WAN NUR FADILLA BINTI WAN HAMAD

MAD This term of this for the second second



WAN NUR FADILLA BINTI WAN HAMAD

(ed toby

(1031620003)

his item A thesis submitted In partial fullfillment of the requirement for the degree of Master of Engineering (Polymer Engineering)

SCHOOL OF MATERIALS ENGINEERING **UNIVERSITI MALAYSIA PERLIS** 2011

WAN NUR FADILLA BINTI WAN HAMAD

MAD This term of this for the second second



WAN NUR FADILLA BINTI WAN HAMAD

(ed toby

(1031620003)

his item A thesis submitted In partial fullfillment of the requirement for the degree of Master of Engineering (Polymer Engineering)

SCHOOL OF MATERIALS ENGINEERING **UNIVERSITI MALAYSIA PERLIS** 2011

THE EFFECT OF POROSITY ON THE MECHANICAL AND DIELECTRIC PROPERTIES OF EPOXY FOAM

PREPARED BY:

WAN NUR FADILLA BINTI WAN HAMAD (1031620003)

SUPERVISOR:

DR TEH PEI LENG

Proposal Submitted in Partial Fulfillment of the Requirements for the Final Year Project

MASTER OF SCIENCE (POLYMER ENGINEERING) SCHOOL OF MATERIALS ENGINEERING UNIVERSITI MALAYSIA PERLIS

APRIL 2011

orthis item is protected by original copyright

THE EFFECT OF POROSITY ON THE MECHANICAL AND DIELECTRIC PROPERTIES OF EPOXY FOAM

PREPARED BY:

WAN NUR FADILLA BINTI WAN HAMAD (1031620003)

SUPERVISOR:

DR TEH PEI LENG

Proposal Submitted in Partial Fulfillment of the Requirements for the Final Year Project

MASTER OF SCIENCE (POLYMER ENGINEERING) SCHOOL OF MATERIALS ENGINEERING UNIVERSITI MALAYSIA PERLIS

APRIL 2011

orthis item is protected by original copyright

| Table | of Contents | ii |
|---------|--|------------------|
| List of | f Tables | vi |
| List of | f Figures | vii |
| List of | f Symbols | X |
| Abstra | ak (BM) | xi |
| Abstra | act (English) | xii |
| CHAF | PTER 1 : INTRODUCTION | 1 |
| | act (English) PTER 1 : INTRODUCTION 1.1 Background 1.2 Problem statement 1.3 Objectives of the research 1.4 Scope of the research | 1 3 4 4 |
| CHAF | PTER 2: LITERATURE REVIEW | 5 |
| | 2.1 Thermoset Material | 5 |
| | 2.1.1 Epoxy | 6 |
| | 2.2 Hardener | 8 |
| | 2.3 Blowing agent | 10 |
| | 2.3.1 Sodium bicarbonate | 12 |
| | 2.4 Additives in polymer | 13 |
| | 2.4.1 Diluent | 14 |
| | 2.4.2 Acetic acid | 15 |
| | 2.5 Polymer foam | 16 |
| | 2.5.1 Epoxy foam | 18 |

| CHAPTER 3: METHODOLOGY | 20 |
|---|----|
| 3.1 Materials | 20 |
| 3.1.1 Epoxy resin | 20 |
| 3.1.2 Hardener | 21 |
| 3.1.3 Sodium bicarbonate | 21 |
| 3.1.3 Sodium bicarbonate 3.1.4 Diluent 3.1.4.1 Butyl Glycidyl Ether | 22 |
| 3.1.4.1 Butyl Glycidyl Ether | 22 |
| 3.1.5 Acetic acid | 23 |
| 3.2 Sample Preparation | 23 |
| 3.2.1 The effect of foaming agent content at room temperature | 23 |
| 3.2.2 The effect of processing temperature | 24 |
| 3.2.3 The effect of acetic acid | 24 |
| 3.2.4 The effect of diluents | 25 |
| 3.3 Testing and Characterization | 26 |
| 3.3.1 Flexural testing | 26 |
| 3.3.2 Dielectric constant | 27 |
| 3.3.3 Dynamic mechanical analysis | 27 |
| 3.3.4 Scanning Electron Microscopy | 27 |
| 3.3.5 Swelling | 28 |
| 3.4 Flow chart of experiment | 30 |
| | |

| CHAPTER 4: RESULTS AND DISCUSSION | 31 |
|---|----|
| 4.1 The effect of blowing agent content on properties of epoxy foam | 31 |

| 4.1.1 Viscosity | 31 |
|---|----|
| 4.1.2 Flexural properties | 32 |
| 4.1.3 Density testing | 34 |
| 4.1.4 Dielectric constant | 35 |
| 4.1.5 Swelling | 36 |
| 4.2 The effect of processing temperatures on properties of epoxy foam | 37 |
| 4.2.1 Viscosity | 37 |
| 4.2.2 Flexural properties | 39 |
| 4.2.3 Density testing | 41 |
| 4.2 4 Dielectric constant | 41 |
| 4.25 Swelling | 42 |
| 4.3 The effect of acetic acid on properties of epoxy foam | 43 |
| 4,3.1 Viscosity | 43 |
| 4.3.2 Flexural properties | 44 |
| 4.3.3 Density testing | 46 |
| 4.3.4 Dielectric constant | 47 |
| 4.3.5 Swelling | 48 |
| 4.4 The effect of diluent content on the properties of epoxy foam | 49 |
| 4.4.1 Viscosity | 49 |
| 4.4.2 Flexural properties | 50 |
| 4.4.3 Density testing | 52 |

| 4.4.4 Dielectric constant | 53 |
|---|----|
| 4.4.5 Swelling | 54 |
| 4.5 Comparison between all processing conditions | 55 |
| 4.5.1 Viscosity | 55 |
| 4.5.2 Flexural properties | 56 |
| 4.5.2.1 Flexural strength | 56 |
| 4.5.2.2 Flexural modulus | 58 |
| 4.5.3 Dynamic mechanical analysis | 61 |
| 4.5.3.1 Storage modulus (E') | 61 |
| 4.5.2 Flexural strength 4.5.2.2 Flexural modulus 4.5.3 Dynamic mechanical analysis 4.5.3.1 Storage modulus (E') 4.5.3.2 Tan δ 4.5.4 Density testing | 62 |
| 4.5.4 Density testing | 63 |
| 4.5.5 Dielectric constant | 64 |
| 4.5.6 Swelling | 66 |
| | |
| CHAPTER 5: CONCLUSION AND RECOMMENDATION | 68 |
| all | |
| Recommendation | 69 |
| REFERENCES | 70 |
| | |

| Table | of Contents | ii |
|---------|--|------------------|
| List of | f Tables | vi |
| List of | f Figures | vii |
| List of | f Symbols | X |
| Abstra | ak (BM) | xi |
| Abstra | act (English) | xii |
| CHAF | PTER 1 : INTRODUCTION | 1 |
| | act (English) PTER 1 : INTRODUCTION 1.1 Background 1.2 Problem statement 1.3 Objectives of the research 1.4 Scope of the research | 1 3 4 4 |
| CHAF | PTER 2: LITERATURE REVIEW | 5 |
| | 2.1 Thermoset Material | 5 |
| | 2.1.1 Epoxy | 6 |
| | 2.2 Hardener | 8 |
| | 2.3 Blowing agent | 10 |
| | 2.3.1 Sodium bicarbonate | 12 |
| | 2.4 Additives in polymer | 13 |
| | 2.4.1 Diluent | 14 |
| | 2.4.2 Acetic acid | 15 |
| | 2.5 Polymer foam | 16 |
| | 2.5.1 Epoxy foam | 18 |

| CHAPTER 3: METHODOLOGY | 20 |
|---|----|
| 3.1 Materials | 20 |
| 3.1.1 Epoxy resin | 20 |
| 3.1.2 Hardener | 21 |
| 3.1.3 Sodium bicarbonate | 21 |
| 3.1.3 Sodium bicarbonate 3.1.4 Diluent 3.1.4.1 Butyl Glycidyl Ether | 22 |
| 3.1.4.1 Butyl Glycidyl Ether | 22 |
| 3.1.5 Acetic acid | 23 |
| 3.2 Sample Preparation | 23 |
| 3.2.1 The effect of foaming agent content at room temperature | 23 |
| 3.2.2 The effect of processing temperature | 24 |
| 3.2.3 The effect of acetic acid | 24 |
| 3.2.4 The effect of diluents | 25 |
| 3.3 Testing and Characterization | 26 |
| 3.3.1 Flexural testing | 26 |
| 3.3.2 Dielectric constant | 27 |
| 3.3.3 Dynamic mechanical analysis | 27 |
| 3.3.4 Scanning Electron Microscopy | 27 |
| 3.3.5 Swelling | 28 |
| 3.4 Flow chart of experiment | 30 |
| | |

| CHAPTER 4: RESULTS AND DISCUSSION | 31 |
|---|----|
| 4.1 The effect of blowing agent content on properties of epoxy foam | 31 |

| 4.1.1 Viscosity | 31 |
|---|----|
| 4.1.2 Flexural properties | 32 |
| 4.1.3 Density testing | 34 |
| 4.1.4 Dielectric constant | 35 |
| 4.1.5 Swelling | 36 |
| 4.2 The effect of processing temperatures on properties of epoxy foam | 37 |
| 4.2.1 Viscosity | 37 |
| 4.2.2 Flexural properties | 39 |
| 4.2.3 Density testing | 41 |
| 4.2 4 Dielectric constant | 41 |
| 4.25 Swelling | 42 |
| 4.3 The effect of acetic acid on properties of epoxy foam | 43 |
| 4,3.1 Viscosity | 43 |
| 4.3.2 Flexural properties | 44 |
| 4.3.3 Density testing | 46 |
| 4.3.4 Dielectric constant | 47 |
| 4.3.5 Swelling | 48 |
| 4.4 The effect of diluent content on the properties of epoxy foam | 49 |
| 4.4.1 Viscosity | 49 |
| 4.4.2 Flexural properties | 50 |
| 4.4.3 Density testing | 52 |

| 4.4.4 Dielectric constant | 53 |
|---|----|
| 4.4.5 Swelling | 54 |
| 4.5 Comparison between all processing conditions | 55 |
| 4.5.1 Viscosity | 55 |
| 4.5.2 Flexural properties | 56 |
| 4.5.2.1 Flexural strength | 56 |
| 4.5.2.2 Flexural modulus | 58 |
| 4.5.3 Dynamic mechanical analysis | 61 |
| 4.5.3.1 Storage modulus (E') | 61 |
| 4.5.2 Flexural strength 4.5.2.2 Flexural modulus 4.5.3 Dynamic mechanical analysis 4.5.3.1 Storage modulus (E') 4.5.3.2 Tan δ 4.5.4 Density testing | 62 |
| 4.5.4 Density testing | 63 |
| 4.5.5 Dielectric constant | 64 |
| 4.5.6 Swelling | 66 |
| | |
| CHAPTER 5: CONCLUSION AND RECOMMENDATION | 68 |
| all | |
| Recommendation | 69 |
| REFERENCES | 70 |
| | |

ACKNOWLEDGEMENT

First and foremost, a great thankful to Allah S.W.T upon the completion of my thesis. A special gratitude to my beloved parents, Wan Hamad Wan Mahmood and Mamunah Daud for their endless love, support and prays throughout my study.

A very sincere gratitude and heartiest appreciation and thanks to my supervisor, Dr Teh Pei Leng for her valued support, in term of knowledge, information, ideas, invaluable guidance and supervision to fulfill my project throughout this semester. I also would like to extent my gratitude to School of Material Engineering for providing facilities and resources for my study. Not forgotten to all laboratory technician of this school especially En. Azmi, En. Wadi, En. Idrus, En. Zaidi, En. Nasir and En. Ku Hasrin for their help, kindness, and cooperation in completing this project. To all my lecturers in the School of Material Engineering, thanks for their help and tolerance.

Last but not least, thanks to all my dearest friends for their valuable help, sharing and caring throughout my whole university life in Universiti Malaysia Perlis. I appreciate for your friendship. Thank you very much.

| Figure | | Page |
|--------|--|------|
| 2.1 | Reaction between bisphenol A and epichlorohydrin | |
| 2.2 | Trietylenetetramine | |
| 2.3 | The chemical reaction between diamine and diepoxy | |
| 2.4 | Reaction between amine and epoxy | |
| 2.5 | Chemical reaction of polyamide and epoxy | |
| 2.6 | Structure of sodium bicarbonate | |
| 2.7 | Butyl Glycidyl ether | |
| 4.1 | The viscosity of epoxy foam with different speeds and sodium bicarbonate | |
| 4.2 | The flexural modulus and strength of epoxy foam at room temperature | |
| 4.3 | SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy and epoxy foam added with (b) 10 phr sodium bicarbonate and (c) 20 phr sodium bicarbonate, respectively at room temperature | |
| 4.4 | The density value for epoxy foam at 0 to 20 phr of sodium bicarbonate at room temperature processing condition. | |
| 4.5 | The value of dielectric constant of epoxy foam at room temperature. | |
| 4.6 | The swelling percentage of epoxy foam with different content of sodium bicarbonate at room temperature | |
| 4.7 | The viscosity of epoxy foam with different speeds and processing temperatures. | |
| 4.8 | The flexural strength and modulus of epoxy foam at the processing temperature of 80°C. | |
| 4.9 | SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy and epoxy foam filled with (b) 20 phr sodium bicarbonate at 80°C, respectively. | |
| 4.10 | The density value of epoxy foam at processing temperature of 80°C. | |

| 4.11 The value of dielectric constant of epoxy foam processed at 80°C. 4.12 The swelling percentage of epoxy foam with different content of sodium bicarbonate at 80°C. 4.13 The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of acetic acid. 4.14 Reaction between acetic acid (CH ₃ COOH) and sodium bicarbonate (NaHCO ₃) 4.15 The flexural strength and modulus of epoxy foam with different sodium bicarbonate content 5 phr of acetic acid. 4.16 SEM micrograph showing the flexural fractore surface morphology of (a) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate for 5 phr of acetic acid, respectively. 4.17 The density values of epoxy foam with acetic acid at different content of sodium bicarbonate. 4.19 The swelling percentage of epoxy foam with different speeds and sodium bicarbonate. 4.20 The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent. 4.21 The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent. 4.22 SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluent. 4.23 Reaction between diluents and hardener. | | |
|---|------|---|
| sodium bicarbonate at 80°C. 4.13 The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of acetic acid. 4.14 Reaction between acetic acid (CH ₃ COOH) and sodium bicarbonate (NaHCO ₃) 4.15 The flexural strength and modulus of epoxy foam with different sodium bicarbonate content 5 phr of acetic acid. 4.16 SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate for 5 phr of acetic acid, respectively. 4.17 The density values of epoxy foam with acetic acid. 4.18 The value of dielectric constant of epoxy foam with acetic acid at different content of sodium bicarbonate. 4.20 The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent. 4.21 The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent. 4.22 SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.11 | The value of dielectric constant of epoxy foam processed at 80°C. |
| bicarbonate content at 5 phr of acetic acid.4.14Reaction between acetic acid (CH3COOH) and sodium bicarbonate (NaHCO3)4.15The flexural strength and modulus of epoxy foam with different sodium bicarbonate content 5 phr of acetic acid.4.16SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate for 5 phr of acetic acid, respectively.4.17The density values of epoxy foam with acetic acid.4.18The value of dielectric constant of epoxy foam with acetic acid at different content of sodium bicarbonate.4.20The swelling percentage of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent.4.21The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent.4.22SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.12 | |
| (NaHCO3)4.15The flexural strength and modulus of epoxy foam with different sodium bicarbonate content 5 phr of acetic acid.4.16SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate for 5 phr of acetic acid, respectively.4.17The density values of epoxy foam with acetic acid.4.18The value of dielectric constant of epoxy foam with acetic acid4.19The swelling percentage of epoxy foam with acetic acid at different content of sodium bicarbonate.4.20The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent.4.21The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent.4.22SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.13 | |
| sodium bicarbonate content 5 phr of acetic acid.4.16SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate for 5 phr of acetic acid, respectively.4.17The density values of epoxy foam with acetic acid.4.18The value of dielectric constant of epoxy foam with acetic acid4.19The swelling percentage of epoxy foam with acetic acid at different content of sodium bicarbonate.4.20The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent.4.21The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent.4.22SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.14 | |
| of (a) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate for 5 phr of acetic acid, respectively.4.17The density values of epoxy foam with acetic acid.4.18The value of dielectric constant of epoxy foam with acetic acid4.19The swelling percentage of epoxy foam with acetic acid at different content of sodium bicarbonate.4.20The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent.4.21The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent.4.22SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.15 | |
| 4.18The value of dielectric constant of epoxy foam with acetic acid4.19The swelling percentage of epoxy foam with acetic acid at different content of sodium bicarbonate.4.20The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent.4.21The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent.4.22SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.16 | of (a) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate |
| 4.19 The swelling percentage of epoxy foam with acetic acid at different content of sodium bicarbonate. 4.20 The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent. 4.21 The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent. 4.22 SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.17 | The density values of epoxy foam with acetic acid. |
| 4.20 The viscosity of epoxy foam with different speeds and sodium bicarbonate content at 5 phr of diluent. 4.21 The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent. 4.22 SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.18 | The value of dielectric constant of epoxy foam with acetic acid |
| 4.21 The flexural strength and modulus for epoxy foam with different sodium bicarbonate content at 5 phr of diluent. 4.22 SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.19 | |
| 4.22 sodium bicarbonate content at 5 phr of diluent. 4.22 SEM micrograph showing the flexural fracture surface morphology of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.20 | |
| of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, both with 5 phr of diluents, respectively. | 4.21 | |
| 4.23 Reaction between diluents and hardener. | 4.22 | of (a) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, |
| | 4.23 | Reaction between diluents and hardener. |
| 4.24 The density value for epoxy foam with diluent. | 4.24 | The density value for epoxy foam with diluent. |

| 4.25 | The value of dielectric constant of epoxy foam with diluent | |
|------|---|--|
| 4.26 | The swelling percentage of epoxy foam with diluent at different content of sodium bicarbonate. | |
| 4.27 | Comparison between the viscosity of (a) pure epoxy and (b) with 20 phr of sodium bicarbonate content at different processing conditions. | |
| 4.28 | Flexural strength of epoxy foam processed at room temperature, 80°C with acetic acid and diluent at different sodium bicarbonate contents. | |
| 4.29 | Flexural modulus of epoxy foam processed at room temperature, 80°C with diluent and acetic acid with different sodium bicarbonate contents. | |
| 4.30 | The surface of epoxy foam (a) at room temperature, (b) at 80°C, (c) containing 5 phr acetic acid and (d) containing 5 phr diluent, with 20 phr sodium bicarbonate content respectively. | |
| 4.31 | The storage modulus of epoxy foam in different parameters | |
| 4.32 | Tan δ of epoxy foam in different kind of parameters | |
| 4.33 | The density of epoxy foam for the processing temperature. | |
| 4.34 | Dielectric constant of epoxy foam processed at various processing conditions at 20 phr of sodium bicarbonate. | |
| 4.35 | The swelling percentage of epoxy foam at various processing condition at 20 phr sodium bicarbonate content. | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

| | Stre | |
|------------|---|--|
| | COX | |
| | | |
| | | |
| | 101 | |
| | | |
| | XOC | |
| | XC | |
| | OT OT | |
| | | |
| | . xell | |
| | ···· | |
| K | | |
| \bigcirc | oriente orient | |

This term is protected by original convitably

| Figure | | Page |
|--------|--|------|
| 2.1 | Reaction between bisphenol A and epichlorohydrin | |
| 2.2 | Trietylenetetramine | |
| 2.3 | The chemical reaction between diamine and diepoxy | |
| 2.4 | Reaction between amine and epoxy | |
| 2.5 | Chemical reaction of polyamide and epoxy | |
| 2.6 | Structure of sodium bicarbonate | |
| 2.7 | Butyl Glycidyl ether | |
| 4.1 | The viscosity of epoxy foam with different speeds and sodium bicarbonate | |
| 4.2 | The flexural modulus and strength of epoxy foam at room temperature | |
| 4.3 | SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy and epoxy foam added with (b) 10 phr sodium bicarbonate and (c) 20 phr sodium bicarbonate, respectively at room temperature | |
| 4.4 | The density value for epoxy foam at 0 to 20 phr of sodium bicarbonate at room temperature processing condition. | |
| 4.5 | The value of dielectric constant of epoxy foam at room temperature. | |
| 4.6 | The swelling percentage of epoxy foam with different content of sodium bicarbonate at room temperature | |
| 4.7 | The viscosity of epoxy foam with different speeds and processing temperatures. | |
| 4.8 | The flexural strength and modulus of epoxy foam at the processing temperature of 80°C. | |
| 4.9 | SEM micrograph showing the flexural fracture surface morphology of (a) neat epoxy and epoxy foam filled with (b) 20 phr sodium bicarbonate at 80°C, respectively. | |
| 4.10 | The density value of epoxy foam at processing temperature of 80°C. | |

| 4.12The sodiu4.13The bicar4.13The bicar4.14Reac (NaF)4.15The sodiu4.16SEM of (a) | value of dielectric constant of epoxy foam processed at 80°C. swelling percentage of epoxy foam with different content of im bicarbonate at 80°C. viscosity of epoxy foam with different speeds and sodium bonate content at 5 phr of acetic acid. tion between acetic acid (CH ₃ COOH) and sodium bicarbonate ICO ₃) Elexural strength and modulus of epoxy foam with different im bicarbonate content 5 phr of acetic acid. micrograph showing the flexural fracture surface morphology) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate phr of acetic acid, respectively. |
|--|---|
| 4.13 The bicar 4.14 Reac (NaF 4.15 The sodiu 4.16 SEM of (a | Im bicarbonate at 80°C. viscosity of epoxy foam with different speeds and sodium bonate content at 5 phr of acetic acid. tion between acetic acid (CH ₃ COOH) and sodium bicarbonate ICO ₃) flexural strength and modulus of epoxy foam with different im bicarbonate content 5 phr of acetic acid. micrograph showing the flexural fracture surface morphology) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate |
| 4.14 Reac (NaF 4.15 The sodiu 4.16 SEM of (a | bonate content at 5 phr of acetic acid. tion between acetic acid (CH ₃ COOH) and sodium bicarbonate ICO ₃) Elexural strength and modulus of epoxy foam with different im bicarbonate content 5 phr of acetic acid. micrograph showing the flexural fracture surface morphology) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate |
| 4.15 The sodiu 4.16 SEM of (a | ICO ₃) Elexural strength and modulus of epoxy foam with different im bicarbonate content 5 phr of acetic acid. micrograph showing the flexural fracture surface morphology) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate |
| 4.16 SEM of (a | m bicarbonate content 5 phr of acetic acid. micrograph showing the flexural fracture surface morphology) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate |
| of (a |) neat epoxy (b) epoxy foam with 20 phr sodium bicarbonate |
| | |
| 4.17 The | density values of epoxy foam with acetic acid. |
| 4.18 The | value of dielectric constant of epoxy foam with acetic acid |
| | swelling percentage of epoxy foam with acetic acid at different ent of sodium bicarbonate. |
| | viscosity of epoxy foam with different speeds and sodium bonate content at 5 phr of diluent. |
| | Ilexural strength and modulus for epoxy foam with different im bicarbonate content at 5 phr of diluent. |
| of (a | micrograph showing the flexural fracture surface morphology) pure epoxy (b) epoxy foam with 20 phr sodium bicarbonate, with 5 phr of diluents, respectively. |
| 4.23 Reac | tion between diluents and hardener. |
| 4.24 The | density value for epoxy foam with diluent. |