Ain Shams University

Faculty of Engineering

Design and Production Engineering Department

Study of the Potentiality of Using Sorghum Stalks Fibres in Reinforcing Polymers

A Thesis Submitted in Partial Fulfilment for the Requirements of the Degree of Master of Science in Mechanical Engineering

By

Bahi Edeen Ahmad Hussein Mostafa Bakeer

Supervised by

Prof. Dr. Hamed I. El-Mously Prof. Dr. Saied A. Shehata

Dr. Iman M. Taha

2013

Statement

This thesis is submitted in partial fulfilment for the degree of Master of Science in design and production engineering, to the faculty of engineering, Ain Shams University. The work included in this thesis was carried out by the author, primarily at the laboratories of the Design and Production Engineering Department, Faculty of Engineering, Ain Shams University. No Part of this thesis has been submitted for degree or qualification at any other university.

Bahi Edeen Ahmad Hussein Mostafa Bakeer

Signature:

Date:

Curriculum vitae

Name: Bahi Edeen Ahmad Hussein Mostafa Bakeer

Birth Date: 19-6-1984

Degree: Bachelor Degree in Mechanical Engineering, Design and Production Section, August 2007

Current Job: Teaching Assistant, Design and Production Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt

Acknowledgment

I would like to express my gratitude to my academic advisors, Prof. Hamed El-Mously, Dr. Iman Taha, and Prof. Dr. Saied A. Shehata for their guidance and motivation during this study. I am extremely thankful to Dr. Tayseer Attia, Dr. Mohammad Farag and Eng. Mohammad Kamal for providing their help and support during this work. I also want to appreciate the efforts of Ahmad El-Mehy and my Colleagues in design and production engineering department, faculty of engineering, Ain Shams University, Cairo, Egypt. Lastly, I sincerely thank my family, especially my mother for her understanding and patience.

Abstract

This work targets the investigation of the potentiality of using sorghum stalks (SS) as reinforcements for high density polyethylene (HDPE), especially for outdoor applications.

Characterisation of sorghum stalks was performed taking into consideration morphological, thermal, chemical, and mechanical properties, to study the potentiality of their use as a polymer reinforcing material. Optical and scanning electron microscopy was used to investigate the morphology of sorghum stalks, and relate mechanical properties to structure. Sorghum stalks have been divided into three equal regions: bottom, middle, and top, and each region was individually studied. The thermal degradation behaviour has been studied using static and dynamic thermogravimetric analysis. The results of this study show that it is not recommended to subject the fibres to elevated temperatures (>200°C) for time periods exceeding 10 min. Tensile testing was used to evaluate the mechanical properties of fibres. The highest tensile strength of 280 N/mm^2 was found at the middle region of the sorghum stalk rind (SSR), while the tensile strength of the pith was found to be about 1.5 N/mm^2.

After compounding SSR with HDPE and MAPE, number-weighted distributions for fibre length and aspect ratio were built showing a right skewed distribution with large number of small particles. The obtained fibre length and aspect ratio distributions were fitted by a two-parameter Weibull model.

With respect to the composite, mechanical properties in tension and bending were evaluated for different compositions of SSR and maleic anhydride polyethylene (MAPE) as a coupling agent.

Compared to pure HDPE, 20wt% SSR/3wt% MAPE composition showed an increase of about 14%, 71%, and 156% in tensile strength, bending strength, and flexural modulus, respectively. 40wt% SSR/0wt% MAPE composition showed an increase about of 346% in flexural modulus.

The resistance to the deteriorating effect of service conditions as in outdoor applications was also studied. Specimens immersed in distilled water, showed a maximum increase in weight by 6.88% at 40wt% SSR/0wt% MAPE composition. After saturation, specimens were tested in bending to compare results with un-aged specimens. A reduction in strength and modulus was found. The mechanical properties in bending of ultraviolet exposed specimens were compared to un-aged and to pure HDPE specimens. There is no significant reduction in mechanical properties compared to unexposed specimens.

Contents

Abstract v

1. Introduction 1

2. Literature review 4

    2.1. Composite materials 4

    2.1.1. Natural fibres 4

    2.1.1.1. Morphology and structure 6

    2.1.1.2. Sorghum stalks 9

    2.1.2. Polymer matrices 11

        2.1.2.1. Polyethylene 13

    2.2. Factors affecting composite behaviour 14

        2.2.1. Volume fraction 14

        2.2.2. Fibre length 16

        2.2.3. Fibre distribution and orientation 19

        2.2.4. Fibre/matrix interface 21

        2.2.5. Processing conditions 22

    2.3. Factors affecting fibre properties 23

    2.4. Service conditions 26

    2.4.1. Weathering conditions 27

    2.4.2. Moisture 29

    2.4.3. Ultraviolet radiation 32

3. Objective and Work Plan 35

4. Experimental Work 37

    4.1. Materials 37

    4.2. Characterisation of sorghum stalks 38

4.2.1. Structure of the sorghum stalk 38
4.2.2. Microscopic investigation 38
4.2.3. Chemical analysis 39
4.2.4. Density 39
4.2.5. Dynamic thermogravimetric analysis 40
4.2.6. Static thermogravimetric analysis 40
4.2.7. Tensile testing 40
4.3. Composite and sample preparation 42
4.4 Characterisation of composite samples 46
4.4.1. Fibre length and aspect ratio distribution 46
4.4.2. Mechanical properties of composite 47
4.4.3. Effect of water absorption on mechanical properties 47
4.4.4. Effect of ultraviolet radiation on mechanical properties 48
5. Results and Discussion 49
5.1. Characterization of sorghum stalk 49
5.1.1. Sorghum stalk Structure 49
5.1.2. Microscopic investigation 51
5.1.3. Chemical analysis 54
5.1.4. Thermal analysis 55
5.1.5. Tensile properties 59
5.2. Characterisation of composite samples 62
5.2.1. Fibre length and aspect ratio distribution 62
5.2.2. Mechanical properties of composites 71
5.2.3. Effect of water absorption on mechanical properties 77
5.2.4. Effect of ultraviolet rays on mechanical properties 82
5.2.5. General discussion 83

6. Conclusions and Future Work 85
References 106

List of Abbreviations

ABS	Acrylonitrile butadiene styrene	
DP	Degree of polymerisation	
DTGA	Dynamic thermogravimetric analysis	
HDPE	High density polyethylene	
HIPS	High impact polystyrene	
IFSS	Interfacial shear strength	[N/mm^2]
LLDPE	Linear low-density polyethylene	
MAPE	Maleic anhydride polyethylene	
MAPP	Maleic anhydride polypropylene	
NFPC	Natural fibre plastic composites	
OPEFB	Oil palm empty fruit bunch	
PC	Polycarbonate	
PCTL	Percentile	
PEEK	Polyetherether ketone	
Phr	Parts per hundred parts of resin	
PMC	polymer matrix composites	
PP	Polypropylene	
PVA	Polyvinyl alcohol	