

Contents

Units

Preface

Foreword

Acknowledgements

Bibliography

Subject index

Part 1 – Computation of the total strains

Chapter 1 – Ply properties

1.1 Introduction

1.2 The standard plies

1.3 The constituent materials

1.4 Standard ply properties

1.5 The ply stiffness matrix [Q]

1.6 The importance of strains

Chapter 2 – Laminate circularity

2.1 Introduction

2.2 Thermal loads

2.3 Thermal loads and circularity

2.4 Hydric loads

2.5 Mechanical loads

2.6 Membrane forces on circular cylinders

2.7 Circular cylinders deflected by lateral loads

2.8 Conclusion

Chapter 3 – Computing the total ply strains

3.1 Introduction

3.2 Computing the thermal strains

3.3 Protocol to compute the thermal strains

3.4 The protocol for hydric strains

3.5 The protocol for mechanical strains

3.6 Total strains

3.7 Laminate engineering constants

Appendix 3.1 Stress-free temperature

Appendix 3.2 Cure shrinkage and residual strains

Chapter 4 – Laminate matrices

4.1 Introduction

4.2 Laminate construction and the critical plies

4.3 Standard laminate matrices

4.4 Rotating the ply matrices

4.5 Computing the laminate matrices

4.6 Matrices of angle-ply ± 55 laminates

4.7 Matrices of angle-ply ± 70 laminates

4.8 Matrices of hoop-chop laminates

Chapter 5 – Total strains in ± 55 laminates

5.1 Introduction

5.2 Thermal strains

5.3 Hydric strains

5.4 Mechanical strains

5.5 Total strains

Chapter 6 – Total strains in ± 70 laminates

6.1 Introduction

6.2 Thermal strains

6.3 Hydric strains

6.4 Mechanical strains on vertical storage tanks

6.5 mechanical strains on non-anchored above ground pipes

6.6 Total strains

6.6.1 Vertical tanks

6.6.2 Above-ground, non-anchored pipes

Chapter 7 – Total strains in hoop-chop sanitation pipes

7.1 Introduction

7.2 Thermal strains on hoop-chop laminates

7.3 Hydric strains on hoop-chop laminates

7.4 Mechanical strains on hoop-chop laminates

7.5 Total strains

Appendix 7.1 – Residual mechanical strains

Part 2 – Computation of durability

Chapter 8 – The eight modes of long-term failure

8.1 Introduction

8.2 The eight modes of long-term failure

8.3 Critical plies

8.4 The long-term load-dependent failures

8.5 Crack densities and equivalent ply strains

8.6 The failure thresholds

8.6.1 Thresholds of fiber loaded UD plies

8.6.2 Thresholds of transverse loaded UD plies

8.6.2.1 Infiltration

8.6.2.2 Weep

8.6.2.3 Stiffness

8.6.2.4 Rupture

8.6.3 Thresholds of chopped plies

8.6.3.1 Infiltration

8.6.3.2 Weep

8.2.3.3 Stiffness

8.3.3.4 Rupture

8.7 The work of R. F. Regester

8.7.1 Time of exposure

8.7.2 Liner presence

8.7.3 Acid concentration

8.7.4 Temperature

8.7.5 Type of cation

8.7.6 The work of Regester in actual service

8.8 Short-term and long-term safety factors

Chapter 9 – The regression equations

9.1 Introduction

9.2 The ply regression equations

9.3 Simplified regression ply equations

9.3.1 Deriving the simplified regression ply equations

9.3.2 The resin effect

9.4 The pure regression equations

9.4.1 Pure static rupture of fiber loaded UD plies ($R = 1.0$)

9.4.2 Pure cyclic rupture of fiber loaded UD plies ($R = 0.0$)

9.4.3 Pure cyclic infiltration of transverse loaded UD plies ($R = 0.0$)

9.4.4 Pure cyclic shear rupture of UD plies

9.4.5 Pure cyclic rupture of chopped plies ($R = 0.0$)

9.4.6 Pure static rupture of chopped plies ($R = 1.0$)

9.5 Tabulated pure regression equations

Appendix 9.1 – The idealized rupture equation

Appendix 9.2 – The fatigue threshold

A1 Transverse loaded UD plies

A2 Chopped plies

A3 UD plies loaded in the fiber direction

Chapter 10 – Temperature, moisture and resin toughness

10.1 Introduction

10.2 Effects of temperature and moisture on the failure thresholds

10.3 An important practical consequence

10.4 Experimental evidence on the weep threshold

10.5 A closer look at the weep failure of oil pipes

10.6 The failure thresholds of chopped plies

10.7 Weep times of sanitation pipes

10.8 Improving the failure thresholds

10.9 Cyclic loadings

Appendix 10.1 – Why brittle plies develop many short cracks

Appendix 10.2 – The resin-glass interphase

Appendix 10.3 – Micro-strains at the fiber level

Chapter 11 – Service life and the corrosion barrier

11.1 Introduction

11.2 Two types of aggressive chemicals

11.3 Non-reactive chemicals

11.4 Durability of the corrosion barrier

11.5 Measuring the penetrated depth

11.6 Measuring the corrosion parameters

11.7 Simplified equations

11.8 Estimating the service life

Appendix 11.1 – Deriving equation (11.1)

Appendix 11.2 – Damages and defects in liners and corrosion barriers

Appendix 11.3 – Residual life of aged laminates

Chapter 12 – Long-term fiber rupture

- 12.1 Introduction
- 12.2 Generalized strain-corrosion of glass fibers
- 12.3 Static loadings
- 12.4 Pure cyclic loading of UD plies
- 12.5 The work of Mark Greenwood
- 12.6 The work of Guangxu Wei
- 12.7 The work of the British Plastics Federation
- 12.8 The unified equation
- Appendix 12.1 – Sudden death

Chapter 13 – Infiltration, weep and stiffness failures

- 13.1 Introduction
- 13.2 The classical HDB
- 13.3 The weep threshold
- 13.4 Liner effect on the weep threshold
- 13.5 Inadequacy of the classical HDB
- 13.6 Measuring the failure thresholds
- 13.7 Cyclic loadings
- Appendix 13.1 – Measuring the infiltration threshold

Chapter 14 – Laminate strain-corrosion

- 14.1 Introduction
- 14.2 The mechanism of laminate strain-corrosion
- 14.3 Laminate strain-corrosion and bending loads
- 14.4 Laminate strain-corrosion cracks
- 14.5 Predicting the time to strain-corrosion rupture
- 14.6 Strain-corrosion in underground sanitation pipes
- 14.7 Static strain-corrosion regression lines of sanitation pipes
- 14.8 Strain-corrosion threshold
- 14.9 Cyclic strain-corrosion

Chapter 15 – Abrasion life

- 15.1 Introduction
- 15.2 The eroded depth
- 15.3 The governing wear equation
- 15.4 Measuring the wear parameters

Chapter 16 – The unified equation

- 16.1 Introduction
- 16.2 Pure regression lines
- 16.3 Deriving the unified equation
- 16.4 Applying the unified equation
- 16.5 Time-independent failures
- 16.6 Block loading
- Appendix 16.1 – The unified equation and the Goodman diagram
- Appendix 16.2 – Ply thresholds transferred to pipes
- Appendix 16.3 – Laminate regression equations

Chapter 17 – The interaction parameter G_{sc}

- 17.1 Introduction
- 17.2 The load paths
- 17.3 Computing the G_{sc} values
- 17.4 Interpolating the G_{sc} values
- 17.5 Computing the fiber-dominated durability
- 17.6 Computing the resin-dominated durability
- 17.7 A few G_{sc} values

Chapter 18 – Numerical computation of the interaction parameter G_{sc}

- 18.1 Introduction
- 18.2 Computing the time-dependent G_{sc}
- 18.3 Computing the time-independent G_{sc}
- Appendix 18.1 Practical range of the long-term safety factors SF

Chapter 19 – The unified equation applied to API 15HR

- 19.1 Introduction
- 19.2 The laminate global strains
- 19.3 The ply local strains
- 19.4 Long-term rupture
- 19.5 Weep failure

Chapter 20 – Short-term strengths of ± 55 oil pipes

- 20.1 Introduction
- 20.2 The general equation
- 20.3 Angle-ply laminates
- 20.4 Strain analysis

Chapter 21 – Impermeable pipes

- 21.1 Introduction
- 21.2 Permeability, diffusivity and solubility
- 21.3 Impermeable sanitation and oil pipes
- 21.4 Applications of impermeable pipes
 - 21.4.1 Anomalous failure in sanitation pipes
 - 21.4.2 Underground storage tanks
 - 21.4.3 Solvent storage and transmission
 - 21.4.4 Industrial effluents
 - 21.4.5 Gas transmission
 - 21.4.6 Chemical service

- 21.5 Market acceptance

Appendix 21.1 Weep threshold of impermeable pipes

Appendix – The fatigue mechanism

- A1 Introduction
- A2 Rupture failure
- A3 Fatigue failure
- A4 Actual and nominal stress waves
- A5 Energy balance

A6 The unified equation

A7 The fatigue limit and the fatigue threshold