TABLE OF CONTENTS

Certificate ii

Acknowledgments vi

Abstract ix

Table of Contents xii

List of Figures xvii

List of Abbreviations and Symbols xxvi

Chapter-1 Introduction **1-14**

1.1 Background 1

1.2 Motivation for the Research 9

1.3 Objectives and Scope of Study 11

1.4 Organization of the Thesis 12

Chapter-2 Literature Review **15-49**

2.1 Introduction 15

2.2 Linear Elastic Fracture Mechanics 16

2.2.1 Stress Intensity Factor 18

2.2.2 Energy Release Rate 20

2.2.3 Small Scale Yielding 21

2.3 Elastic Plastic Fracture Mechanics 21

2.3.1 The Path Independent *J* integral 23

2.3.2 Crack Tip Opening Displacement 24

2.3.3 Relation Between *J* and CTOD 26

2.3.4 Plastic Zone Shape 28

2.4 Fracture Mechanics of Pressure Sensitive Yielding Materials 29

2.4.1 Studies Based on Small Deformation Formulation 30

2.4.2 Studies Based on Large Deformation Formulation 32

2.5 Fracture Mechanics of Plastically Incompressible Materials: Crack Tip Blunting and Fields 34

2.6 Fracture Mechanics under Fatigue Loading 36

2.6.1 Studies Based on Small Deformation Formulation 37

2.6.2 Studies Based on Large Deformation Formulation 38

2.7 Fracture Mechanics of Elastic-Plastic Solids with Plastic Non-normality 39

2.8 Crack Growth Modeling Strategies 41

(a) Node Release Technique 41

(b) Extended Finite Element Method 42

(c) Cohesive Zone Model 42

(d) Crack Tip Blunting Model 43

2.9 Computational Methods in Fracture Mechanics 43

2.9.1 Methods of Stress Calculations 44

2.9.1.1 Analytical Methods 44

2.9.1.2 Numerical Methods 45

(a) Finite Difference Method 46

(b) Finite Element Method 46

(c) Boundary Element Method 47

(d) Meshless Method 48

2.10 Concluding Remarks 49

Chapter-3 Finite Deformation Formulation 51-66

3.1.Introduction 51

3.2 Continuum Mechanics 52

3.2.1 Kinematics of Deformation 52

3.2.1.1 Motion 53

3.2.1.2 The Deformation Gradient 54

3.2.1.3 Strain Measures 56

3.2.1.4 The Velocity Gradient 57

3.2.1.5 Stress Measures 57

3.2.1.6 The Rate Viewpoint 59

3.2.2 Fundamental/balance Laws 60

3.2.2.1 Conservation of Mass 60

3.2.2.2 Conservation of Linear Momentum 60

3.2.2.3 Conservation of Angular Momentum 61

3.3. Quasi-static Deformation Histories 61

3.3.1 Conservational Formulation 63

3.3.2.Convected Coordinate Formulation 64

3.4 Concluding Remarks 66

Chapter-4 Constitutive Relationships **67-73**

4.1 Introduction 67

4.2 Constitutive Relations 68

4.3 Concluding Remarks 72

Chapter-5 Numerical Procedures and Geometry Analysed **75-94**

5.1 Introduction 75

5.2 Description of Analyses 75

5.2.1 Problem Formulation 76

5.2.2 Rate Tangent Formulation 78

5.2.3 Finite Element Equations 81

5.2.4 Geometry Description 85

5.3 Finite Element Issues 87

5.3.1 Element Description 87

5.3.2 Mesh Generation 90

5.3.3 Material Model 91

5.3.4 Equation Solver and Solution Control Options 93

5.4 Concluding Remarks 93

Chapter-6 Results and Discussion **95-170**

6.1 Introduction 95

6.2 Problem Definition with Boundary Conditions 96

6.2.1 Boundary Conditions for Monotonic Loading 96

6.2.2 Boundary Conditions for Cyclic Loading 97

6.3 Convergence Studies 99

6.3.1 Mess Convergence 99

6.3.2 Program Verification Analysis 102

6.4 Some Results under Monotonic Loading (Plastic Normality Condition) 104

6.4.1 Applied *J* versus Crack Tip Opening Displacement 104

6.4.2 Plastic Zone Shape and Size 107

6.4.3 Near Crack Tip Fields 109

6.5 Some Results under Cyclic Loading (Plastic Normality Condition) 123

6.5.1 Crack Tip Deformation 123

6.5.2 Plastic Zone Shape and Size 141

6.5.3 Near Crack Tip Fields 147

6.6 Some Results under Monotonic Loading (Plastic Non-normality Condition) 158

6.6.1 Crack Tip Deformation 158

6.6.2 Near Crack Tip Fields 160

6.7 Concluding Remarks 170

Chapter-7 Summary and Conclusion **171-175**

7.1 Introduction 171

7.2 Numerical Investigations 171

7.3 Recommended Future Work 173

References **177**

List of Publications **197**

Appendix **199**