Contents

Front matter i

Title Page ii

Certificate iii

Declaration by the Candidate iv

Copyright Transfer certificate v

Acknowledgements vi

Abstract vii

Contents viii

List of Figures xii

List of Tables xiv

List of Symbols xvi

Abbreviations xviii

1. Introduction

1.1 Overview 1
1.2 Composite and sandwich plates 1
1.3 Carbon nanotube 4
1.3.1. Carbon nanotube reinforced composite plate 12
1.3.2. Distribution of CNTs in CNTRC plate 18
1.4 CNTs reinforced composite plate resting on a Pasternak's elastic foundation 20
1.5 Method used to analyze the behavior of CNTs reinforced composite plate 21
1.5.1. Analytical method used for analysis of CNTRC plate 21
1.5.2. Numerical method used for analysis of CNTRC plate 22
1.6 Solution Schemes for governing differential equation of CNTRC plate 23
1.7. Organization of thesis 24

2. Literature review

2.1. Introduction 27
2.2. Development of CNTs 27
2.2.1. The mechanical behavior of carbon nanotube reinforced composites plates 28
2.2.2. Structural responses of CNTRC composite and sandwich plate 30
2.2.3. Theories used for the analysis of carbon nanotube reinforced 32

composite structure
2.2.4. Computational modelling techniques for the analysis of carbon nanotube reinforced composite structure 35
2.2.5. Carbon nanotube reinforced composite structure resting on the elastic foundation 36
2.3. Development of plate theory 39
2.3.1. Elasticity Solutions (3 D) 41
2.3.2. Modeling of plates using Plate Theories 42
2.3.2.1. Plate theories 43
2.3.2.2. Classical Plate theory 44
2.3.2.3. First Order Shear Deformation theory 46
2.3.2.4. Higher-Order Shear Deformation theories 46
2.3.3. Extension of the plate theories for the modelling of multi-layered structures 50
2.3.3.1 Equivalent Single Layer (ESL) Approach 50
2.3.3.2. Layer wise (LW) approach 50
2.3.3.3. Zigzag (ZZ) Approach 51
2.4 Solution Schemes 51
2.5 Critical Observation from Literature Review 54
2.6 Motivation and Literature Gap 54
2.7 Objectives and Scope of the Present Work 57
2.8 Summary 59

3. Mathematical Formulation

3.1 Introduction 61
3.2 Basic Assumptions 63
3.3 Properties of carbon nanotube reinforced composite plate 65
3.4 Stress-Strain Constitutive Relations 66
3.5 Strain displacement relationships 67
3.6 Plates on elastic foundation 68
3.7 Displacement field 69
3.8 Analytical Formulation 72
3.8.1. Equations of motion 73
3.8.2. Navier's Solution Methodology 79
3.8.2.1. Solution of differential equation for bending analysis 82
3.8.2.2. Solution of differential equation for free vibration 83
3.8.2.3. Buckling analysis 85
3.9 Finite Element (FE) Formulation 86
3.9.1 Hamilton's principle 91
3.9.1.1. Strain energy due to linear strains 91
3.9.1.2. Strain energy due to non-linear strains 92
3.9.1.3. The variation in the strain energy of the elastic foundation 94
3.9.1.4. Kinetic energy store in carbon nanotubes reinforced composite plate 94
3.9.1.5. Work done by the applied transverse load 95
3.9.1.6. Strain energy store due to artificial constraints 95

3.9.2 Governing equations 96
3.10 Material properties 98
3.11 Non-dimensional parameter 100
3.12 Summary 100

4. Result and Discussion

4.1 Introduction 103

4.2 Structural analysis of the carbon nanotube reinforced composite plates 106

4.2.1 Bending analysis of the carbon nanotube reinforced composite plates 107

4.2.1.1. Non-dimensional transverse deflection of the carbon nanotube reinforced composite plate 110

4.2.1.1.1. Non-dimensional transverse deflection of the carbon nanotube reinforced composite plate under uniformly distributed load 111

4.2.1.1.2. Non-dimensional transverse deflection of the carbon nanotube reinforced composite plate under sinusoidal load 112

4.2.1.2. Non-dimensional stress analysis of the carbon nanotube reinforced composite plate 112

4.2.1.2.1 Non-dimensional normal stress distribution of carbon nanotube reinforced composite plate 114

4.2.1.2.2. Non-dimensional in plane shear stress distribution of carbon nanotube reinforced composite plate 121

4.2.1.2.3. Non-dimensional transverse shear stress distribution of carbon nanotube reinforced composite plate 123

4.2.2. Free Vibration analysis of carbon nanotube reinforced composite plate 126

4.2.3. Buckling analysis of carbon nanotube reinforced composite plate 132

4.2.3.1. Buckling analysis of the carbon nanotube reinforced composite plate under uni-axial compressive load 134

4.2.3.2. Buckling analysis of the carbon nanotube reinforced composite plate under bi-axial compressive load 138

4.3. Structural analysis of the carbon nanotube reinforced sandwich plate 141

4.3.1. Bending analysis of the carbon nanotube reinforced sandwich plate 144

4.3.1.1. Transverse and in plane deflection of the carbon nanotube reinforced sandwich plate 144

4.3.1.2. Normal stress analysis of the carbon nanotube reinforced sandwich plate 151

4.3.1.3. Non-dimensional transverse shear stresses of the carbon 156

nanotube reinforced sandwich plate
4.3.2. Free vibration analysis of carbon nanotube reinforced sandwich plate 157
4.4. Structural analysis of functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation 160
4.4.1. Bending analysis of functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation 160
4.4.1.1. Transverse deflection of functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation 161
4.4.1.2. Non-dimensional stress analysis of functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation 165
4.4.2. Free vibration analysis of functionally graded Carbon nanotube reinforced composite plates resting on Pasternak elastic foundation 171
4.4.3. Buckling analysis of functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation 173
4.4.3.1. Buckling analysis of uni-axially loaded functionally graded carbon nanotube reinforced composite plates resting on Pasternak's elastic foundation 173
4.4.3.2. Buckling analysis of bi-axially loaded functionally graded Carbon nanotube reinforced composite plates resting on Pasternak elastic foundation 178
4.5. Closure 183

5. Conclusions

5.1 Concluding Remarks 185
5.2 Contribution of the thesis 188
5.3 Scope for Future Research 189

References 191

Appendix 219

About the Author 222