

Contents

| | |
|--|-----------|
| ABSTRACT | viii |
| ملخص..... | ix |
| KEYWORDS | xi |
| DEDICATION | xii |
| ACKNOWLEDGEMENTS | xiii |
| LIST OF TABLES | xv |
| LIST OF FIGURES | xvii |
| LIST OF ABBREVIATIONS..... | xix |
| UNIT ABBREVIATIONS..... | xxi |
| INTRODUCTION | 1 |
| 1.1 The 'E' in Sustainable Development | 1 |
| 1.2 Background on the creation and management of biosolids | 1 |
| 1.3 Current levels of sewage sludge production | 5 |
| 1.4 Public acceptance barriers to biosolids recycling | 7 |
| 1.5 Factors influencing current and future biosolids management practices | 9 |
| 1.6 Research objective..... | 10 |
| LITERATURE REVIEW | 11 |
| 2.1 Background and introduction..... | 11 |
| 2.2 Incineration as a management option..... | 12 |
| 2.3 Land application as a management option..... | 13 |
| 2.4 Land filling as a management option..... | 15 |
| 2.5 Cost comparison of disposal and recycling routes for sewage sludge..... | 16 |
| 2.6 Sewage sludge as a construction material..... | 18 |
| 2.6.1 Background | 19 |
| 2.6.2 Use of biosolids and biosolids ash in clay bricks | 20 |
| 2.6.3 Wastewater sludge as a cementitious and blended cement materials..... | 20 |
| 2.6.4 Biosolids use in load-bearing structures | 21 |
| 2.6.5 Industrial sewage sludge use in concrete works | 21 |
| 2.6.6 Potential technical limitations | 22 |
| 2.6.7 Local barriers..... | 23 |
| 2.6.8 Increased energy costs | 23 |
| RESEARCH DESIGN AND APPLIED METHODOLOGIES | 25 |

| | |
|---|----|
| 3.1 Introduction | 25 |
| 3.2 Experimental approach | 25 |
| 3.3 Materials and methods | 28 |
| 3.3.1 Portland Cement..... | 28 |
| 3.3.2 Water | 29 |
| 3.3.3 Aggregates | 30 |
| 3.3.3.1 Physical properties Relative density | 30 |
| 3.3.3.2 Physical properties Absorption capacity and surface moisture..... | 30 |
| 3.3.4 Wastewater Sewage sludge (dewatered biosolids) | 31 |
| 3.3.4.1 Sample collection..... | 32 |
| 3.3.4.2 Sample preparation | 32 |
| 3.4 Experimentation program and testing procedures | 38 |
| 3.4.1 Concrete mix design | 38 |
| 3.4.2 Sample proportioning..... | 38 |
| 3.4.2.1 Benchmark test: biosolids as additive | 38 |
| 3.4.2.2 Biosolids and ashes as sand replacement..... | 40 |
| 3.4.3 Assessment of the concrete blocks manufacturing technology | 41 |
| 3.4.4 Assessing physical properties..... | 43 |
| 3.4.4.1 Consistence tolerance (slump)..... | 43 |
| 3.4.4.2 Compressive strength..... | 45 |
| 3.4.4.3 Water Absorption | 50 |
| 3.4.4.4 Density | 50 |
| RESULTS AND DISCUSSION | 51 |
| 4.1 Introduction | 51 |
| 4.2 Compressive strength | 51 |
| 4.2.1 Control Samples (Free from biosolids/ashes)..... | 51 |
| 4.2.2 Samples containing sun-dried biosolids..... | 52 |
| 4.2.3 Concrete samples containing incinerated biosolids (ashes) | 56 |
| 4.3 Consistence tolerance..... | 59 |
| 4.4 Water absorption..... | 61 |
| 4.5 Density | 62 |
| 4.6 Biosolids and biosolids ashes as partial replacement for fine aggregates | 65 |
| 4.6.1 Compressive strength..... | 65 |

| | |
|--|----|
| 4.6.2 Slump | 66 |
| 4.6.3 Density and water absorption..... | 67 |
| 4.7 Evaluation of economic savings | 67 |
| CONCLUSIONS AND RECOMMENDATIONS | 71 |
| 5.1 Introduction | 71 |
| 5.2 Conclusions | 71 |
| 5.3 Recommendations..... | 73 |
| 5.4 Lessons learned..... | 73 |
| BIBLIOGRAPHY..... | 75 |
| APPENDICES..... | 80 |
| Appendix I Concrete Mix Design Procedure..... | 81 |
| Appendix II Estimation of Biosolids production in Palestine..... | 88 |
| Appendix III Compressive strength sample calculation..... | 91 |
| Appendix IV Control Samples Detailed Results | 93 |