

**EFFECT OF BEATING, POLYVINYL
ALCOHOL AND KAOLIN ON PROPERTIES OF
PAPER FROM OIL PALM EMPTY FRUIT
BUNCH**

ASMAHAIZA BINTI MOHAMAD NOOR

Universiti Sains Malaysia

2014

**EFFECT OF BEATING, POLYVINYL ALCOHOL AND
KAOLIN ON PROPERTIES OF PAPER FROM OIL PALM
EMPTY FRUIT BUNCH**

by

ASMAHAIZA BINTI MOHAMAD NOOR

Thesis submitted in fulfillment of the requirements

for the degree of

Master of Science

School of Materials and Minerals Resources Engineering

Universiti Sains Malaysia

July 2014

ACKNOWLEDGEMENT

Praise and thanks to Allah SWT for giving me valuable opportunity and strength to accomplish my master project. First of all, I am highly pleased to express my best regards, profound gratitude, and deep appreciation to my honourable supervisor, Prof Hanafi B. Ismail and Dr. Mazlan B. Ibrahim as my co-supervisor, for their constant supervision, inspiring guidance, enthusiastic encouragement and sagacious advice throughout my research.

Furthermore, I would like to take this opportunity to thanks to whom help me a lot to deal with the laboratory machines and other things especially laboratory assistants from School of Industrial Technology, Mr. Abu Mangsor and also to technicians from School of Materials and Mineral Resources Engineering. I really appreciate their contribution towards my project. Moreover, I would like to thank to my beloved parents and family for giving me valuable support and encouragement for me to perform well in this research project.

Lastly, I would like to apologize to everyone whom involve in my project if there is any inconvenience and mistake that I made throughout this project. I am very glad that this project finished on time and I had gained a lot of experiences in this research. Thank you very much.

TABLE OF CONTENTS

| | |
|--------------------------------|--------------|
| ACKNOWLEDGEMENT | ii |
| LIST OF TABLES | iii |
| LIST OF FIGURES | xiii |
| LIST OF EQUATIONS | xix |
| LIST OF ABBREVIATIONS | xxi |
| ABSTRAK | xxii |
| ABSTRACT | xxiii |
| | |
| CHAPTER 1 INTRODUCTION | |
| 1.1 Introduction | 1 |
| 1.2 Problem Statement | 3 |
| 1.3 Objectives of the Research | 6 |

CHAPTER 2 LITERATURE REVIEW

| | |
|---|----|
| 2.1 Pulp and Paper Industri in Malaysia | 7 |
| 2.2 Availability of Oil Palm Biomass in Malaysia | 11 |
| 2.3 Oil Palm Empty Fruit Bunch (OPEFB) | 16 |
| 2.3.1 Physical and Mechanical Properties of EFB | 18 |
| 2.3.2 Chemical Composition of Empty Fruit Bunch (EFB) Fiber | 21 |
| 2.3.2.1 Cellulose | 23 |
| 2.3.2.2 Hemicellulose | 24 |
| 2.3.2.3 Lignin | 26 |
| 2.4 Pulping | 27 |
| 2.4.1 Mechanical Pulping | 29 |
| 2.5 Effect of Beating Process on Fiber | 32 |
| 2.6 Polyvinyl Alcohol (PVA) as Polymer Additives in Papermaking | 36 |
| 2.7 Filler | 39 |

CHAPTER 3 METHODOLOGY

| | |
|---|----|
| 3.1 Raw Materials | 41 |
| 3.1.1 Oil Palm Empty Fruit Bunch (OPEFB) Fiber | 41 |
| 3.1.2 Polyvinyl Alcohol (PVA) | 41 |
| 3.1.3 Sodium Tetraborate Decahydrate | 42 |
| 3.1.4 Kaolin | 42 |
| 3.2 Preparation Raw Material and Additives | 42 |
| 3.2.1 Preparation of Empty Fruit Bunch (EFB) | 42 |
| 3.2.2 Preparation of Polyvinyl Alcohol (PVA) Solution | 43 |
| 3.2.3 Preparation of Borax Solution | 44 |
| 3.3 Preparation of Empty Fruit Bunch Pulp | 44 |
| 3.3.1 Mechanical Pulping | 44 |
| 3.3.2 Pulp Screening | 45 |
| 3.4 Preparation of Beaten EFB Pulp | 46 |
| 3.4.1 Disintegration | 46 |
| 3.4.2 Thickening | 47 |
| 3.4.3 Beating | 48 |

| | |
|---|----|
| 3.5 Treatment of OPEFB with Additives | 49 |
| 3.5.1 Treatment of OPEFB with Polyvinyl Alcohol (PVA) | 49 |
| 3.5.2 Treatment of OPEFB with Kaolin | 50 |
| 3.5 Pulp Stock Preparation and Handsheet Making | 51 |
| 3.6.1 Pulp Stock Preparation | 51 |
| 3.6.1.1 Unbeaten Pulp Stock | 51 |
| 3.6.1.2 Beaten Pulp Stock | 52 |
| 3.6.2 Canadian Standard Freeness (CSF) | 52 |
| 3.6.3 Actual Stock Consistency | 54 |
| 3.6.4 Handsheet Making | 56 |
| 3.6.5 Pressing | 57 |
| 3.6.6 Drying | 58 |
| 3.7 Testing | 59 |
| 3.7.1 Physical Testing | 59 |
| 3.7.1.1 Grammage | 59 |
| 3.7.1.2 Thickness | 60 |

| | |
|---|----|
| 3.7.1.3 Density | 61 |
| 3.7.2 Optical Testing | 61 |
| 3.7.3 Mechanical Testing | 61 |
| 3.7.3.1 Paper Cutting for Mechanical Testing | 62 |
| 3.7.3.2 Tensile Strength | 63 |
| 3.7.3.3 Burst Strength | 64 |
| 3.7.3.4 Tear Resistance | 65 |
| 3.8 Characterization | 67 |
| 3.8.1 Scanning Electron Microscope (SEM) Analysis | 67 |

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Effects on Unbeaten and Beaten OPEFB Mechanical Pulp Toward Paper

| | |
|--|----|
| Properties | 68 |
| 4.1.1 Effect on Physical Properties on Handsheet | 70 |
| 4.1.1.1 Thickness | 70 |
| 4.1.1.2 Density | 72 |
| 4.1.1.3 Grammage | 73 |
| 4.1.2 Optical Properties | 74 |
| 4.1.2.1 Opacity | 74 |
| 4.1.2.2 Brightness | 76 |
| 4.1.3 Mechanical Properties | 77 |
| 4.1.3.1 Tensile Strength | 77 |
| 4.1.3.2 Burst Strength | 79 |
| 4.1.3.3 Tear Strength | 81 |
| 4.1.4 Scanning Electron Microscope (SEM) | 83 |
| 4.1.5 Conclusion | 85 |

4.2 Determination of Optimum PVA Loading toward by Properties of Beaten EFB

| | |
|--|----|
| Mechanical Pulp | 86 |
| 4.2.1 Physical Properties | 86 |
| 4.2.1.1 Thickness | 86 |
| 4.2.1.2 Density | 88 |
| 4.2.1.3 Grammage | 89 |
| 4.2.2 Optical Properties | 90 |
| 4.2.2.1 Opacity | 90 |
| 4.2.2.2 Brightness | 91 |
| 4.2.3 Mechanical Properties | 93 |
| 4.2.3.1 Tensile Strength | 93 |
| 4.2.3.2 Burst Strength | 95 |
| 4.2.3.3 Tear Resistance | 96 |
| 4.2.4 Scanning Electron Microscope (SEM) | 98 |
| 4.2.5 Conclusion | 99 |

4.3 Determination of Optimum Kaolin Added to the Handsheet of Beaten EFB

| | |
|--|-----|
| Mechanical Pulp with Optimum PVA Loading | 100 |
| 4.3.1 Physical Properties | 100 |
| 4.3.1.1 Thickness | 100 |
| 4.3.1.2 Density | 102 |
| 4.3.1.3 Grammage | 103 |
| 4.3.2 Optical Properties | 104 |
| 4.3.2.1 Opacity | 104 |
| 4.3.2.2 Brightness | 105 |
| 4.3.3 Mechanical Properties | 106 |
| 4.3.3.1 Tensile Strength | 107 |
| 4.3.3.2 Burst Strength | 108 |
| 4.3.3.3 Tear Resistance | 109 |
| 4.3.4 Scanning Electron Microscope (SEM) | 110 |

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion 112

5.2 Recommendations 114

REFERENCES 115

APPENDICES

APPENDIX A

APPENDIX B

APPENDIX C

LIST OF TABLES

| <u>Tables</u> | <u>Page</u> |
|---|--------------------|
| Table 2.1 Projection of Oil Palm Biomass Availability in Malaysia (Tonnes/year) | 15 |
| Table 2.2 Morphological Properties of EFB Fiber in Comparison with Aspen Fiber (Law <i>et al.</i> , 2007) | 19 |
| Table 2.3 Chemical Compositions of EFB Fiber (Gonzalo <i>et al.</i> , 2007) | 22 |
| Table 2.4 Decomposition of EFB in the Field (Suhaimi and Ong, 2011). | 22 |
| Table 2.5 Classification of Pulping Technique (Smook, 1992) | 29 |
| Table 2.6 Properties of Mechanical Pulp | 31 |
| Table 2.7 Summarization of Beating Effects and its Consequences (Cowan, 2003) | 36 |
| Table 2.8 Summarization on Filler Characteristics and Properties. | 40 |
| Table 3.1 Amount of PVA and Borax in Pulp Stock | 50 |
| Table 3.2 Amount of Kaolin in Pulp Stock | 50 |

LIST OF FIGURES

| <u>Figures</u> | <u>Page</u> |
|--|--------------------|
| Figure 2.1 Pulp and paper manufacturers in Malaysia (Roda and Rathi, 2006). | 9 |
| Figure 2.2 Malaysia pulp production and consumption (Roda and Rathi, 2006). | 10 |
| Figure 2.3 Malaysia paper production and consumption (Roda and Rathi, 2006). | 10 |
| Figure 2.4 Oil palm plantations in Malaysia | 11 |
| Figure 2.5 Oil palm plantation areas in Malaysia (MPOB, 2011) | 13 |
| Figure 2.6 Oil palm production areas in Malaysia (MPOB, 2011) | 13 |
| Figure 2.7 Fresh fruit bunch (a) and empty fruit bunch of oil palm (b and c). | 17 |
| Figure 2.8 Transverse section of oil palm fiber cell wall thickness | 20 |
| Figure 2.9 Molecular structure of cellulose (Perisko and Randall, 2008) | 24 |
| Figure 2.10 Monomers of hemicelluloses (Anonymous, 1996) | 26 |
| Figure 2.11 Lignin building blocks (Jeffries, 1994) | 27 |
| Figure 2.12 External fibrillation of fibers | 33 |
| Figure 2.13 Structure of Polyvinyl Alcohol (PVA) | 37 |

| | |
|---|----|
| Figure 2.14 Crosslinking of PVA with Sodium Tetraborate | 38 |
| Figure 3.1 Moisture Analyzer | 43 |
| Figure 3.2 Sprout Bauer Disc Refiner | 45 |
| Figure 3.3 Sommerville Screener | 46 |
| Figure 3.4 Disintegrator | 47 |
| Figure 3.5 Pulp Thickening | 47 |
| Figure 3.6 PFI Mill | 48 |
| Figure 3.7 Canadian Standard Freeness (CSF) Tester | 54 |
| Figure 3.8 Pressing panel | 58 |
| Figure 3.9 Precision Micrometer | 60 |
| Figure 3.10 Specific part of handsheet for mechanical testing | 62 |
| Figure 3.11 High Pressure Mullen Burst Tester | 65 |
| Figure 3.12 Elmendorf Tearing Tester | 66 |
| Figure 4.1 Freeness of unbeaten and beaten EFB mechanical pulp | 68 |
| Figure 4.2 Thickness of handsheets from unbeaten and beaten EFB mechanical pulp | 70 |

| | |
|--|----|
| Figure 4.3 Density of handsheets from unbeaten and beaten EFB | |
| mechanical pulp | 72 |
| Figure 4.4 Grammage of handsheets from unbeaten and beaten EFB | |
| mechanical pulp | 73 |
| Figure 4.5 Opacity of handsheets from unbeaten and beaten EFB | |
| mechanical pulp | 75 |
| Figure 4.6 Brightness of handsheets from unbeaten and beaten EFB | |
| mechanical pulp | 76 |
| Figure 4.7 Tensile index of handsheets from unbeaten and beaten EFB | |
| mechanical pulp | 78 |
| Figure 4.8 Burst index of handsheets from unbeaten and beaten EFB | |
| mechanical pulp | 80 |
| Figure 4.9 Tear index of handsheets from unbeaten and beaten EFB | |
| mechanical pulp | 82 |
| Figure 4.10 SEM micrograph on surface view (X200 magnification) | |
| of unbeaten EFB handsheet | 84 |

| | |
|---|----|
| Figure 4.11 SEM micrograph on surface view (X200 magnification) | |
| of beaten EFB handsheet | 85 |
| Figure 4.12 Thickness of handsheets from beaten EFB mechanical pulp with | |
| different percentage of PVA | 87 |
| Figure 4.13 Density of handsheets from beaten EFB mechanical pulp with | |
| different percentage of PVA | 88 |
| Figure 4.14 Grammage of handsheets from beaten EFB mechanical pulp with | |
| different percentage of PVA | 89 |
| Figure 4.15 Opacity of handsheets from beaten EFB mechanical pulp with | |
| different percentage of PVA | 91 |
| Figure 4.16 Brightness of handsheets from beaten EFB mechanical pulp with | |
| different percentage of PVA | 92 |
| Figure 4.17 Tensile index of handsheets from beaten EFB mechanical pulp with | |
| different percentage of PVA | 94 |
| Figure 4.18 Burst index of handsheets from beaten EFB mechanical pulp with | |
| different percentage of PVA | 96 |

| | |
|---|-----|
| Figure 4.19 Tear index of handsheets from beaten EFB mechanical pulp with different percentage of PVA | 97 |
| Figure 4.20 SEM micrograph on surface view (X200 Magnification) of beaten EFB handsheets with 0% (a), 3% (b) and 6 % (c) of PVA | 99 |
| Figure 4.21 Thickness of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 101 |
| Figure 4.22 Density of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 102 |
| Figure 4.23 Grammage of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 103 |
| Figure 4.24 Opacity of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 104 |
| Figure 4.25 Brightness of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 106 |
| Figure 4.26 Tensile index of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 108 |

| | |
|---|-----|
| Figure 4.27 Burst index of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 109 |
| Figure 4.28 Tear index of handsheets from beaten EFB mechanical pulp with 3% of PVA and different kaolin loading | 110 |
| Figure 4.29 SEM micrograph on surface view of beaten EFB handsheets with 3% of PVA and 0% (a), 6% (b) and 10% (c) of kaolin | 111 |

LIST OF EQUATIONS

| <u>Equations</u> | <u>Page</u> |
|---|--------------------|
| Equation 3.1 Moisture content (%) | 43 |
| Equation 3.2 Consistency of pulp (%) | 51 |
| Equation 3.3 Actual consistency (%) | 55 |
| Equation 3.4 Grammage of handsheet (g/m^2) | 59 |
| Equation 3.5 Density of handsheet (g/cm^3) | 61 |
| Equation 3.6 Tensile strength of handsheet (N/m) | 63 |
| Equation 3.7 Tensile index of handsheet (Nm/g) | 63 |
| Equation 3.8 Burst index of handsheet ($\text{kPa}\cdot\text{m}^2/\text{g}$) | 64 |
| Equation 3.9 Tear index of handsheet ($\text{mN}\cdot\text{m}^2/\text{g}$) | 66 |

LIST OF ABBREVIATIONS

| | |
|-------|--|
| % | Percent |
| °C | Degree celcius |
| ASEAN | Association of Southeast Asian Nations |
| BW | Basis Weight |
| EFB | Empty fruit bunch |
| FFB | Fresh fruit bunch |
| kPa | kilo Pascal |
| MC | Moisture content |
| mm | millimeter |
| MPOB | Malaysian Palm Oil Board |
| N | Newton |
| OPEFB | Oil palm empty fruit bunch |
| OPF | Oil palm frond |
| OPT | Oil palm trunk |
| POME | Palm oil mill effluent |
| PVA | Polyvinyl alcohol |
| SEM | Scanning Electron Microscopy |
| T | Breaking length |

| | |
|-------|--|
| TAPPI | Technical Association of the Pulp and Paper Industry |
| TEA | Tensile Energy Absorbed |
| TI | Tensile Index |
| TKKS | Tandan kosong kelapa sawit |

KESAN PEMUKULAN, POLIVINIL ALKOHOL (PVA) DAN KAOLIN TERHADAP SIFAT –SIFAT KERTAS DARIPADA TANDAN KOSONG KELAPA SAWIT

ABSTRAK

Kesan memukul, polivinil alkohol (PVA) dan kaolin pada sifat-sifat kertas daripada tanda kosong kelapa sawit (TKKS) telah dikaji. Kesan pulpa mekanikal TKKS terpukul dan tidak terpukul, peratus PVA yang ditambah dan peratus kaolin yang ditambah ke dalam stok pulpa terhadap sifat-sifat kertas daripada pulpa mekanikal TKKS telah dibentangkan. Pemukulan oleh pemukul PFI pada 15000 revolusi secara ketara meningkatkan sifat-sifat pulpa mekanikal TKKS dengan meningkatkan sifat-sifat fizikal, mekanikal dan optik bagi kertas dihasilkan. 3% PVA ditambah dalam pulpa mekanikal terpukul tandan kosong kelapa sawit (TKKS) memberi kekuatan optimum ke atas sifat mekanik. Walau bagaimanapun, disebabkan kehadiran lignin dalam pulpa mekanikal terpukul TKKS, penambahan kaolin ke dalam stok pulpa pulpa mekanikal dengan 3% PVA tidak memberi kesan yang banyak kepada kecerahan kertas. Secara ringkasnya, dengan 3% PVA dan 6% kaolin ditambah ke dalam stok pulpa daripada pulpa mekanikal terpukul TKKS menunjukkan pulpa kesan yang penting ke atas sifat mekanik kertas.

EFFECT OF BEATING, POLYVINYL ALCOHOL (PVA) AND KAOLIN ON PROPERTIES OF PAPER FROM OIL PALM EMPTY FRUIT BUNCH

ABSTRACT

Effect of beating, polyvinyl alcohol (PVA) and kaolin on properties of paper from oil palm empty fruit bunch were investigated. The effect of unbeaten and beaten OPEFB mechanical pulps, percentage of PVA addition and percentage of kaolin added into pulp stock toward properties of paper from OPEFB mechanical pulp were presented. Beating by PFI mill at 15000 revolutions significantly improves properties of OPEFB mechanical pulp by enhancing the physical, mechanical and optical properties of handsheets produced. 3% of PVA added into beaten mechanical pulp of oil palm empty fruit bunch (OPEFB) gives optimum strength on mechanical properties. However, due to lignin present in beaten OPEFB mechanical pulp, addition of kaolin into pulp stock of mechanical pulp treated with 3% of PVA does not affect much on brightness of handsheets. In a nutshell, with 3% of PVA and 6% of kaolin added into the pulp stock of beaten OPEFB mechanical pulp shows excellent effects on mechanical properties of handsheet.