UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Fabrication and Characterization of Oil Palm Shell Powder Filled Polypropylene

Thesis submitted in accordance with the partial requirements of the Universiti Teknikal Malaysia Melaka for the Degree of Bachelor of Manufacturing Engineering (Engineering Materials) with Honours

By

Wan Mazuwan Bin Wan Azhal

Faculty of Manufacturing Engineering

March 2008

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PSM

JUDUL:

FABRICATION AND CHARACTERIZATION OF OIL PALM SHELL POWDER FILLED POLYPROPYLENE.

SESI PENGAJIAN:
Semester 2/2007-2008

Saya **WAN MAZUWAN BIN WAN AZHAL**
mengaku membenarkan laporan PSM / tesis (Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM / tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM / tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
√	TIDAK TERHAD	

(TANDATANGAN PENULIS)
Alamat Tetap:
Lot 1015, Piasau Lorong 6,
Jalan Nerium 2,
98000 Miri, Sarawak.

Tarikh: 3 APRIL 2008

(TANDATANGAN PENYELIA)
Cop Rasmi:
MOHD. EDEEROZEY BIN ABD. MANAF
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200 Ayer Keroh
75450 Melaka

Tarikh: 3 APRIL 2008

* Jika laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this thesis entitled "**FABRICATION AND CHARACTERIZATION OF OIL PALM SHELL POWDER FILLED POLYPROPYLENE**" is the results of my own research except as cited in references.

MOHD. EDEEROZEY BIN ABD. MANAF
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh,
75450 Melaka

Signature	:	
Author's Name	:	**Wan Mazuwan Bin Wan Azhal**
Date	:	3 April 2008

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (*Engineering Materials*) with Honours. The members of the supervisory committee are as follow:

Mohd. Edeerozey Bin Abd. Manaf
(PSM Supervisor)

3 April 2008

ABSTRACT

The purpose of doing this project is to study the mechanical properties of oil palm shell powder (OPSP) filled polypropylene (PP) and effect OPSP weight fraction on OPSP/PP composites. OPSP is obtained by the pulverization process of oil palm shell. Pulverization process is conducted at Universiti Tun Hussein Onn (UTHM) by using variables speed rotor mill. The oil palm shell is supplied by Seri Intan Palm Oil Sdn Bhd, Teluk Intan, Perak. Meanwhile PP used in this experiment is available at Universiti Teknikal Malaysia Melaka (UTeM). PP is mixed with the OPSP using extrusion machine and using hot press process to fabricate the mixture into composite with 5wt%, 10wt% and 15wt% OPSP. Plate of 3mm and 2mm were prepared for testing samples. A pure PP is also fabricated in purpose of comparing the mechanical properties between pure form of the polymer and filled polymer. In terms of tensile properties, Young's modulus shows an increase at 10wt% OPSP, whereas tensile strength decreased with the increase in OPSP weight fraction. Flexural strength and flexural modulus increase with the increase in OPSP weight fraction. Impact strength of composite with 10wt% OPSP exhibits higher value compared to the other weight fraction. Furthermore, increasing of OPSP percentage results in increase of water absorption. Scanning electron microscopy (SEM) is used to study the microstructure of tensile fracture. As conclusion, it is found that adding OPSP has improved the properties of PP composite and the better OPSP weight fraction in PP composite is 10wt%. However, poor interfacial adhesion reflects the filler particle size and believed to has caused weakness in composite mechanics behaviors.

ABSTRAK

Projek ini adalah bertujuan untuk mengkaji sifat mekanikal dan kesan peratusan kandungan serbuk tempurung kelapa sawit (OPSP) ke atas komposit serbuk tempurung kelapa sawit diperkuatkan dengan termoplastik 'polypropylene'(PP). OPSP dihasilkan melalui proses penghancuran tempurung kelapa sawit yang dijalankan di Universiti Tun Hussein Onn (UTHM) dengan menggunakan mesin 'variables speed rotor mill' . Tempurung kelapa sawit yang digunakan di dalam projek ini telah di perolehi daripada kilang kelapa sawit Seri Intan yang terletak di Teluk Intan, Perak. Sementara itu PP yang digunakan untuk projek ini boleh didapati di Universiti Teknikal Malaysia Melaka (UTeM). PP akan di campur dengan OPSP menggunakan mesin 'extrusion'. Papan komposit dengan ketebalan 2mm dan 3mm dihasilkan dengan menggunakan mesin 'Hot Press'. Peratusan OPSP komposit yang dihasilkan ialah 0%, 5%, 10% dan 15%. Dalam konteks ketegangan, kekuatan tegangan berkurang manakala 'Young Modulus' meningkat dengan peningkatan peratusan OPSP. Kekuatan kelenturan dan ketahanan impak dan kadar resapan air pula meningkat dengan peningkatan peratusan OPSP. Kajian mikrostruktur untuk patah pada ujian ketegangan di jalankan dengan menggunakan mesin 'Scanning Electron Microscope'(SEM). Sebagai kesimpulan, di dapati penambahan peratusan OPSP akan meninggkatkan sifat mekanikal pada komposit. Walaubagaimanapun, saiz zarah OPSP yang besar menyebabkan kekurangan pada sifat-sifat mekanikal komposit.

ACKNOWLEDGEMENT

I would like to express my appreciation to the individuals who had played a part in ensuring a successful occurrence and flow of activities throughout the duration of my final year project. Endless appreciation and gratitude to my supervisor, Mr. Edeerozey Abd. Manaf and to my second examiner Mr. Fairuz Dimin for their encouragement and support and for spending quite some time with myself, providing a lot of guidance and ideas for my project research. Their knowledge and experience really inspired and spurred myself. I truly relished the opportunity given in working with them. Last but not least, my appreciation to all technicians involved to complete this project especially to polymer lab technician in UTHM. Finally, my sincere appreciation is dedicated to my parents and family and as well as the friends for their priceless assistance and patronage throughout the process of data gathering.

TABLE OF CONTENTS

Abstract ... i
Abstrak ... ii
Acknowledgement ... iii
Table of Contents ... iv
List of Figures ... viii
List of Tables ... x
List of Charts ... xi
List of Abbreviations, Symbols, Specialized Nomenclature ... xii

1. INTRODUCTION ... 1
1.1 Background and Problem Statements ... 1
1.1.1 Background ... 1
1.1.2 Problem Statements ... 1
1.2 Research Scopes ... 2
1.3 Research Objectives ... 2

2. LITERATURE REVIEW ... 3
2.1 Introduction ... 3
2.2 Polymer Matrix Composites (PMC) ... 3
2.3 PMC Processing Technique ... 4
2.3.1 Compression Moulding ... 5
2.4 Reinforcement ... 6
2.5 Natural Fiber Composite ... 7
2.6 Value-added Agriculture ... 8
2.7 Thermoplastics ... 8

2.8 Current status of palm oil industry in term of biocomposite 9

3. MATERIALS AND METHODOLOGY 10

3.1 Raw Material 10

3.1.1 Polypropylene 10

3.1.3 Oil Palm Shell 13

3.2 Specimen Preparation 14

3.2.1 Process sequence of composite fabrication 14

3.2.2 Oil palm shell powder preparation 14

3.2.2.1 Process Flow of OPSP preparation 15

3.2.3 Polypropylene 16

3.2.4 Composite Formulation 17

3.2.5 Fabrication process 17

3.2.5.1 Extrusion 17

3.2.5.2 Process Flow of extrusion 18

3.2.5.3 Process Flow of crushing 19

3.2.5.4 Hot Press 20

3.2.5.5 Process Flow of hot press 21

3.2.5.6 Cutting sample for testing 23

3.3 Mechanical Testing 26

3.3.1 Tensile Test 26

3.3.1.1 Test Specimen (ASTM D638) 27

3.3.1.3 Test procedure 29

3.3.1.4 Test analysis 30

3.3.2 Flexural Test 31

3.3.2.1 Test Specimen (ASTM D790) 31

3.3.3 Impact Test 32

3.3.3.1 Test Specimen (ASTM D256) 33

3.4 Physical Testing 34

3.4.1 Water Absorption Test 34

3.4.1.1 Test Specimen (ASTM D570) ... 34
3.4.1.2 Test procedure ... 34

3.5 Microstructure Observations ... 35

4. RESULT ... 37
4.1 Tensile Testing ... 37
4.1.1 Raw Data ... 37
4.1.2 Data Analysis ... 38
4.2 Flexural Testing ... 40
4.2.1 Raw Data ... 40
4.2.2 Data Analysis ... 41
4.3 Impact Testing ... 43
4.4 Water Absorption Testing ... 45
4.5 SEM of Tensile Fracture ... 47

5. DISCUSSION ... 49
5.1 Tensile Test ... 49
5.2 Flexural Test ... 52
5.3 Impact Test ... 54
5.4 Water Absorption Test ... 55
5.5 Microstructure Observation of Fracture Surface ... 56

6. CONCLUSION AND RECOMMENDATION ... 58

REFERENCES ... 60

APPENDICES

A Example of graph and data obtained from tensile test

B Example of graph and data obtained from flexural test

C Variable rotor mill machine

D Various types of sieve used in rotor mill machine

E ASTM D638 Standard Test Method for Tensile Properties

F ASTM D790 Standard Test Method for Flexural Properties

G ASTM D256 Standard Test Method for Impact Properties

H ASTM D570 Standard Test Method for Water Absorption

LIST OF FIGURE

2.1	Compression moulding process	6
3.1	Molecular structure of Polypropylene	10
3.2	Oil palm shell	13
3.3	Polypropylene	16
3.4	Thermo HAAKE Polyab Extruder OS	17
3.5	Hot press machine	20
3.6	Composite Board (5% OPSP weight fraction)	22
3.7	Composite Board (10% OPSP weight fraction)	22
3.8	Composite Board (15% OPSP weight fraction)	22
3.9	Plastic specimen cutting machine	23
3.10	Specimen gripping	24
3.11	Specimen of Tensile Test	25
3.12	Specimen of Flexural Test	25
3.13	Specimen of Impact Test	25
3.14	Tensile configurations	27
3.15	Engineering stress-strain curve	27
3.16	Standard tensile test specimen	28
3.17	Flexural test	31
3.18	Impact test machine	32
3.19	Sample position for Izod and Charpy impact test	33
3.20	SEM component	35
3.21	SEM principle	36
4.1	SEM Micrograph tensile fracture surface of PP	47
4.2	SEM Micrograph tensile fracture surface of 5% OPSP weight fraction	47
4.3	SEM Micrograph tensile fracture surface of 10% OPSP weight fraction	48
4.4	SEM Micrograph tensile fracture surface of 15% OPSP weight fraction	48

5.1 Microstructure of pure PP tensile fracture ... ... .56
5.2 Microstructure of 5wt% OPSP tensile fracture 56
5.3 Microstructure of 10wt% OPSP tensile fracture 57
5.4 Microstructure of 15wt% OPSP tensile fracture 57

LIST OF TABLE

3.1 Features, Fabrication and Applications of PP 11
3.2 Typical properties of PP 12
3.3 Elemental composition of OPS 13
3.4 Typical properties of PP Homopolymer 600G 16
3.5 Number of sample for mechanical testing 26
3.6 Test analysis for Tensile Test 30
4.1 Result of tensile test of PP specimen 37
4.2 Result of tensile test of 5% OPSP weight fraction 38
4.3 Result of tensile test of 10% OPSP weight fraction 38
4.4 Result of tensile test of 15% OPSP weight fraction 38
4.5 Data Analysis of Tensile Test 39
4.6 Result of flexural test of PP specimen 40
4.7 Result of flexural test of 5% OPSP weight fraction 40
4.8 Result of flexural test of 10% OPSP weight fraction 41
4.9 Result of flexural test of 15% OPSP weight fraction 41
4.10 Data Analysis of Flexural Test 41
4.11 Impact Energy (Joules) 43
4.12 Impact Strength (J/m^2) 43
4.13 Water Absorption of PP specimen 45
4.14 Water Absorption of 5% OPSP weight fraction 45
4.15 Water Absorption of 10% OPSP weight fraction 45
4.16 Water Absorption of 15% OPSP weight fraction 46
6.1 Typical Properties of Oil palm shell powder filled polypropylene 58

LIST OF CHART

4.1 Comparison of Tensile Strength with different OPSP weight fraction... 39
4.2 Comparison of Young's Modulus with different OPSP weight fraction... ... .39
4.3 Comparison of Flexural Modulus with different OPSP weight fraction... 42
4.4 Comparison of Flexural Strength with different OPSP weight fraction... 42
4.5 Comparison of Impact Strength with different OPSP weight fraction... 44
4.6 Comparison of Water Absorption with different OPSP weight fraction... 46
5.1 Elongation at Tensile fracture with different OPSP weight fraction....................49
5.2 Tensile Strength of different OPSP weight fraction..49
5.3 Young's Modulus of different OPSP weight fraction...49
5.4 Flexural Strength of different OPSP weight fraction...49
5.5 Flexural Modulus of different OPSP weight fraction...49

LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

^0C	-	degrees Celsius
^0F	-	degrees Fahrenheit
%	-	Percent
+/-	-	plus or minus
ASTM	-	American Standard Testing Method
BMC	-	High Bulk Compound
CMC	-	Ceramic-Matrix Composite
in	-	inches
kg	-	kilograms
m	-	Meter
MDF	-	Medium Density Fibreboard
MMC	-	Metal-Matrx Composites
OPSP	-	Oil palm shell powder
PAI	-	Polyphenylene Sulfide Polyaimide-imide
PEEK	-	Polyetheretherketone
PES	-	Polyethersulphone
PMCs	-	Polymer–Matrix Composites
PP	-	Polypropylene
SEM	-	Scanning Electron Microscope
SMC	-	Sheet Molding Compound
TMC	-	Thick Molding Compound
UTeM	-	Universiti Teknikal Malaysia Melaka
UTHM	-	Universiti Tun Hussein Onn
UTM	-	Universal Testing Machine
WPG	-	Weight Percentage Gain

CHAPTER 1
INTRODUCTION

1.1 Background and Problem Statement

1.1.1 Background

Recently, natural bio-resources have attracted the attention of scientist and engineers, and many attempts have been made to prepare and evaluate natural bio-resources for various applications. This is because natural bio-resources offers low density, low cost, are environmentally harmless and have good mechanical properties.

Oil palm shell powder (OPSP) and polypropylene (PP) are used to produce the composites in this research. In this project, the OPSP and PP are compounded using extruder. The extruder compound then crushed, and pressed to obtain a flat panel of OPSOP/PP composite. Boards with different weight fraction of OPSP at constant density are achieved by changing the weight ratio of the PP and OPSP mixing.

1.1.2 Problem Statement

There are few studies that have focused on fabricating lighter and tougher composites, despite these bio-composites for automotive parts having potential to improve fuel consumption. In this research, a lighter and tougher bio-composite board using OPSP which is in the particle shape reinforcing polypropylene will be fabricated. The effect of the OPSP weight fraction on the mechanical properties of the composites will then be examined.

1.2 Research Scopes

The composites are fabricated using hot press molding technique. Tensile, flexural and impact test are carried out to determine the mechanical properties of the composites. Water absorption test is carried out to determine the physical properties of the composites. Their microstructures are observed using Scanning Electron Microscope (SEM).

1.3 Research Objectives

The purpose of this research is:

i. To study the mechanical properties of oil palm shell powder filled polypropylene composites.
ii. To study the effect of oil palm shell powder weight fraction on oil palm shell powder filled polypropylene composites.
iii. To study the microstructures of tensile fracture of oil palm shell filled polypropylene composites.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

A composite material is a macroscopic combination of two or more distinct materials, having a recognizable interface between them. Composites are used not only for their structural properties, but also for electrical, thermal, tribological, and environmental applications. Composites are commonly classified at two distinct levels. The first level of classification is usually made with respect to the matrix constituent. The major composites classes include metal-matrix composites (MMC), ceramic-matrix composites (CMC) and polymer-matrix composites (PMC). The second level of classification refers to the reinforcement form. It refers to particulate reinforcements, whisker reinforcements, continuous fiber laminated composites, and woven composites.

2.2 Polymer Matrix Composites (PMC)

PMC is the composites that used polymer as a matrix. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared with metals and ceramics. This meant that there was a considerable benefit to be gained by reinforcing polymers and that the reinforcement, initially at least, did not have to exceptional properties. Processing of PMC need not involve high pressures and does not require high temperature. It follows that problems associated with the degradation of the reinforcement during manufacture are less significant for PMC than for composites with other matrices. Also the equipment required for PMC may be simpler. For these reasons polymer matrix composites developed rapidly and soon became accepted for structural applications. Today glass-reinforced polymers are still by the far most used composite material in term of volume with the exception of concrete.

Although PMC have all those of advantages, its also have some of disadvantages includes their low maximum working temperatures, high coefficients of thermal expansion and hence dimensional instability, and sensitivity to radiation and moisture. The absorption of water from the environment may have many harmful effects which degrade mechanical performance, including swelling, formation of internal stresses and lowering of the glass-transition temperature. Overall, the properties of the composite are determined by the properties of the reinforcement, properties of the resin, the ratio of reinforcement to resin in the composite (OPSP Weight Fraction) and the geometry and orientation of the fibers in the composite.

2.3 PMC Processing Technique

The processing techniques for Polymer Matrix Composites is vary from simple labour intensive methods suitable for one-offs to automated methods for rapidly producing large numbers of complex components. The methods selections for processing PMC are depend on factors such as cost, shape of component, number of components and required performance. In this research, the processing technique used is compounding and compression which is including the hot press moulding process.

2.3.1 Compression Moulding

There are three types of compression moulding techniques. These are: preform moulding, Sheet Moulding Compound moulding, and Bulk Moulding Compound. All of them utilise the same type of high pressure moulding equipment, but differ in the form of the material that is placed in the moulds to form the part and the need for the reinforcement to flow. The materials most commonly moulded by this technique are fibreglass and either polyester or epoxy. Generally, the short fiber lengths necessary for use in this type of process preclude the use of this technique for high-performance parts. The equipment is a press (usually hydraulically driven) that is fitted with both male and female dies (hence the term matched-die moulding). Generally, the dies are made of a hard metal (such as tool steel) and can be highly polished and chromium plated to obtain a fine finish. The pressures developed by the press can range up to several hundred tons, which is useful for obtaining good part uniformity and consolidation.

Hot press moulding process is a matched metal tool placed between the platens of a hydraulic press and heated to between 130°C and 170°C. The prepreg or reinforcement material is placed in the tool which has a cavity in the shape of the component required. The tool is rapidly closed and the cure is completed within 2-3 minutes. The tool is opened and the component removed. In order to aid removal of the component from the tool, release agents are either incorporated into the resin mix or applied to the surface of the tool. This method uses the various compounds including SMC (Sheet Moulding Compound and BMC (Bulk Moulding Compound). The compounds use polyester resin, filler, catalyst, pigment and other additives. The fiber preforms are typically a sprayed chopped fiber and binder or thermally deformed Chopped strand mat containing a thermoplastic binder. This method does allow for a high production rate and is preferred by the automotive industry.

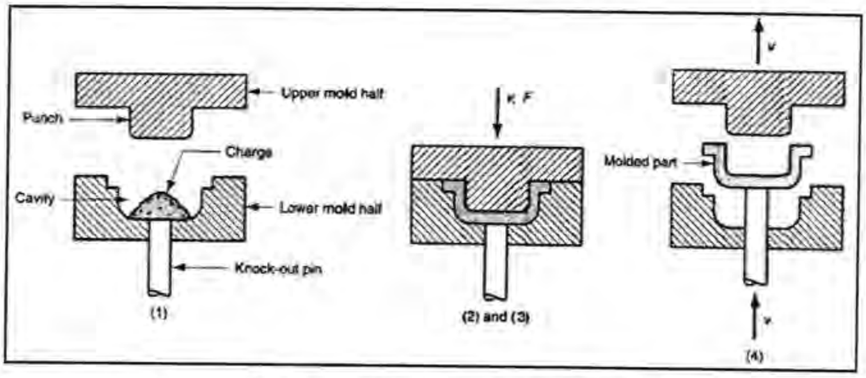

Figure 2.1: Compression Molding Process

2.4 Reinforcement

The most common forms of reinforcement for structural composites are fibers, whisker and particulate. They vary greatly in cost, availability and properties. The ultimate choice is determined by considerations of property requirements, processing possibilities and cost effectiveness. Fibers provide the greatest opportunity to tailor the material properties of the composite such that materials with whisker or particulate reinforcements are often considered as improved plastics rather composite materials. Fibers have one axis much greater than its others with the smaller axes often being circular or near circular. Fibers are generally stronger and stiffer along the long axis due to the process of the fiber.

Continuous fiber (where the fiber reinforcement runs continuously for a significant portion of the structure) is the most widely exploited type of reinforcement and fibers of greatly contrasting constitution and properties are widely available. These include glass, carbon (graphite), silicon carbide (SiC), and alumina and organic polymers such as polyaramid and polyethylene.

Short Fibers are often referred to as discontinuous reinforcement. Their shorter length may confer processing advantages (e.g. for use in moulding compounds) and is often either cheaper (due to reduced quality of fiber than used in continuous fibers) or more readily available.

Whiskers are unique, needle-shaped single crystals of metals or ceramics. They are typically of the order of 10 μm × 10 μm × 1 mm or smaller. The most important materials in this class are silicon carbide9 and silicon nitride. Ceramic whiskers are of great interest for the reinforcement of metals, glasses and ceramics. They have higher strengths than any other reinforcing materials but their small dimensions result in handling problems. It should also be noted that very small whiskers of 1 μm minimum dimension have been identified as a severe health risk if inhaled. They must therefore be handled with extreme caution. Many plastics are filled with inert fillers to either cheapen them or to confer a degree of property enhancement.

Particulate Reinforcements are usually fillers of acicular or plate-like shape such as mica, talc and wollastonite (CaCO3). Flake glass and silicon carbide are also used. Thousands of tons of these basic, cheap fillers are used annually in the plastics industry, but the products are normally regarded as plastics rather than composites. The most important particulate-based composites systems are those where silicon carbide particles (5 -20 gm) are used to reinforce light alloys. The composites may be prepared by either a melt or powder metallurgy route and may be hot worked. They offer very significant improvements in stiffness at elevated temperatures.

2.5 Natural Fiber Composite

Natural fiber composite combine plant fibers with resins to create natural based composite materials. A variety of plant fibers with high tensile strength can be used including oil palm shell powder, kenaf, sisal, jute, industrial hemp, and flax. Fibers can be combined with traditional resins or newer plant based resins. The result is a plant based alternative for many traditional steel and fiberglass applications. Some advantages of natural fiber composite over traditionally composites are reduced weight, increased flexibility, greater moldability, less expensive, sound insulation, and renewable resources. Current and potential applications of natural fiber composites are vehicle door panels (currently used by most automobile manufacturers for most interior panels), interior furniture panels, industrial equipment panels, partition panels and acoustic panels.

2.6 Value-Added Agriculture

Natural fiber composites introduce an additional profit component for current agricultural economies. As products are developed to use natural fiber composites the demand for locally grown fiber crops will increase. The development of fiber processing facilities will become necessary and will create jobs in rural areas.

2.7 Thermoplastic

A thermoplastic material will soften when heated above glass transition temperature. It can then be easily shaped and on cooling will harden in this form. However, on reheating it will soften again and can be reshaped if required before hardening when the temperature drops. They are "melt processable", which means they can be formed into useful shapes while in the melted or viscous phase. In most manufacturing processes, thermoplastics are heated, then formed by injection molding, extrusion or thermoforming and finally cooled so the end product retains its shape.

Today, many types of thermoplastics are available with a wide range of useful properties. Common types of thermoplastics are Polyethylene, Polypropylene, Polystyrene, Polyetheretherketone (PEEK), Polyetherimide (PEI), Polyethersulphone (PES) Polyphenylene Sulfide Polyaimide-imide (PAI). They can be made as flexible as rubber, as rigid as metal and concrete or as clear as glass, for use in a wide range of piping and other products. Some can withstand temperatures of up to 600°F (315°C).