. Improvement in compressive strength of both mortar and concrete reaches a maximum at about $10^5$/ml cell concentration at 28 days. Microorganism was expected to contribute more to the strength of cement mortar/concrete with a longer incubation period and thus the strength improvement is more at 28 days compared to 3 days, 7 days and 14 days. It seems that at this range the microorganisms continues to metabolize to induce precipitation during the incubation period effectively and obtained good nourishment (Refer table 4.1 and table 4.6).

2. With the increase in water cement ratio of mortar/concrete having different cell concentrations, the reduction in compressive strength is noticed as in the case of controlled concrete (Refer table – 4.4 & 4.5 and table 4.7 & 4.9)

3. The addition of microorganisms having different cell concentration in concrete has no direct effect on the workability of concrete at particular water –cement ratio.

4. Split tensile strength of concrete is also increased with the addition of *Shewanella* species and maximum at about $10^5$/ml cell concentration at 28 days. (Refer table 4.8 and table 4.9).
5. There is no improvement in compressive strength of mortar with the addition of *Escherichia coli* (*E. coli*) microorganisms at different cell concentration (Refer table 4.2).

6. There is no significant improvement on the compressive strength of mortar due to the addition of media only (without microorganism) (Refer table 4.3).

7. Scanning Electron Microscope (SEM) examination on cement mortar and concrete reveals the growth of fibrous filler material within the pores due to the presence of such microorganisms. This special growth modifies the porosity and pore size distribution of cement mortar (Refer figure 4.8(a)-(f) and figure 4.10(a)-(g)).

8. Image analysis of both treated and untreated concrete suggests improvement in textural behavior due the addition of microorganism and also enhancement in the coherence between sand particles and the matrix in micro-scale due to preferential crystallization at the cement sand-matrix interfaces (Refer figure- 4.11(a)-(e)).

9. The Mercury Intrusion Porosimetry test results of cement mortar also confirm the refinement of pore structure within the cement mortar matrix. The maximum improvement in pore refinement within the mortar matrix is noted at cell concentration of $10^5$ cell/ml (Refer figure- 4.12).

10. X-ray Diffraction (XRD) analysis of cement mortar samples shows the development of new phase consisting of a chemical composition of CaAl$_2$Si$_2$O$_8$ due to the addition of microorganisms in cement mortar (Refer figure 4.13-figure-4.17).

11. Ultrasonic Pulse Velocity (UPV) test and Water Absorption test confirms the improvement of strength due to the addition of appropriate quantity of
microorganisms and provide an idea about higher durability behavior (Refer figure- 4.18-figure 4.21).

12. Finally, it may be inferred that the enrichment culture of the particular facultative anaerobic thermopile grows inside the mortar or concrete matrix and produces minute particles in the form of some crystals resulting in strength improvement by the refinement of pore structure. The major advantage of using this microorganism in concrete technology is that the microorganism being facilitative anaerobic and water grown, it grows well inside the mortar or concrete matrix without supply of oxygen.

5.2 Suggestion for Future Studies

1. A further detailed study on the beneficial effect on mortar/concrete of this novel thermophilic facultative anaerobic iron reducing microorganism isolated from the hot spring of Bakreshwar, West Bengal India, is necessary.

2. The effect of different curing conditions (such as in presence of media at different temperature) on the strength improvement of mortar/concrete with microorganism is also an important area of this research.

3. The long-term performance such as strength, shrinkage and durability of mortar/concrete containing such microorganisms at different curing condition and cell concentration is to be studied for practical use.

4. The identification of the other favorable microorganisms for mortar/concrete and their causes to improve the overall behavior of mortar/concrete through concrete microstructure analysis is also an important research area.
5. Subsequently, development of innovative cement based material utilizing these favourable microorganisms in mortar/ concrete as a self-healing concrete is to be made.

6. A safe and environmentally accepted methodology of microbial remediation of micro-cracks and fissures in concrete structure is to be developed.