การใช้เศษผ้านอนวูฟเวนจากกระบวนการผลิตเสื้อกาวน์แพทย์เป็นสารตัวเติมในพอลิเอทิลีนชนิดความหนาแน่นสูง

นางสาวภัทราภรณ์ สิงห์สถิตย์

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USE OF MEDICAL GOWN NONWOVEN FABRIC MANUFACTURING WASTE AS A FILLER IN HIGH DENSITY POLYETHYLENE

Miss Pattaraporn Singsatit

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งานวิจัยนี้เป็นการนำเศษส่วนเกินจากกระบวนการผลิตเสื้อกาวน์แพทย์ซึ่งเป็นผ้านอนวูฟเวนพอลิเอสเทอร์ผสมฝ้ายกลับมาใช้งานใหม่เป็นสารตัวเติมในพอลิเอทิลีนชนิดความหนาแน่นสูง (HDPE) โดยนำเศษผ้านอนวูฟเวนมาดัดแปรด้วยมาเลอิกแอนไฮไดรด์ 5 10 และ 15 เปอร์เซ็นต์โดยน้ำหนัก และใช้เวลาในการดัดแปร 2 3 และ 4 ชั่วโมง จากนั้นนำเศษผ้าที่ผ่านการดัดแปรมาวิเคราะห์โครงสร้างทางเคมีด้วยเทคนิคฟูเรียร์ทรานสฟอร์มอินฟราเรดสเปกโทรสโกปีและลักษณะสัณฐานวิทยาด้วยกล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด ก่อนนำไปผสมกับ HDPE และขึ้นรูปด้วยกระบวนการอัดแบบโดยใช้เศษผ้านอนวูฟเวนเป็น 5 10 15 และ 20 เปอร์เซ็นต์โดยน้ำหนักตามลำดับ จากการทดสอบสมบัติเชิงกล พบว่า HDPE ซึ่งเติมด้วย 10 เปอร์เซ็นต์ของเศษผ้านอนวูฟเวนที่ผ่านการดัดแปรด้วยมาเลอิกแอนไฮไดรด์ 10 เปอร์เซ็นต์ และใช้เวลาในการดัดแปร 2 ชั่วโมง มีสมบัติเชิงกลโดยรวมซึ่งได้แก่ สมบัติด้านแรงดึง สมบัติด้านแรงดัดโค้ง และความทนแรงกระแทกดีกว่า HDPE ที่เติมด้วยเศษผ้านอนวูฟเวนที่ไม่ผ่านการดัดแปรและที่ดัดแปร ณ ภาวะอื่น

ภาควิชาวัสดุศาสตร์ ลายมือชื่อนิสิต……………………………………
สาขาวิชาวิทยาศาสตร์พอลิเมอร์ประยุกต์และเทคโนโลยีสิ่งทอ ลายมือชื่ออาจารย์ที่ปรึกษา………………………
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PATTARAPORN SINGSATIT: USE OF MEDICAL GOWN NONWOVEN FABRIC MANUFACTURING WASTE AS A FILLER IN HIGH DENSITY POLYETHYLENE. THESIS ADVISOR: ASST. PROF. VIMOLVAN PIMPAN, Ph.D, 99 pp. ISBN 974-53-1593-1.

The objective of this research is to recycle nonwoven fabric waste from medical gown–manufacturing process by using as a filler in high–density polyethylene (HDPE). Before nonwoven fabric waste was mixed with HDPE, this fabric waste was modified with 5, 10 and 15 % by weight of maleic anhydride using modification time of 2, 3 and 4 hours. The chemical structure of modified fabric waste was confirmed by FT-IR spectroscopy while scanning electron microscopy was used to investigate its surface morphology. The samples were prepared by compression molding using the amount of fabric waste at 5, 10, 15, and 20 %w/w, respectively. After mechanical tests were employed, it was found that HDPE filled with 10% of fabric waste treated by 10% of maleic anhydride for 2 hours exhibited overall mechanical properties including tensile properties, flexural properties and impact strength better than HDPE filled with unmodified fabric waste or those modified with other conditions.

Department Materials Science Student's signature........................
Field of study Applied Polymer Science and Textile Technology Advisor's signature........................
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CHAPTER I

INTRODUCTION

Nowadays, the consumption of synthetic polymers have increased rapidly. This is because these materials have many advantageous properties over other materials including glass, metals, ceramics and woods. For example, they are light-weight, resistant to chemicals and environmental atmosphere. Furthermore, they can be easily processed into desired products by many methods. Therefore, they are used in various applications such as textiles, packaging, automobile parts, etc. It has been known that the waste management for manufacturing wastes and post-consumer products made from these synthetic polymers have dealt with some difficulties. Burning of these wastes and products may result in releasing dangerous gases to the atmosphere while burying them in soil cannot destroy the products because they are slowly biodegradable. Therefore, alternative methods to reduce these wastes and products have been developed.

One commonly used method is to recycle these manufacturing wastes and post-consumer products. Recycling can be divided into two types: chemical recycling and physical recycling. The principle of chemical recycling is to convert high molecular weight polymers into low molecular weight substances via chemical reactions. The obtained substances can be used as the reactants for preparations of other chemicals and polymers. In the case of physical recycling, manufacturing wastes and post-consumer products are reprocessed generally into new products using reclaimation process or commingled plastics waste processing. Due to its simpler, cheaper and more environmental friendly process, physical recycling is more favorable than chemical recycling.

This research emphasizes on physical recycling of textile manufacturing waste. Possiblity of using polyester/cotton (PET/C) nonwoven fabric waste from medical gown manufacturing industry as filler in high-density polyethylene (HDPE) is investigated. In order to promote surface adhesion between the fabric waste and HDPE, PET/C nonwoven is modified by esterification with maleic anhydride before compression molding with HDPE. This research also focus on the effects of the amount of maleic anhydride and the reaction time used for modification and the weight ratio of the fabric waste to HDPE on the mechanical properties of filled HDPE. Tensile, flexural and impact properties of filled HDPEs prepared from various amounts of fabric waste modified at different conditions are compared in order to determine the suitable condition which results in filled HDPE with optimum mechanical properties.

CHAPTER II

THEORY AND LITERATURE REVIEW

2.1 Recycling [1]

Recycling is one of The "Four R's" of Waste Management. The other three R are Reduction, Reuse and Recovery. Each R represents the steps for waste management as follows:

Reduction : avoiding unnecessary waste generation in the first place.

Reuse : using objects, devices, or substances again.

Recycling : using "waste" material in place of virgin material to manufacture new products.

Recovery : extracting energy or material resources from otherwise discarded mixed wastes.

2.1.1 Definition of Recycling[1]

Recycling can be defined according to ASTM D5033-90 as reprocessing of manufacturing or post-consumer wastes in order to produce either the same or new products. It can be divided into 4 types as follows.

1. Primary Recycling : reprocessing of manufacturing waste in order to produce the same product. The product is usually not contaminated by other materials.
2. Secondary Recycling : reprocessing of post-consumer waste in order to produce new products which are different from previous application. Such product is normally contaminated by other materials.
3. Tertiary Recycling : converting of high molecular weight polymers into low molecular weight substances via chemical reactions. The obtained products from these reactions are predominantly the monomers of those polymers. These products can be used as the reactants for preparations of other chemicals and polymers.
4. Quaternary Recycling : using of the energy derived from burning of wastes

2.1.2 Type of Recyclable Synthetic Polymers [2]

There are about 50 different groups of synthetic polymers, with hundreds of different varieties. Many of them are used as plastics. To make sorting and thus recycling easier because the American Society of Plastics Industry developed standard marking codes to help consumers identify and sort the main types of recyclable plastics. These types and their most common uses are given in Table 2.1

Table 2.1 Standard marking codes for recyclable plastics [2]

♳	PET	**Poly(ethylene terephthalate)** - Fizzy drink bottles and oven-ready meal trays.
♴	HDPE	**High-density polyethylene** - Bottles for milk and washing-up liquids.
♵	PVC	**Poly(vinyl chloride)** - Food trays, cling film, bottles for squash, mineral water and shampoo.
♶	LDPE	**Low-density polyethylene** - Carrier bags and bin liners.
♷	PP	**Polypropylene** - Margarine tubs, microwaveable meal trays.
♸	PS	**Polystyrene** - Yoghurt pots, meat foam or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
♹	OTHER	Any other plastics that do not fall into any of the above categories. An example is melamine, which is often used in plastic plates and cups.

According to a 2001 Environment Agency report, 80% of post-consumer plastic waste is sent to landfill, 8% is incinerated and only 7% is recycled. In addition to reduce the amount of plastic waste by disposal, plastic recycling can have several advantages:

- Conservation of non-renewable fossil fuels - Plastic production uses 8% of the world's oil production, 4% as feedstock and 4% during manufacture.
- Reduced consumption of energy.
- Reduced amounts of solid waste going to landfill.
- Reduced emissions of carbon-dioxide (CO_2), nitrogen-oxide (NO) and sulphur-dioxide (SO_2)

2.1.3 Type of Recycling

2.1.3.1 Chemical or Feedstock Recycling [2]

Feedstock recycling describes a range of polymer recovery techniques which break down polymers into their constituent monomers, which in turn can be used again in refineries, or petrochemical and chemical production. A range of feedstock recycling technologies is currently being studied. These include: pyrolysis, hydrogenation, gasification and thermal cracking. Feedstock recycling has a greater flexibility over composition and is more tolerant to impurities than mechanical recycling, although it is capital intensive and requires very large quantities about 50,000 tons per year of used polymers for reprocessing to be economically.

2.1.3.2 Physical or Mechanical Recycling [2]

This type of recycling is generally applied to synthetic polymers used as plastics. Mechanical recycling of plastics refers to processes which involve the melting, shredding or granulation of waste plastics. Plastics must be sorted prior to mechanical recycling. At the moment in the UK, most sorting for mechanical recycling is done by trained staffs who manually sort the plastics into polymer type and/or color. Technology is being introduced to sort plastics automatically, using various techniques such as X-ray fluorescence, infrared and near infrared spectroscopy, electrostatics and flotation. Following sorting, the plastic is either melted down directly and molded into a new shape, or melted down after being shredded into flakes and then processed into granules called regranulation.

2.1.3.2.1 Generic Reclamation Process

Separating, sorting, and washing plants for contaminated plastics vary from manufacture to manufacturer but consist essentially of the following steps.

2.1.3.2.1.1 Size Reduction

Shredders are available with two or four cutting shafts, and it is important that the cutters have separate drives running at widely different speeds. Excessive wear of cutters was formerly a problem, but this problem has now been overcome. Throughputs of up to 3 tons/h are possible. These machines can handle bales, hollow bodies to dustbin size, and also cables.

For handling bulky products, such as sacks and foam parts, rotating screw shafts can be used. Guillotines are used when it is essential to separate large waste parts that have fused or meshed together. In industrial waste, this can be fiber bales, film rolls, or heavy plastic chunks.

Follow the shredding, sorting, and prewashing stages of the operation, and prepare the plastic material to the size subsequently suited for melt processing, that is, grain size of 1/8-1/4 inch. Wet milling or granulation is often used and prevents the blocking of screens and also the degradation of material as a result of frictional heat. Dirt is prevented from collecting on the cut edges of the reclaimed material. If powdered materials are ultimately required, the scrap is cooled with liquid nitrogen (an expensive operation limited to specific applications) and pulverized. The material is screened, and large particles (300μm) are returned for further pulverizing.

2.1.3.2.1.2 Washing Systems

As already mentioned, the prewashing stage following shredding enables contaminants, such as stones, metal, and glass, to be removed, avoiding damage to cutting blades in the subsequent fine granulation stage.

Wet milling and granulation follow the removal of metal, minerals, and other contaminants, and the presence of water prevents degradation of the material by frictional heat. In both washing stages, the concentration of detergent used, the power of the mixing, operator, the temperature of the water, and the washing time must be optimized to the particular scrap being processed follow.

Dirty oil from used containers is emulsified by the hot detergent during the washing stage. This emulsion must be removed before the water can be reused in the pre washing cycle. Dirt and other contaminants from the oil separate out as sludge at the bottom of the settling tank and is easily removed.

After wet milling, a dewatering screw removed the comminuted material from the wet mill, separating dirt has become detached. The separating tank is designed to remove all contaminants, including fine foreign matter, which sink in water.

2.1.3.2.1.3 Melt Processing

Before melt processing using extrusion equipment fitted with a face to face cutting system, the material is homogenized in silos and mixed thoroughly to ensure that the finished product is homogeneous.

2.1.3.2.2 Commingled Plastics Waste Processing

Commingled plastics waste processing involves the use of mixed plastics waste, as received as feedstock. It differs significantly from generic processing in that it needs very little sorting and almost no cleaning. The plastic waste, in the majority of cases, is directly processed into molded parts.

Commingled processing is often associated with “plastic lumber” made using the Klobie extrusion molding process. The Klobie system enables mixed, contaminated plastic waste to be molded directly into linear shapes. The plastics fed to Klobie system may be highly contaminated by paper, soft metal, dirt, or thermoset plastics.

A thermoplastic portion may be comprised of both rigid and flexible plastics. The minimum percentage of the thermoplastic portion varies from one technology to another. A number of technologies are commercially available using the same principle or modifications to process commingled plastics waste. Although they may differ in certain aspects, their main target is the processing of post consumer plastic waste as coming from the collection operator. Among the processes are the Advanced Recycling Technology (ART), Superwood International (SWI), and Recycloplast and, to a lesser extent, Suzue Denki.

There is a wide range of products made from recycled plastic. This includes polyethylene bin liners and carrier bags; PVC sewer pipes, flooring and window frames; building insulation board; video and compact disc cassette cases, fencing and garden furniture; water butts, garden sheds and composers; seed trays; anoraks and fleeces; fibre filling for sleeping bags and duvets; and a variety of office accessories. Despite the wide range of recycled plastics applications, the actual tonnage of waste plastic which is returned to the material cycle is relatively small. Currently, recycled plastics are rarely used in food packaging - the biggest single market for plastics - because of concerns about food safety. A method of addressing this problem is by enclosing the recycled plastic between layers of virgin plastic to ensure the packaging conforms to hygiene standards. These multi-layered containers are now being used in some drinks bottles, but recycling cannot eliminate the colors from plastics so they cannot be used in transparent or light colored applications. Another constraint on the use of recycled plastics is that, to be economically viable, plastic processors require large quantities of recycled plastics, manufactured to tightly controlled specification at a competitive price in comparison to that of virgin polymer.

This is a challenging task, particularly in view of the diversity of sources of waste plastics, the wide range of polymers used and the high potential for contamination of plastics waste.

Besides plastics waste, other types of waste can be also recycled by physical recycling as in this case, polyester/cotton nonwoven fabric from medical gown manufacturing industry is recycled to use as filler for high density polyethylene (HDPE). The following sections will give detail description of subjects related to this research.

2.2 Nonwoven [3]

The term used to designate the products generally known as nonwovens, was coined in most languages in opposition to woven fabrics, which implicitly were taken as a reference. A nonwoven was something that was not woven.

Even the German name “Viesstoffe” wasn’t clear as it could be confused with ceramic material and in any case remained ambiguous in its unusual spelling. Only specialists know that nonwovens are unique engineered fabrics which offer cost effective solutions as e.g. in hygiene convenience items, or as battery separator, or filters, or geotextiles, etc.

As a main characteristic the CEN definition indicates that a nonwoven is a fabric made of fibers that is consolidated in different ways. Nonwoven fabrics are made out of fibers, without any restriction, but not necessarily from fibers. There can be very short fibers of a few millimeters length as in the wet laid process; these can be “ordinary” fibers, as used in the traditional textile industry, or then very long filaments etc. Properties and characteristics of nonwoven fabrics depend on a large part from the type of fibers it is ultimately made of. These fibers can be natural or man-made, organic or inorganic; The characteristic of a fibers being that it is longer than its thickness, or diameter. Such fibers can also be produced continuously in connection with the nonwoven process itself and then cut to length, or then extruded directly e.g. from polymer granules into a filament and then fibrous structure.

2.2.1 Nonwoven Manufacturing Processes

There are three main routes web forming:

- the drylaid system with carding or airlaying as a way to form the web;
- the wetlaid system;
- the polymer-based system, with includes sun laying(spun bonding) or specialized technologies like melt blow, or flash spun fabrics etc.

The lack of sufficient frictional forces however has to be compensated by bonding the fiber to provide web strength. Consolidation of the web after its formation is the second step in the nonwoven manufacturing process.

This consolidation sets the final characteristics of the fabric and therefore, if possible, ought to be chosen with the end application in mind. Such consolidation can be done by use of chemical means (chemical bonding) like binders. These can be applied uniformly by impregnating, coating or spraying or intermittently, as in print bonding. The consolidation can also be reached by thermal means (cohesion bonding), like the partial fusion of the constituting fibers or filaments. Such fusion can be achieved e.g. by calendering or thought-air blowing or by ultra-sonic impact.

Finally, consolidation can be achieved by mechanical means (frictional bonding), like needling, stitching, water-jet entangling or a combination of these various means.

Customers needs can be future met by modifying or adding to the existing properties of the fabric through finishing. A variety of chemical substances can be employed before or after bonding or various mechanical processes can be applied to the nonwoven in the final stage of the manufacturing process.

The choice of the raw material and the final constituting of fibrous element, the depositing of the fibers as a fibrous material of a varying density, the parameters which can be played in order to reach the required properties. This conforms what indicated earlier that nonwovens are engineered fabrics par excellence. When ingredients, web formation and consolidation are chosen in order to meet the best characteristics needed for the end of application, and then for sure, we have a winner.

2.2.2 Nonwoven Properties and Applications

Nonwovens are in fact products in their own right with their own characteristics and performances, but also weaknesses. They are around us and we use them everyday, without knowing then oftenly. Indeed they are frequently hidden from view. Nonwovens can be made absorbent, breathable, drape able, flame resistant, heat sealble, light, lint-free, mould able, soft, stable, stiff, tear resistant, water repellent, if needed. Obviously though, not all the properties mentioned can be combined in a single nonwoven, particularly those that are contradictory.

Their applications are multifold. Examples of their uses can be listed as follow:

- Personal care and hygiene as in baby diapers, feminine hygiene products, adult incontinence items, dry and wet pads
- Healthcare, like operation drapes, gowns and packs, face masks, dressings and swabs, osteomy bag lines, etc
- Clothing: interlinings, insulation and protection clothing, industrial workwear, chemical defence suits, shoe components, etc.
- Home: wipes and dusters, tea and coffee bags, fabric softeners, food wraps, bed and tables linen, etc.
- Automotive: boot liners, shelf trim, oil and cabin air filters, moulded bonnet liners, heat shield, etc.
- Construction: roofing and tile underlay, thermal and noise insulation, house wrap, etc.
- Geotextiles: asphalt overlay, soil stabilization, drainage and erosion control, etc.
- Filtration: air and gas, Havac, Hepa, Ulpa filters
- Industrial: cable insulation, abrasives, reinforced plastic, battery separators, satellite dishes, artificial leather, air conditioning. coating.
- Agriculture, home furnishing, leisure and travel, school and office, etc.

2.3 Poly(ethylene terephthalate) [4]

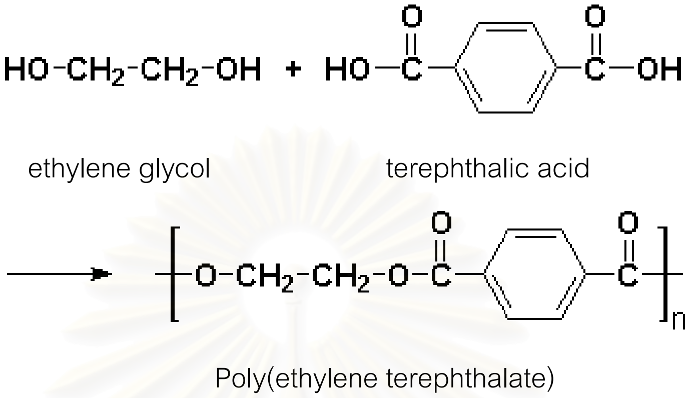


Figure 2.1 Synthesis of poly(ethylene terephthalate)[5]

Poly(ethylene terephthalate) (PET), or poly(ethylene terephthalic ester) (PETE), is a condensation polymer produced from the monomers ethylene glycol, $HOCH_2CH_2OH$, a dialcohol, and dimethyl terephthalate, $CH_3O_2C–C_6H_4–CO_2CH_3$, as see figure 2.1 By the process of transesterification, these monomers form ester linkages between them, yielding a polyester. This resin has been used extensively in three major product types – fibers, films, and molding resins. The fibers have been used for textile applications, formerly used alone but now usually blended with wool or cotton. The polyester gives wrinkle resistance, permanent pleat capability, and staining resistance to the fabric. Fibers made from polyester are also used as reinforcements in tires, conveyor belts and hoses. PETE fibers are manufactured under the trade names of DuPont's Dacron and Kodak's Kodel. PET films are used extensively because of their ruggedness and clarity. The films are used as magnetic tapes, substrates for photographic films, release films drawing foils, and because of the high operating temperature capability of PET, as sterilizable packaging for medical and other applications, A copolymer PET with a modified glycol is available as a film that is completely amorphous and has improved processing. This copolymer is called PETG. Typical PET film brand names include: DuPont's Malar and Kodak's Kodar.

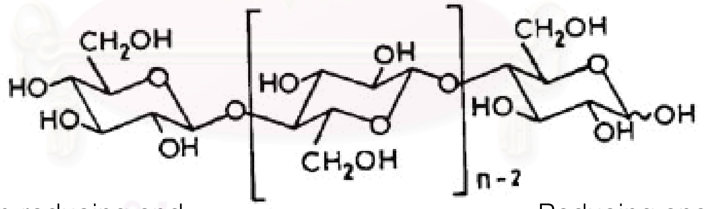
The used of PET for soft drink bottles requires that resin be tough (so that it can withstand a drop), inexpensive, and have a low permeability to carbon dioxide. PET is a reasonable compromise and has performed well in this application. The used PET for soft drink bottles has increased its use in other bottles applications, some where permeability is not a major issue. The clarity and durability of PET, along with the excellent odor resistance have led to many of these applications.

2.4 Cellulose [6]

Cellulose $(C_6H_{10}O_5)_n$ is a long-chain polymer polysaccharide carbohydrate, of beta-glucose as see bellow. It forms the primary structural component of plants and is not digestible by humans .

CO_2 (g) + H_2O(l) + light --- $C_6H_{12}O_6$(s) + O_2(g)

(The equation for photosynthesis).



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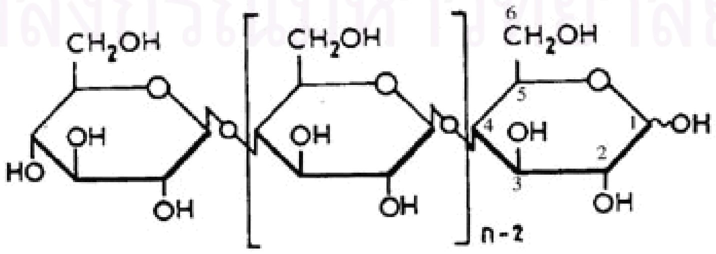


Figure 2.2 Structure of cellulose [6]

2.4.1 History and Applications

Cellulose is a common material in plant cell walls and was first noted as such in 1838. It occurs naturally in almost pure form only in cotton fiber; in combination with lignin and any hemicellulose, it is found in all plant material. Cellulose is the most abundant form of living terrestrial biomass Cellulose, especially cotton linters, is used in the manufacture of nitrocellulose, historically used in gunpowder. Some animals, particularly ruminants and termites, can digest cellulose with the help of symbiotic micro-organisms - see methadone.
Cellulose is processed to make cellophane and rayon. Cellulose is also used within the laboratory as a solid-state substrate for thin layer chromatography.

2.4.2 Chemistry

Cellulose monomers (beta-glucose) are linked together through 1,4 glycosidic bonds. Cellulose is a straight chain (no coiling occurs). In microfibrils, the multiple hydroxide groups hydrogen bond with each other, holding the chains firmly together and contributing to their high tensile strength. This strength is important in cell walls, where they are meshed into a carbohydrate matrix, helping keep plants rigid.Given a cellulose material, the portion that does not dissolve in a 17.5% solution of sodium hydroxide at 20^{o}C. is Alpha Cellulose, which is true cellulose; the portion that dissolves and then precipitates upon acidification is Beta Cellulose, and the proportion that dissolves but does not precipitate is Gamma Cellulose.

Many of the kinds of vegetation that have large percentages of cellulose are also singularly or when combined very beneficial to humans. The percentages of common vegetation are given in Table 2.2.

Table 2.2 The Percentages of common vegetation [7]

Plant Material	Percent Cellulose
Cotton	95-99
Ramie	80-90
Bamboo	40-50
Wood	40-50
Wood Bark	20-30
Mosses	25-30
Bacteria	20-30

2.4.3 Cotton [7]

Cotton is a soft fiber that grows around the seeds of the cotton plant . The fiber is most often spun into thread and used to make a soft, breathable textile.

Cotton is a valuable crop because only about 10% of the raw weight is lost in processing. Once traces of wax, protein, etc. are removed, the remainder is a natural polymer of pure cellulose. This cellulose is arranged in a way that gives cotton unique properties of strength, durability, and absorbency. Each fiber is made up of twenty to thirty layers of cellulose coiled in a neat series of natural springs. When the cotton boll (seed case) is opened the fibers dry into flat, twisted, ribbon-like shapes and become kinked together and interlocked. This interlocked form is ideal for spinning into a fine yarn.

Today cotton is produced in many parts of the world, including Europe, Asia, Africa, the Americas and Australia, using cotton plants that have been selectively bred so that each plant grows more fiber. In 2002, cotton was grown on 330,000 km^2 of farmland. 47 billion pounds (21 million tons) of raw cotton worth 20 billion dollars US were grown that year.

The cotton industry relies heavily on chemicals such as fertilizers and insecticides, although some farmers are moving towards an organic model of production, and chemicalfree organic cotton products are now available. Historically, one of the most economically destructive pests in cotton production has been the boll weevil.

Most cotton is harvested mechanically, either by a cotton picker, a machine that removes the cotton from the boll without damaging the cotton plant, or by a cotton stripper which strips the entire boll off the plant. Cotton strippers are generally used in regions where it is too windy to grow picker varieties of cotton and generally used after application of a defoliant or natural defoliation occurring after a freeze. Cotton is a perennial crop in the tropics and without defoliation or freezing, the plant will continue to grow. Cotton is a close relative of okra and hibiscus.

The logistics of cotton harvesting and processing have been improved by the development of the cotton module builder, a machine that compresses harvested cotton into a large block, which is then covered with a tarp and temporarily stored at the edge of the field.

In addition to the textile industry, cotton is used in fishnets, coffee filters, tents and in bookbinding. The first Chinese paper was made of cotton fiber, as is the modern US dollar bill and federal stationery. Fire hoses were once made of cotton. Denim, a type of durable cloth, is made mostly of cotton, as are shirts. The cottonseed which remains after the cotton is ginned is used to produce cottonseed oil, which after refining can be consumed by humans like any other vegetable oil. The cottonseed meal that is left is generally fed to livestock .

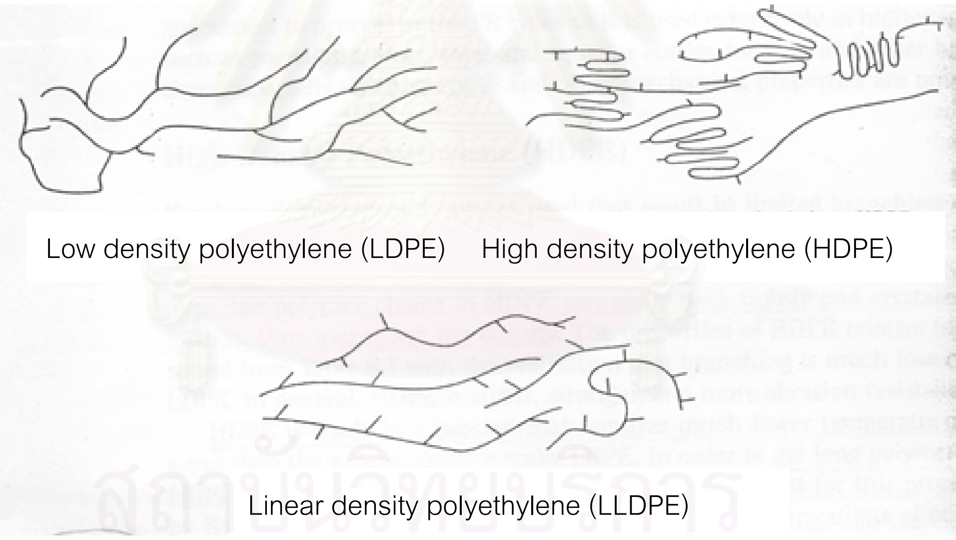
2.5 Polyethylene [8]

Polyethylene (PE) is virtually defined by its name as a polymer of ethylene produced by addition polymerization. However, linear polymers with the formula $(CH_2)_n$ have also been prepared by condensation reactions. Polyethylene is polymerized from ethylene gas that is easily and inexpensively obtained from ether natural gas (methane) or from crude oil. Furthermore, the processes that are used to make PE are easily scaled to make the polymer in very large quantities. To further reduce its cost, the temperatures required for processing

PE into final shapes are also the lower of any of the common, high-used thermoplastic materials. This means that comparatively little energy is required in the molding operations. The moldings operations are further simplified because PE is stable during processing and poor quality parts can be reground are reprocessed with very little difficulty. PE applications that require this low cost and ease of processing include trash bags, packaging and other films, containers (such as milk bottles) , many children's toys, and various house wares.

Many properties of PE can be predicted from its basic polymer representation. For instance, PE consists of only carbons and hydrogens, usually with high molecular weights, and so it is relatively insensitive to most solvents.

Three general types of commercially made PEs differ chiefly in their molecular structures caused by the amount and type of branching and are illustrated in Figure 2.3.


Low density polyethylene (LDPE) High density polyethylene (HDPE)

Linear density polyethylene (LLDPE)

Figure 2.3 Structures of three commercial polyethylenes [8]

The PE materials are distinguished on the basis of density rather than branching because density is a property that is easily measured and is directly dependent on the amount and type of branching. The differences in polymer shapes represented in Figure 2.3 are idealized. There is some overlap in the nature of the materials and so the densities of the materials are normally given in ranges. These normal density ranges are given in Table 2.3.

Table 2.3 Density of polyethylenes

Type of Polyethylene	Density (g/cm^3)
Low-density polyethylene (LDPE)	0.910-0.925
High-density polyethylene (HDPE)	0.935-0.960
Linear-low-density polyethylene (LLDPE)	0.918-0.940

2.5.1 High-density Polyethylene (HDPE)

If polymerization conditions are used lower temperature and lower pressure, the result is a PE that is more linear, with only a few, short branches. This type of PE is called high-density polyethylene (HDPE). As the name implies, the polymer chain in HDPE can easily pack tightly and crystalline structures are formed, thus increasing the density.

HDPE is made in a process that requires much lower temperatures and lower pressure. In order to get long polymer chain under the HDPE conditions, a catalyst is requires, The first catalyst for the process was developed by Karl Ziegler in 1952 and was then applied to polymerizations of other monomers by Giulio Natta. The catalyst is called a Ziegler-Natta catalyst, which is a general name applied to all similar catalysts even though some more recent types may be covered by different patents from different inventors.

HDPE is used in preference to LDPE when greater stiffness or strength is required. For instance, milk, walls, detergent and bleach bottles are HDPE because they are usually made with very thin walls to save material and cost, yet must retain their shape. HDPE gives sufficient stiffness to accomplish.

The HDPE molecules are essentially linear with little entanglement in the melt, when HDPE is melt, HDPE molecules tend to be aligned in the direction of flow, especially when the flow path is highly restricted. This orientation also leads to rapid crystallization and high shrinkage upon cooling. Hence, the cooling rate of HDPE is faster than LDPE which can be an advantage in very high-volume processes such as the manufacture of margarine tubs. This orientation in the melt also adds to the strength of the melt, which is useful in blow molding.

The optical properties of HDPE reflect the increased crystallinity. HDPE is used for packaging but is most often used for applications such as grocery bags, where visual clarity is unimportant and strength is at a premium.

The disadvantage of HDPE is more brittleness compared to LDPE. In applications where the high strength of HDPE and high impact toughness are required, a very high molecular weight grade of HDPE has been produced. This material is called ultra high molecular weight polyethylene (UHMWPE) and is really a subgroup of HDPE, since it is made by a similar process.

Polyethylene is a wax-like thermoplastic softening at about 80-130°C with a density less than of water. It is tough but has moderate tensile strength, is an excellent electrical insulator and has very good chemical resistance. In the mass it is translucent or opaque but thin films may be transparent. The mechanical properties are very dependent on the molecular weight and on the degree of branching of polymer.

2.6 Fillers [9]

The term “filler” is usually applied to solid additives incorporates into the polymer to modify its physical (usually mechanical) proprieties.

Particulate fillers are divided into two types: inert fillers and reinforcing fillers. The term inert filler is something of a misnomer as many properties may be affected by incorporation of such filler. For example, in plasticized PVC compound the addition of inert filler will reduce die swell on extrusion, increase modulus and hardness, may provide a white base for coloring, improve electrical insulation properties and reduce tackiness. Inert fillers will also usually substantially reduce the cost of the compound. Amounts the fillers uses are calcium carbonates, china clay, talc, and barium sulphate. For normal uses such fillers should be quite insoluble in any liquids with which the polymer compound is liable to come into contact.

It is important to stress that with each chemical type of filler a number of grades are usually available. Such grades may differ in the following ways:

1. Average particle size and size distribution.
2. Particle shape and porosity.
3. Chemical nature of the surface.
4. Impurities such as grit and metal ions.

When employed in electrometric systems, it is commonly observed that the finer the particle size, the higher the values of such properties as tensile strength, modulus and hardness. Coarser particles will tend to give compound less strong than compounds with the filler absent, but if the particle size is sufficiently fine there is an enhancement in the above–mentioned properties (at least up to an optimum loading of filler) and the phenomenon is known as reinforcement.

The particle shape also has an influence; for example, the some what plate-like china clay particles tend to be oriented during processing to give products that are anisotropic. Other plastics tend to have an uneven surface and are difficult to wet with polymer whilst others are porous and may absorb other additives and render them ineffective.

The chemical nature of the surface can have a vital effect. Mineral fillers often have polar groups, for example hydroxyl groups, on the surface which render them attractive to water but not to organic polymer. To improve the wettings of polymer to fillersand hence obtain better produces mineral fillers are often treated. For example, calcium carbonate may be treated with stearic acid. The acid group attaching itself to the filler particle whilst others the aliphatic chain is compatible with the polymer. Some clay is amine-treated whilst other are coated with a glycol or similar product. Besides improved wetting such treatment can have a second function. Surface hydroxyl groups tend to H-bond to other additives such as antioxidations and some cross-linking components, making them ineffective. Preferential absorption by a less expensive additive such as a glycol can give much improved results. The most recent developments are coupling agents such as certain silanes which in effect form a polymer shell around the surface of the particle and improve the wetting to main polymer. These are discussed further in the next section.

Impurities in mineral fillers can have serious effects. Coarse particles (grit) will lead to points of weakness in soft polymers which will therefore fair under stresses below that which might be expected. Traces of copper, manganese and iron can affect the oxidative stability whilst lead may react with sulphur-containing additives or sulphurous fumes in the atmosphere to give a discolored product.

Reinforcing particulate fillers are effective primarily with elastomers although they can cause an increase in tensile strength with plasticised PVC. Pure gim styrene–butadiene rubber (SBR) Vulcan sates have tensile strength of about 3 MPa. By mixing in 50 Phr of a reinforcing carbon black the tensile can large increases in tensile strength are not observed but as with SBR an increase in modulus, tear resistance and abrasion resistance can be seen. It is often found that a property such as tensile strength usually goes through a maximum value with change in carbon black loading. At first the increase in polymer – black interfacial area is the dominating effect but if the black concentration becomes too high the diminishing volume of rubber in the composite is insufficient to hold the filler particles together. In general reinforcement appears to depend on three factors:

1. An extensity factor - the total amount of surface area of filler per unit volume in contact with the elastomer.
2. An intensity factor - the specific activity of the filler-polymer interface causing chemical and/or physical bonding.
3. Geometrical factors such as structure (aggregation) and porosity of the particles.

For equivalent particle size the carbon blacks are the most powerful reinforcing fillers. However, fine particle size silicas can be very useful in non-black compounds whilst other fillers such as aluminum hydroxide, zinc oxide and calcium silicate have some reinforcing effect.

Rubbery materials are often incorporated into rigid amorphous thermoplastics to improve their toughness but it is a moot point whether or not they should be referred to as rubbery fillers. Well-Know example is SBR and polybutadiene in polystylene, butadiene-arcylonitril rubbers in PVC and ethylene-propylene rubber in polypropylene.

Fibrous fillers have been long used in plastics materials. Wood flour, cotton flock, macerated fabric, macerated paper and short lengths of synthetic organic fibers such as nylon can improve the impact strength and often the rigidity and toughness of molding compositions. Inorganic fibers such as asbestos and glad fiber are also used in molding compositions, both thermoplastic and thermosetting, where heat resistance and strength respectively are required. More recently, chopped carbon fiber and whiskers (single crystals of high length-diameter ratio of very high strength) have been used for highly specialized purposes.

Fibrous fillers are often embedded in a laminar form. The fibers used have higher moduli that the resins in with they are embedded so that when the composite of resin plus fiber is strained in the plane of the fibrous layer and the bulk of the stress is taken up by the fiber. This results in an enhancement of both strength and modulus when compared with the unfilled resin.

As a general rule woven fabrics give higher figures for strength and moduli paper and mats, an exception occurring with asbestos mats. Of the woven fabrics in common use, those from glass fibers suitably treated to ensure good wetting give the highest strength. Exceptionally high tensile strength can sometimes be obtained using carbon fibers but the results laminates have a low interlaminar strength. Attempts to improve on this by stitching between layers with carbon fiber have been described.

2.7 Modification [10]

Fiber-reinforced polymer composites are very attractive because of their ease of fabrication, economy and superior mechanical properties. The effect of fiber content on the mechanical properties of polymer composites is of particular interest and significance. It is often observed that the increase in fiber content leads to an increase in the strength and modulus, and also in the toughness if the matrix has low toughness. However, for injection molded composites, fiber breakage results from fiber–polymer interaction, fiber–fiber interaction, and fiber contact with the surfaces of processing equipment. Due to the increased fiber–fiber interaction and fiber–equipment wall contact, fiber length decreases with increasing fiber content and this reduction in fiber length then reduces fiber reinforcing efficiency.

To improve the properties of the composites, the natural reinforcing fibers can be modified by physical and chemical methods. Physical methods, such as stretching, calendering, electronic discharge (corona, cold plasma), and the production of hybrid yarn, do not change the chemical composition or structure but only surface properties of the fiber. The most important chemical modification involves coupling methods. The coupling agent used contains chemical groups, which can react with the fiber and the polymer. The bonds formed are covalent and hydrogen bonds which improve the interfacial adhesion. Graft copolymerizations are common methods used for natural fiber-reinforcing plastics. Also common is treatment with compounds containing methyl groups, isocyanates, triazine or organosilanes. The modifications via conventional reactions such as etherification and esterification are also used. [11, 12]

2.8 Literature Reviews

Vichaimakepat et al. [13] reported on recycling of poly(ethylene terephthalate)-cellulose based nonwoven fabric waste from medical gown-manufacturing process by using as a filler in high-density polyethylene (HDPE) plastic. The products were formed by compression molding at 190°C. The ratios of fabric waste to HDPE were varied from 0:100, 5:95, 10:90, 15:85, to 20:80, respectively. All products were then subjected to several mechanical tests. It was found that all fabric waste filled products exhibited higher impact strength than the unfilled one. Furthermore, it was also observed that as the fabric waste content increased, the impact strength increased. However, the tensile strength, the bending strength and hardness of all filled products were lower that those of unfilled product and as the fabric waste content increased, these properties decreased. These results suggest a possibility to use this medical gown waste as a filler in HDPE by adjusting the fabric waste content that would be suitable in order to achieve the products with desired properties.

Pradhan et al. [14] studied polymer matrix composite using coconut shell powder (CSP) as a filler material has been processed by a powder metallurgy technique. A mixture of ultrahigh molecular weight polyethylene (UHMWPE) powder and CSP was compacted at 200 ˚C in a die-punch arrangement. The composite material remained tough when the CSP content was 20–30 %of the volume, as revealed by notch impact tests and fractography studies. However, the compressive strength of the UHMWPE–CSP composite decreased rapidly beyond 20 %of the volume CSP. In this paper, preliminary results are presented to throw light on mechanical properties and on some aspects of the processing method used.

Singleton et al. [15] studied a composite laminate based on natural flax fiber and recycled high density polyethylene was manufactured by a hand lay-up and compression molding technique. The mechanical properties of the composite were assessed under tensile and impact loading. Changes in the stress–strain characteristics, of yield stress, tensile strength, and tensile (Young's) modulus, of ductility and toughness, all as a function of fiber content were determined experimentally. A significant enhancement of toughness of the composite can be qualitatively explained in terms of the principal deformation and failure mechanisms identified by optical microscopy and scanning electron microscopy. These mechanisms were dominated by delamination cracking, by crack bridging processes, and by extensive plastic flow of polymer-rich layers and matrix deformation around fibers. Improvements in strength and stiffness combined with high toughness can be achieved by varying the fiber volume fraction and controlling the bonding between layers of the composite.

Santos et al. [10] studied the incorporation of fibers of recycled poly(ethylene terephthalate) (PET) in polypropylene (PP). Composites of PP/PET with 3, 5 and 7% of PET fibers (w/w) were prepared by monoscrewextrusion followed by injection molding and the mechanical behavior was estimated by the measurement of the tensile strength, the Izod impact strength and the surface hardness (Shore D). The morphology was determined by scanning electron microscopy (SEM), showing good dispersion of the fibers but no interaction between the polymer phases. It was observed that the incorporation of recycled-PET fibers (rPETFs) in PP is an efficient way to recycle PET, increasing significantly the mechanical properties of PP.

Mwaikambo et al. [16] reported on Kapok/cotton fabric has been used as reinforcement for conventional polypropylene and maleic anhydride grafted polypropylene resins. Treating the reinforcement with acetic anhydride and sodium hydroxide has modified the fabric (fibers). Thermal and mechanical properties of the composites were investigated. Results show that fiber modification gives a significant improvement to the thermal properties of the plan fibers, whereas tests on the mechanical properties of the composites showed poor tensile strength. Mercerization and weathering were found to impart toughness to the materials, with acetylation showing slightly less rigidity compared to other treatments on either the fiber or composites. The modifies polypropylene improved the tensile modulus and had the least toughness of the kapok/cotton reinforced composites. MAiPP reinforced with the plant fibers gave better flexural strength and the same flexural modulus at lower fiber content compared with glass fiber reinforced MAiPP.

Gassan et al. [11] studied the effectiveness of MAH-PP copolymers (graft copolymer of PP and maleic anhydride) as coupling agents in jute-polypropylene composites. The fiber treatment time and the MAH-PP concentration influenced the mechanical properties of the composites. Flexural strength of the composites with MAH-PP treated fibers was higher than that of unmodified fibers, and increased with fiber loading. The cyclic-dynamic values at an increasing load indicated that the coupling agent reduces the progress of damage. Dynamic strength (dynamic failure stress at load increasing test) of the MAH-PP modified composites is therefore raised by about 40%. SEM investigations confirm that the increase in properties is caused by improved fiber-matrix adhesion. There was less inclination for fibers to pull out of the matrix.

Herrera-Francoand et al [17] studied the mechanical behavior high density polyethylene (HDPE) reinforced with continuous henequen fibers (Agave fourcroydes) was studied. Fiber-matrix adhesion was promoted by fiber surface modifications using an alkaline treatment and a matrix preimpregnation together with a silane coupling agent. The use of the silane coupling agent to promote a chemical interaction, improved the degree of fibrematrix adhesion. However, it was found that the resulting strength and stiffness of the composite depended on the amount of silane deposited on the fiber. A maximum value for the tensile strength was obtained for a certain silane concentration but when using higher concentrations, the tensile strength did not increase. Using the silane concentration that resulted in higher tensile strength values, the flexural and shear properties were also studied. The elastic modulus of the composite did not improve with the fiber surface modification. The elastic modulus, in the longitudinal fiber direction obtained from the tensile and flexural measurements were compared with values calculated using the rule of mixtures. It was observed that the increase in stiffness from the use of henequen fibers was approximately 80% of the calculated values. The increase in the mechanical properties ranged between 3 and 43%, for the longitudinal tensile and flexural properties, whereas in the transverse direction to the fiber, the increase was greater than 50% with respect to the properties of the composite made with untreated fiber composite. In the case of the shear strength, the increase was of the order of 50%. From the failure surfaces it was observed that with increasing fiber matrix interaction the failure mode changed from interfacial failure to matrix failure.

CHAPTER III

EXPERIMENT

3.1 Materials and Reagents

3.1.1 High-density Polyethylene

Commercial-available high-density polyethylene (HDPE) (H6007 JU-P lot 6A 180315) having melt flow index of 7.5 was supplied by Thai Polyethylene Co., Ltd.

Table 3.1 Properties of high-density polyethylene

Properties	Unit	Testing Method	H6007JU
Melt flow index	g/10 s	ASTM D1238	7.5
Density	g/cm^3	ASTM D1505	0.967
Tensile strength	kg/cm^2	ASTM D638	310
Elongation at break	%	ASTM D 638	220
Flexural modulus	kg/cm^2	ASTM D 790	>650
Impact strength	kg-cm/cm	ASTM D256	13,500
Hardness, SHORD D	-	ASTM D2240	68

3.1.2 Nonwoven Fabric Manufacturing Waste

Medical gown nonwoven fabric manufacturing waste composing of poly(ethylene terephthalate) and cotton fibers was supplied by Mölnycke Health Care (Thailand) Limited.

3.1.3 Reagents

1) Maleic anhydride, GR grade was purchased from Fluka.
2) Sodium hydroxide, AR grade was purchased from Ajex Fine Chem.
3) 98% Hydrochloric acid, AR grade was purchased from J.T Beker.

3.2 Apparatus and Equipment

1) Compression molding machine
2) Grinding machine, Misubishi electric Co., Ltd.
3) Weighing balance
4) Cutting machine, Yasuda
5) Universal testing machine: LLOYD 100 KN, Intro Enterprise Co., Ltd.
6) Universal testing machine: LLOYD 500, Intro Enterprise Co., Ltd.
7) Impact testing machine : Zwick 5102
8) FT-IR spectrometer : Perkin Elmer System 2000-FT-IR
9) Scanning electron microscope : JSM-6400

3.3 Methodology

The flow chart of the entire experimental procedure is shown below in Figure 3.1.

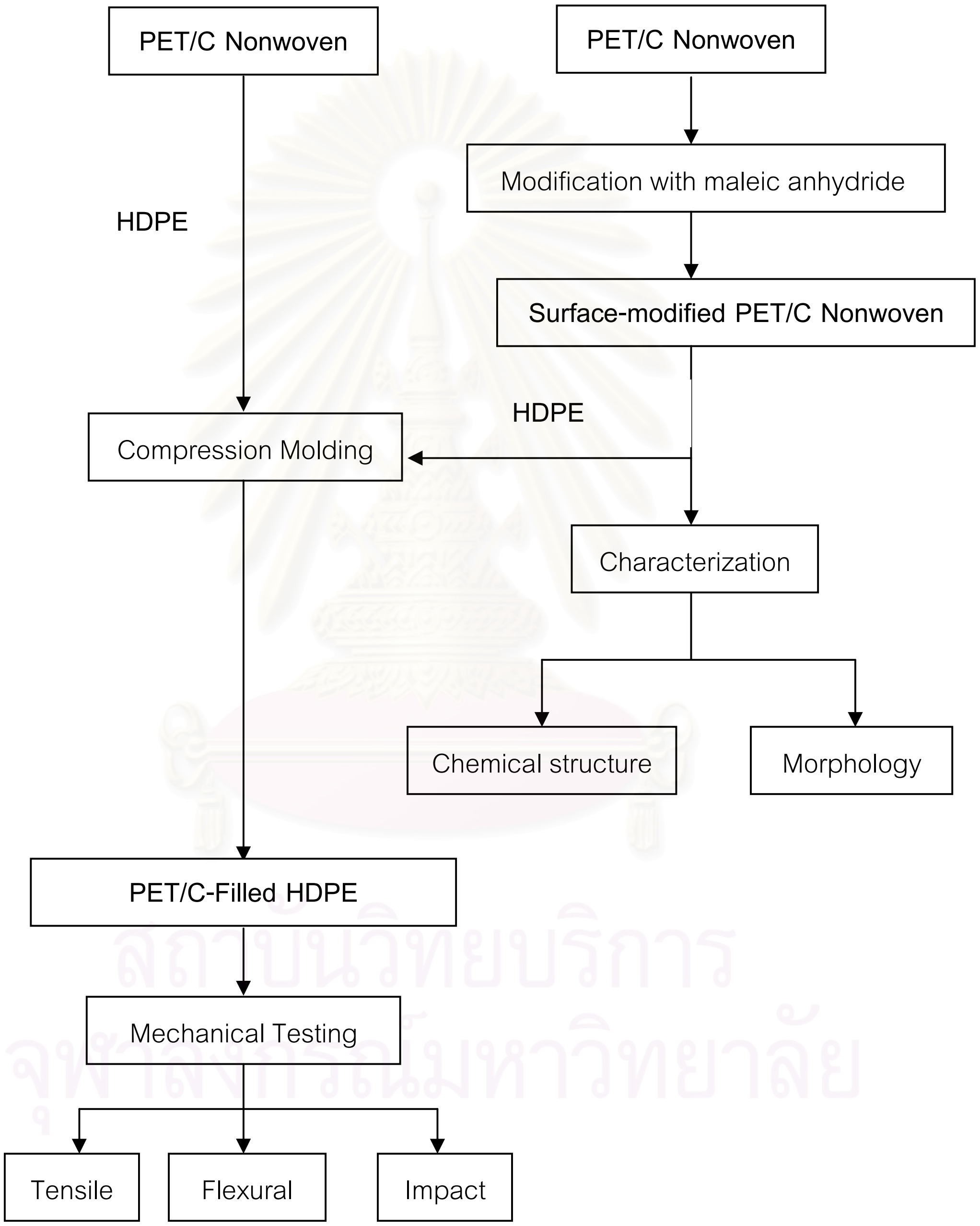


Figure 3.1 Flow chart of experimental procedure

3.4 Experimental Procedure

3.4.1 Modification of Fabric Waste

1) The fabric waste was cut into small pieces and then weighed in order to calculate the amounts of sodium hydroxide and maleic anhydride which should be used.

2) Aqueous solution of sodium hydroxide was prepared in a 5,000 cm^3 beaker. The cut fabric waste was put and stirred in this solution at speed of 1100 rpm at 50°C and maintained for 30 minutes.

3) Maleic anhydride was slowly added and the mixture was stirred at 60°C. In order to study the effects of modification conditions on mechanical properties of filled HDPE, the amount of maleic anhydride was varied from 5, 10 to 15 %w/w of the fabric waste and the modification time was varied from 2, 3 to 4 hours

4) The mixture was neutralized with hydrochloric acid solution. After that, the fabric waste was collected, rinsed with distilled water and dried at 70°C for 24 hours.

3.4.2 Characterizations of Modified and Unmodified Fabric Wastes

3.4.2.1 Chemical Structure

Chemical structures of modified and unmodified fabric wastes were identified using a Perkin Elmer System 2000 FT-IR Spectrometer as shown in Figure 3.1. About 2 mg of fiber were availed from the fabric waste and ground into powder. The powdered material was then mixed with potassium bromide (KBr) and pressed into a small disc having a thickness of 1 mm.

Figure 3.2 FT-IR spectrometer

3.4.2.2 Morphology

JSM-6400 scanning electron microscope as shown in Figure 3.2 was used to study the surfaces of unmodified and modified fabric wastes. Prior to the analysis, the samples were coated with Au/Pd alloy by means of a Polaron sputtering apparatus.

Figure 3.3 Scanning electron microscope: JSM-6400

3.4.3 Preparation of Fabric Waste-filled High-density Polyethylene

1) Modified and unmodified fabric wastes were mixed with HDPE using fabric waste 5, 10, 15, and 20% respectively. The variation was done in order to study the effect of the amount of fabric waste on mechanical properties of filled HDPE.

2) Each mixture was placed in a steel mold whose dimension is 150 mm x 150 mm x 4 mm. It was then compressed using compression molding machine as shown in Figure 3.3 using a pressure of 100 MPa at 190°C for 5 minutes. Finally, the compressed sheet was allowed to cool down at room temperature for 30 minutes.

3) The product was cut by cutting machine and it was ground into smaller size by grinding machine.

4) The product from 3) was recompressed using the same compression molding machine and compression condition. Finally, the compressed sheet was allowed to cool down at room temperature for 30 minutes.

5) The product was cut into the standard specimens according to ASTM test methods using cutting machine.

Figure 3.4 Compression molding machine

3.4.4 Mechanical Testing of Fabric Waste-filled High-density Polyethylene

The following mechanical properties of HDPE filled with modified and unmodified fabric wastes were measured according to ASTM test methods.

3.4.4.1 Tensile Properties

Tensile properties including tensile strength, %elongation at break and Young's modulus of HDPE filled with modified and unmodified fabric wastes were determined based on ASTM D638-90 using Universal Testing Machine as shown in Figure 3.5

Figure 3.5 Universal testing machine: LLOYD 100 KN

The test specimen (Type IV) dimension is presented in Figure 3.6.

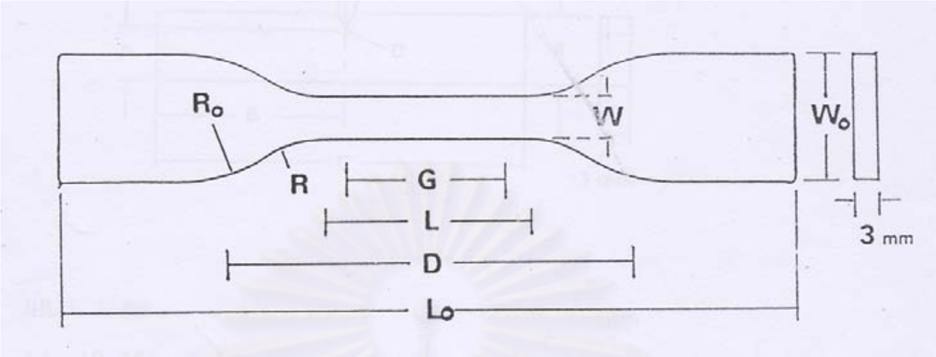


Figure 3.6 Schematic of tensile test specimen (Type IV)

W:	6 mm	W_0:	19 mm	G:	25 mm	R:	14 mm
L:	33 mm	L_0:	115 mm	D:	65 mm	R_0:	25 mm

The tensile testing conditions were as follows:

Temperature:	25	°C
Relative humidity:	50	%
Load cell	1000	N
Speed of testing:	5	mm/min
Distance between grips:	64	mm
Gage length:	25	mm

3.4.4.2 Flexural Properties

Flexural properties including flexural strength and flexural modulus of HDPE filled with modified and unmodified fabric wastes were determined based on ASTM D790-81 using Universal testing machine as shown in Figure 3.7.

Figure 3.7 Universal testing machine: LLOYD 500

The test specimen (Method I) dimension is presented in Figure 3.8.

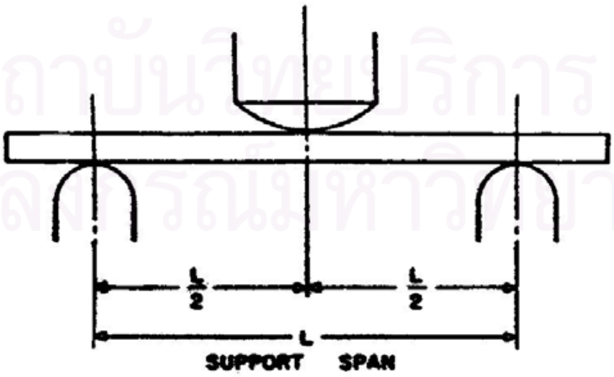


Figure 3.8 Schematic of flexural test specimen (Three Point Bending)

The flexural testing conditions were as follows:

Depth:	3.2	mm
Width:	25	mm
Length:	80	mm
Support Span	50	mm
Test speed	100.00	mm/min

3.4.4.3 <u>Impact Strength</u>

Impact strength of HDPE filled with modified and unmodified fabric wastes were determined based on ASTM D256-90b using impact testing machine as shown in Figure 3.9.

Figure 3.9 Impact testing machine

The impact test specimen (Izod-type) is shown in Figure 3.10.

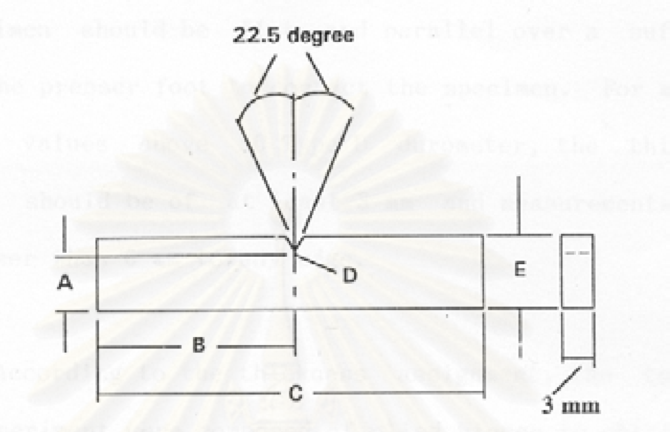


Figure 3.10 Schematic of Izod typed test specimen.

Unit: mm

A: 10.16 ± 0.05

C: 63.50 max, 53.50 min

B: 32.00 max, 31.50 min

D: 0.25 ± 0.05

E: 12.70 ± 0.15

The machine parameters and testing conditions of impact test were listed below:

Temperature:	25	°C
Relative humidity:	50	%
Pendulum capacity:	11.0	J
Depth of specimen:	10.16	mm

CHAPTER IV

RESULTS AND DISCUSSION

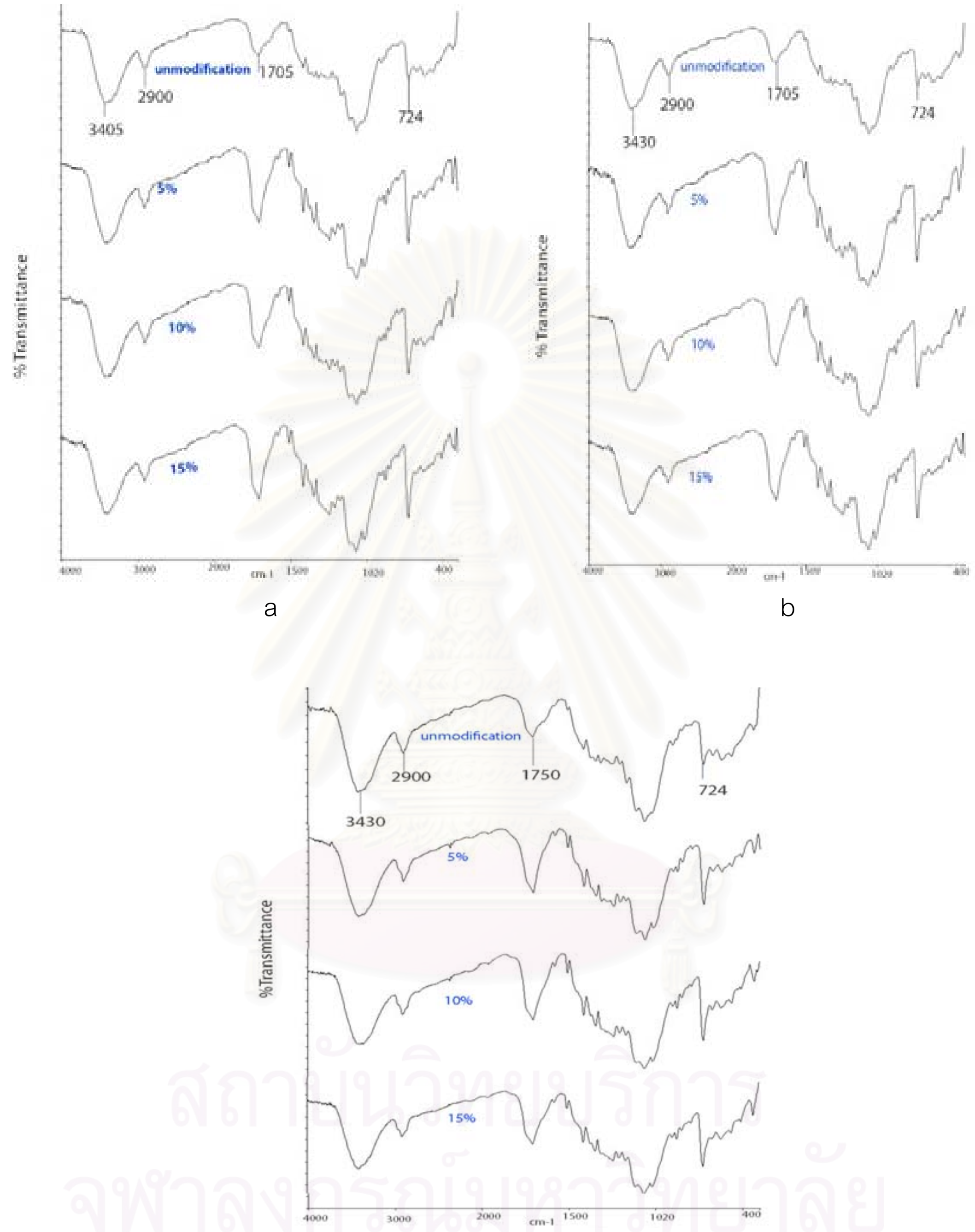
The effects of surface modification of medical gown nonwoven fabric manufacturing waste used as a filler in high density polyethylene (HDPE) and also its content on mechanical properties of filled HDPE were studied. The samples of HDPE filled with unmodified and maleic anhydride modified fabric wastes were prepared by compression molding. The samples were tested for the following properties tensile strength, % elongation, Young's modulus, izod impact strength, flexural strength, deformation at maximum load and flexural modulus. Chemical structures and morphology of unmodified and modified fabric wastes were also characterized. The results are presented as follows:

4.1 Characterizations of Modified and Unmodfied Fabric Wastes

Fabric waste was modified by esterification with maleic anhydride at 5, 10 and 15%w/w of the fabric waste using modification times of 2, 3 and 4 hours. FT-IR spectroscopy was used to determine the chemical structure of esterified fabric waste while scanning electron microscopy was used to investigate its surface morphology. The results are compared to those of unmodified fabric waste.

4.1.1 Chemical Structure

FT-IR spectra of unmodified and modified fabric wastes are shown in Figure 4.1.



a b

c

Figure 4.1 FT-IR spectra of unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.

All spectra of unmodified fabric waste shown in Figure 4.1 exhibit the characteristic peaks of polyester and cotton fibers which are the components of medical gown nonwoven fabric. The characteristic broad peak between 958-1190 cm^{-1} is attributed to C-O stretching of ether bond. Another strong broad peak corresponding to O-H stretching hydroxyl group appears at 3000-3600 cm^{-1}. Small peak at 1705 cm^{-1} corresponds to C=O stretching of carbonyl group.

From Figure 4.1, it can be seen that all spectra of maleic anhydride-modified fabric waste show an increase in intensity of the peak corresponding to carbonyl bond stretching at 1705 cm^{-1} and the appearance of the peak attributed to H-C=C-H bending at 724 cm^{-1}. This observation is a result of the incorporation of maleic anhydride segment to cellulose via esterification as shown in Figure 4.2.

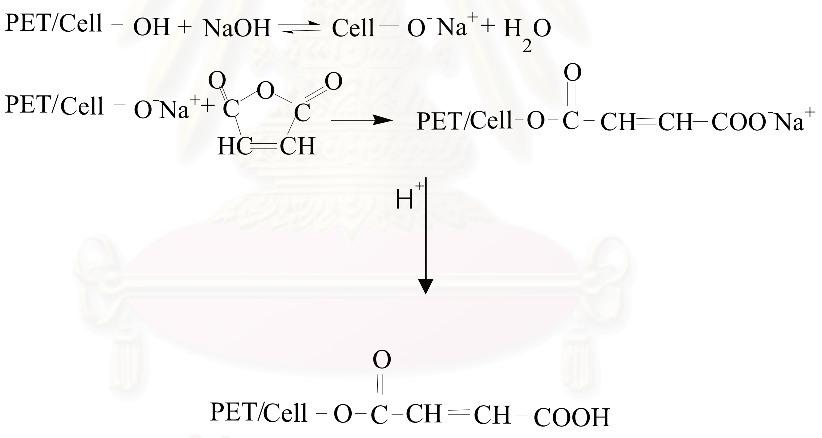


Figure 4.2 Esterification of cellulose and maleic anhydride

4.1.2 Morphology

At 1000X magnification, the SEM micrograph in Figure 4.4 shows a smooth fiber surface of unmodified fabric waste. On the other hand, the fiber surfaces of modified fabric wastes shown in Figures 4.5 - 4.7 are rougher and disoriented caused by the incorporation of maleic anhydride segments. However, there are pores in some areas and some parts of the fiber are missing. These indicate the degradation of the fiber. This degradation was possibly caused by acid hydrolysis of cellulose as shown in Figure 4.3 which competed with esterification during the modification. As the amount of maleic anhydride and/or reaction time increase, the degradation of the fiber increase. This suggests that increasing the amount of maleic ahnydride and/or reaction time favors the degradation reaction.

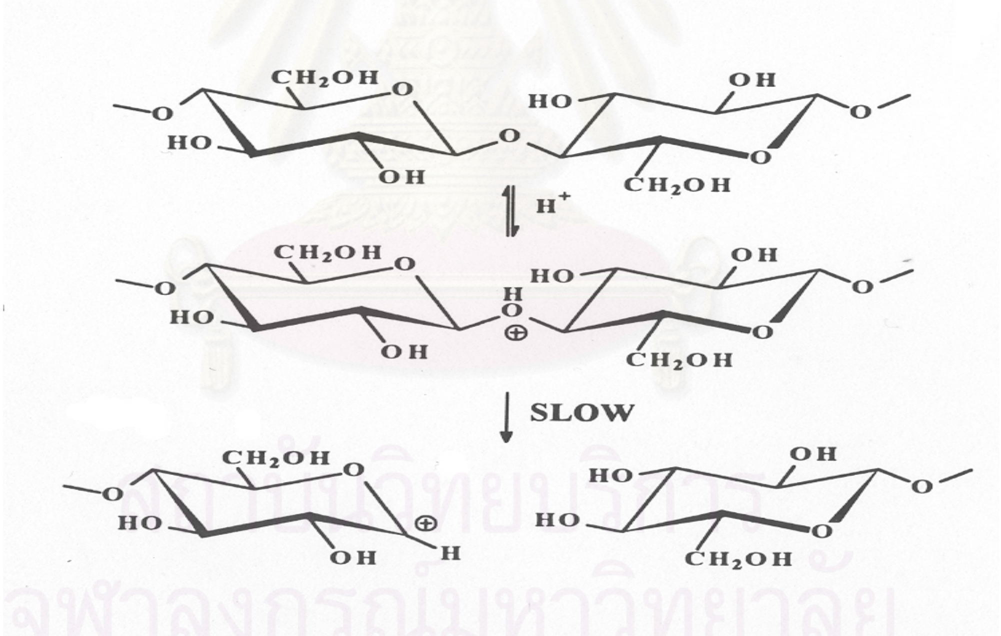


Figure 4.3 Acid hydrolysis of cellulose [18]

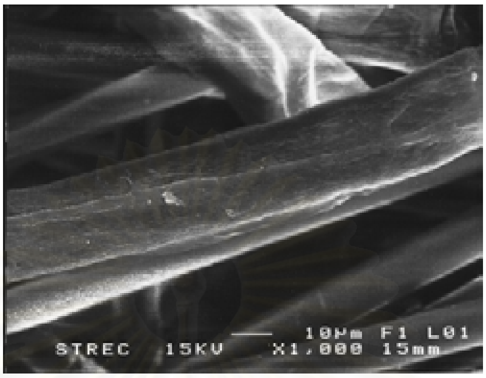
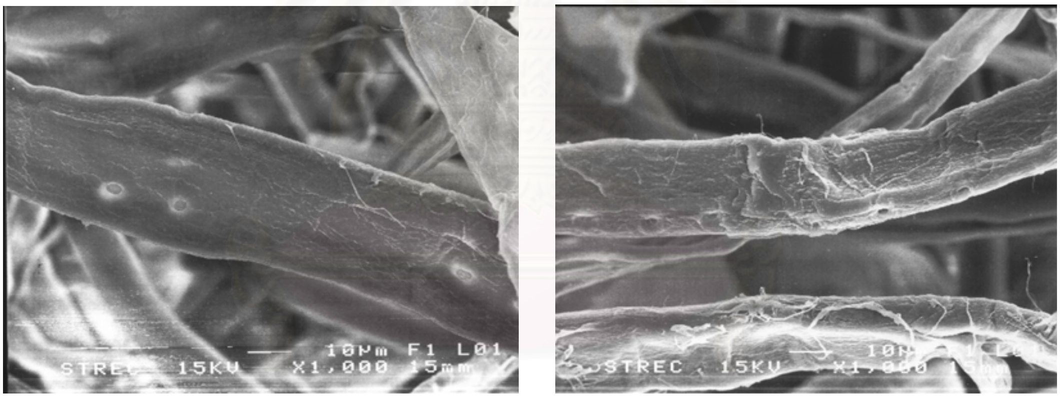
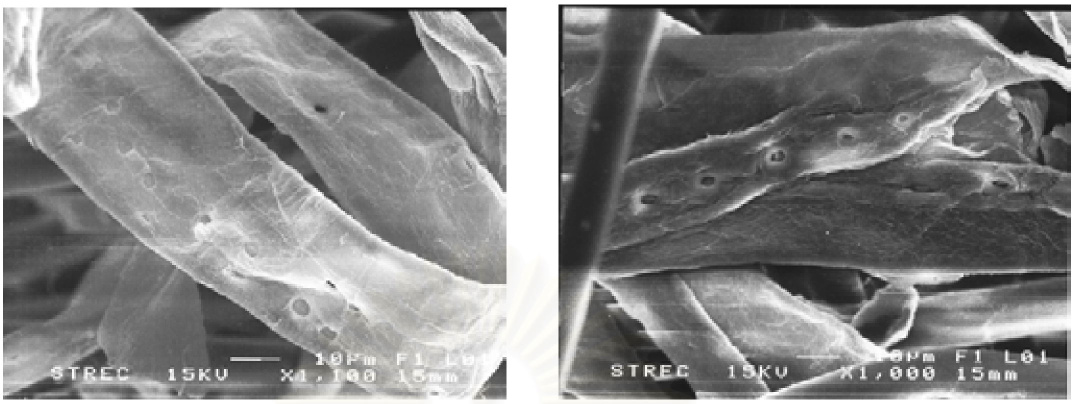


Figure 4.4 SEM micrograph of the fiber surface of unmodified fabric waste.



5% 15%

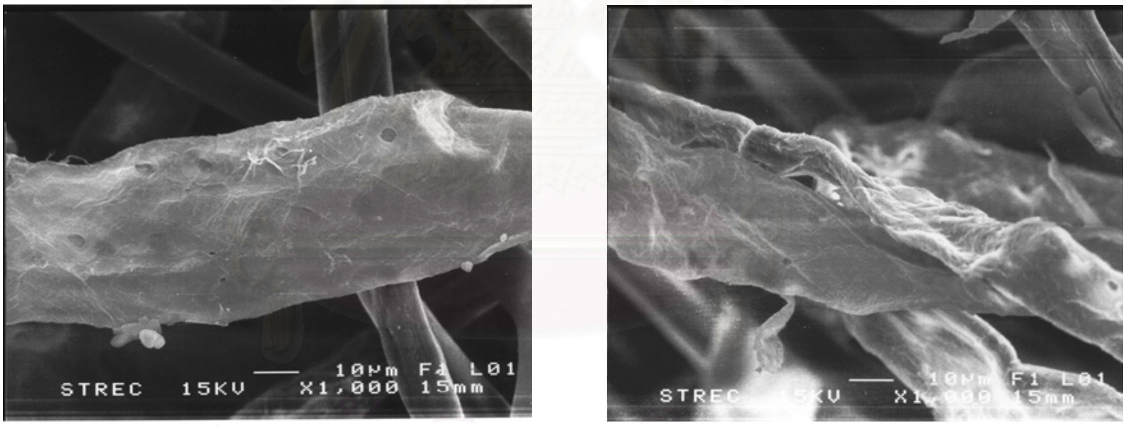
Figure 4.5 SEM micrograph of the fiber surfaces of fabric wastes modified with maleic anhydride 5 and 15%w/w using modification time of 2 hours.



5%

15%

Figure 4.6 SEM micrograph of the fiber surfaces of fabric wastes modified with maleic anhydride 5 and 15%w/w using modification time of 3 hours.



5%

15%

Figure 4.7 SEM micrograph of the fiber surfaces of fabric wastes modified with maleic anhydride 5 and 15%w/w using modification time of 4 hours.

4.2 Appearances of Unfilled and Fabric Waste-filled High-density Polyethylene

Tables 4.1-4.4 show that the appearances of all HDPEs filled with unmodified and modified fabric wastes are similar. Due to its green color, the fabric waste is clearly seen distinguishing from opaque white HDPE.

Table 4.1 HDPEs filled with unmodified fabric waste

Maleic anhydride	% fabric waste				
	0	5	10	15	20
0%					

Table 4.2 HDPEs filled with fabric wastes modified by maleic anhydride for 2 hours

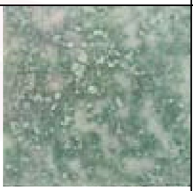
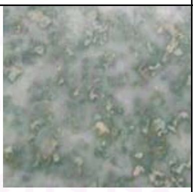
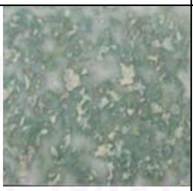
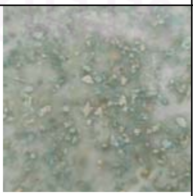
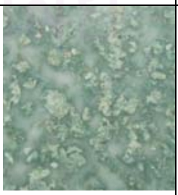
Maleic anhydride	% fabric waste				
	0	5	10	15	20
5%					
10%					
15%					

Table 4.3 HDPEs filled with fabric wastes modified by maleic anhydride for 3 hours

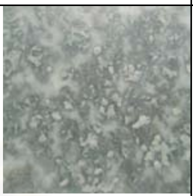
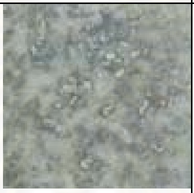
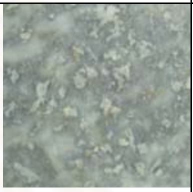
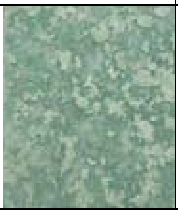
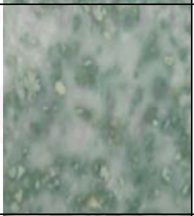
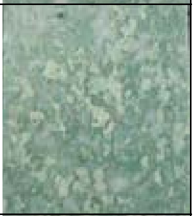
Maleic anhydride	% fabric waste				
	0	5	10	15	20
5%					
10%					
15%					

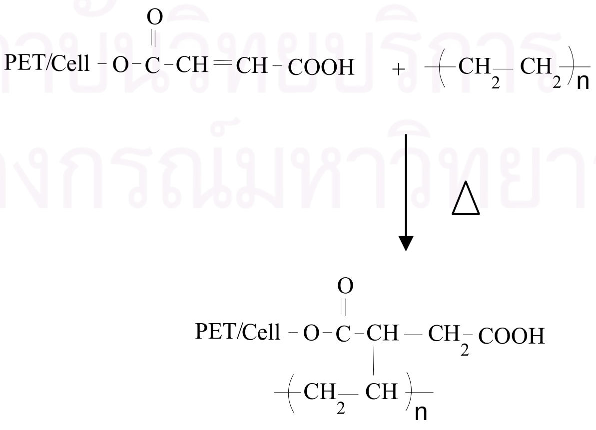
Table 4.4 HDPEs filled with fabric wastes modified by maleic anhydride for 4 hours

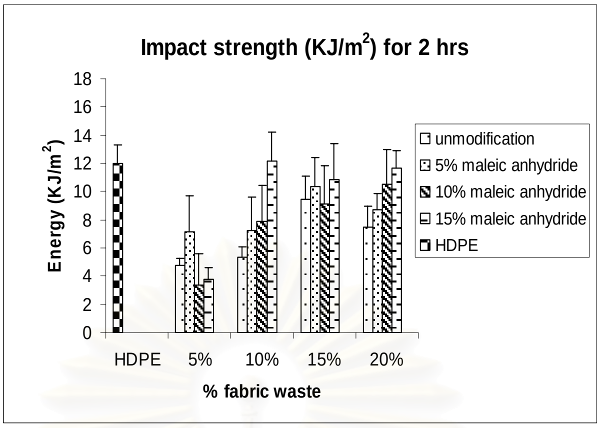
Maleic anhydride	% fabric waste				
	0	5	10	15	20
5%					
10%					
15%					

4.3 Mechanical Properties of Appearances of Unfilled and Fabric Waste-filled High-density Polyethylene

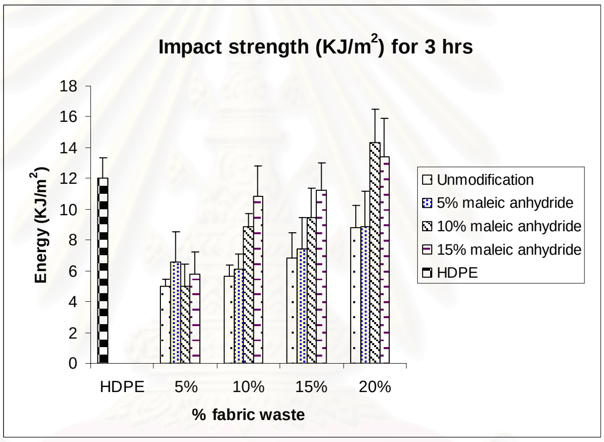
4.3.1 Impact Strenght

It can be seen from Figure 4.8 that impact strength of HDPEs filled with modified fabric wastes are generally higher than those of HDPEs filled with unmodified fabric waste and it is clearly seen that impact strength of both HDPEs generally increases with increasing filler content from 5 to 20 %. At the modification time of 2 hours and the same amount of fabric waste content, impact strength of filled HDPEs shows tendency to increase as the degree of modification increases as shown in Figure 4.8a. This may be caused by higher interfacial adhesion between the fabric and HDPE due to the reaction that possibly occurred as shown below. Therefore, the impact load transfer between the two components was enhanced. On the other hand, when modification time of 3 and 4 hours were used, impact strength of filled HDPEs prepared from the fabric modified with 15% maleic anhydride was lower than those of filled HDPEs prepared from the fabric modified with 5 and 10% maleic anhydride as shown in Figures 4.8b and 4.8c. This may be a result of the degradation of cellulose fibers caused by acid hydrolysis which is favorable at high amount of maleic anhydride and long reaction time as was previously discussed.

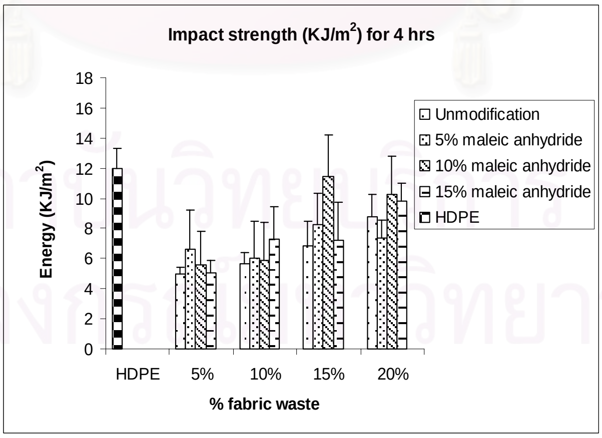




a



b



c

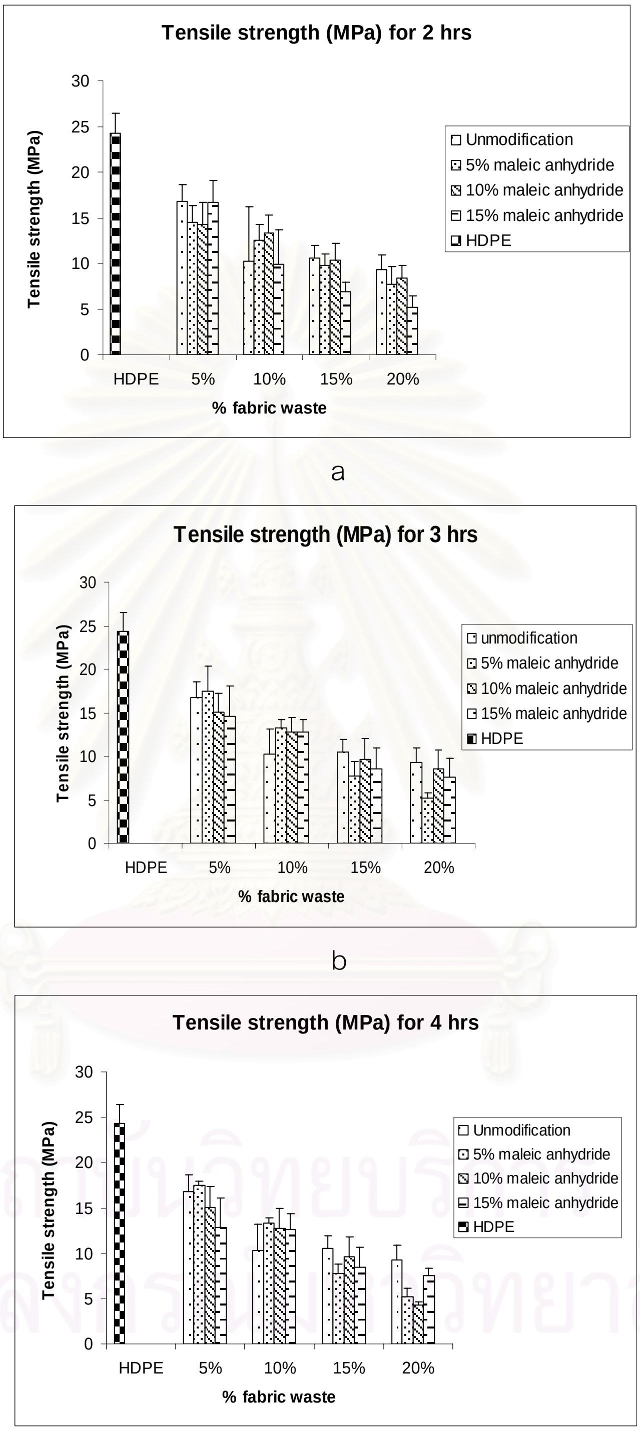
Figure 4.8 Impact strength of HDPEs filled with unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.

4.3.2 Tensile Properties

It can be seen from Figure 4.10 that tensile strength of HDPEs filled with unmodified and modified fabric waste generally decreases with increasing the filler content from 5 to 20%. At the same modification time and the same amount of fabric waste content, tensile strength of all HDPEs was almost comparable. The effect of degree of modification was not clearly observed since the destruction of the samples did not occur between interface of fabric waste and HDPE matrix but occurred at fabric waste. This may be because the fabric waste was not uniformly distributed in HDPE matrix as shown in Tables 4.1-4.4. Consequently, there were some parts of the sample which only the fabric waste was presented as shown in Figure 4.9. Since nonwoven fabric waste is easily to tear apart, these areas containing only fabric waste were the defects of the samples which can be easily destroyed as tensile load was applied. When considering the effect of reaction time on this property, as same as the effect of degree of modification, it was not clearly shown due to the same reason.

% Elongation and Young's modulus of unfilled and filled HDPEs were shown in Figures 4.11 and 4.12. The effects of the amount of maleic anhydride and the reaction time were not also clearly seen resulted from the destruction at fabric waste as previously discussed.

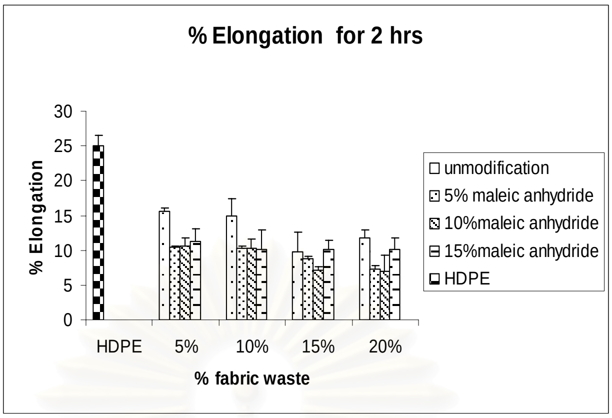
Figure 4.9 A sample of filled HDPE after subjecting to tensile test


Tensile strength (MPa) for 2 hrs

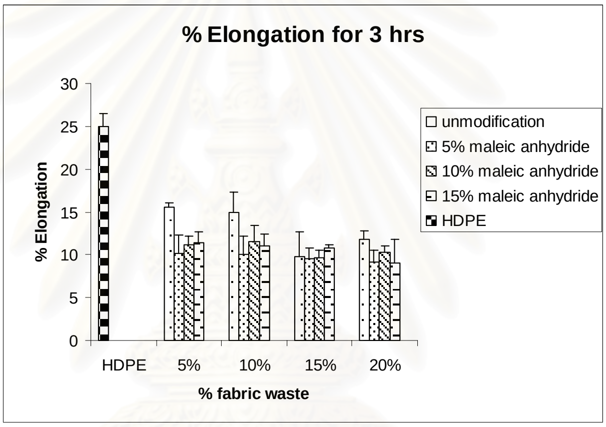
Tensile strength (MPa) for 3 hrs

Tensile strength (MPa) for 4 hrs

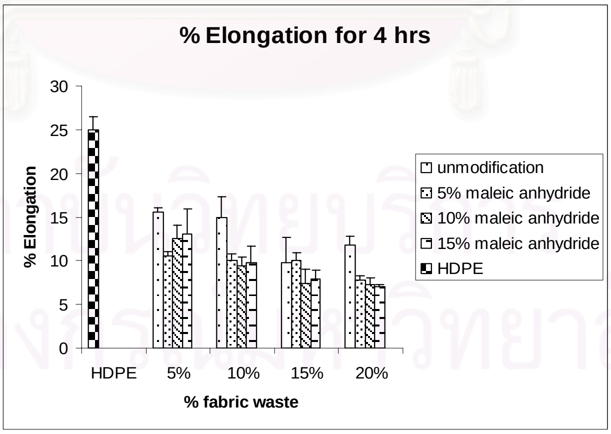
Figure 4.10 Tensile strength of HDPEs filled with unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.



a

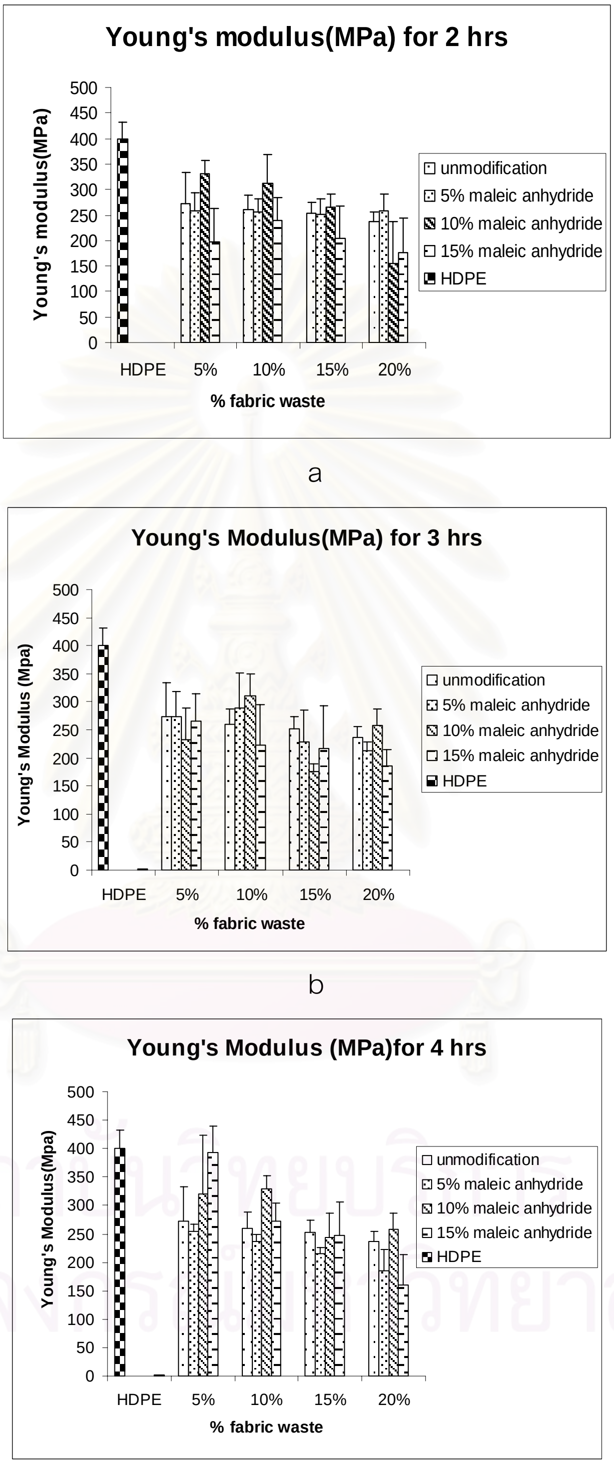


b



c

Figure 4.11 % Elongation of HDPEs filled with unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.



a

b

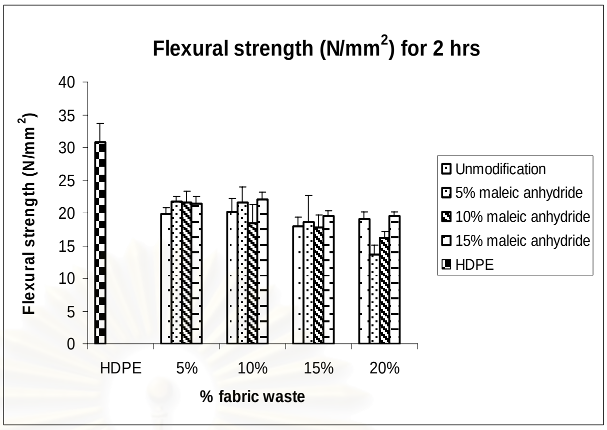
c

Figure 4.12 Young’s Modulus of HDPEs filled with unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.

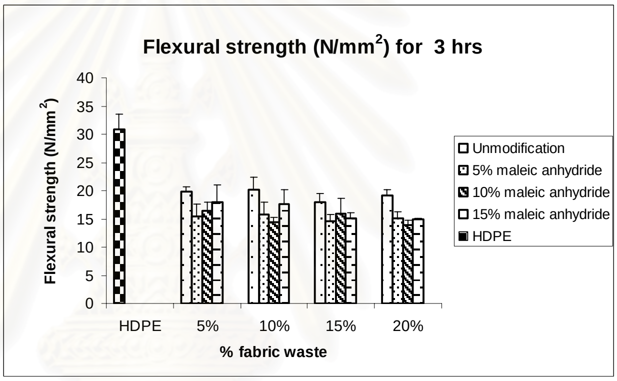
4.3.3 Flexural properties

It can be seen from Figure 4.14 that flexural strength of HDPEs filled with unmodified and modified fabric waste are comparable even though the filler content increases from 5 to 20 %. This suggests that the amount of fabric does not affect this property; In addition this property is not affect by the degree of modification. However, it was found that the reaction time shows significant effect on flexural strength. From Figures 4.14a to 4.14c, as the reaction time increases from 2 to 4 hours, flexural strength of all samples generally decreases. This may be a result of the degradation of cellulose fibers caused by acid hydrolysis which is favorable at long reaction time as was previously discussed. This results in lower molecular weight cellulose fibers and also less interfacial adhesion between fabric waste and HDPE matrix as shown in Figure 4.13. In contrast to flexural strength, deformation at maximum load of the samples increases with increasing reaction time as shown in Figure 4.15. This is due to the same reason. Because of less interfacial adhesion between the two components, therefore, it is easier for polymeric molecules to move apart from each other. As a result, flexural modulus of these samples also increases with decreasing the reaction time as shown in Figure 4.16.

Figure 4.13 A sample of filled HDPE after subjecting to flexural test



a



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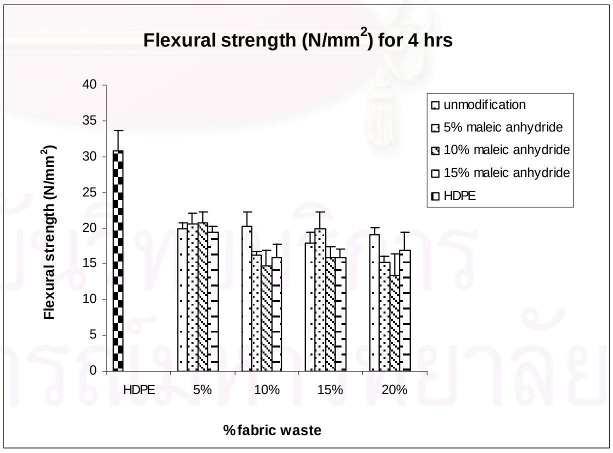
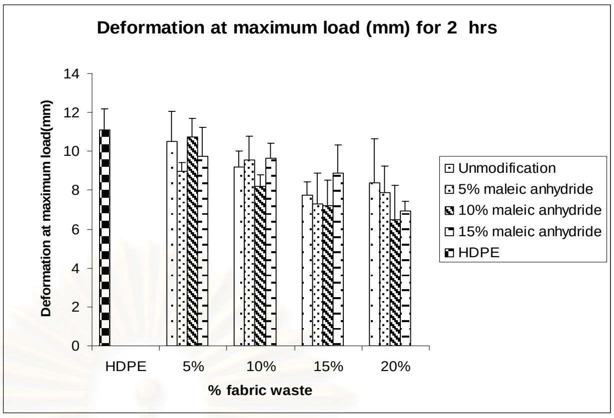
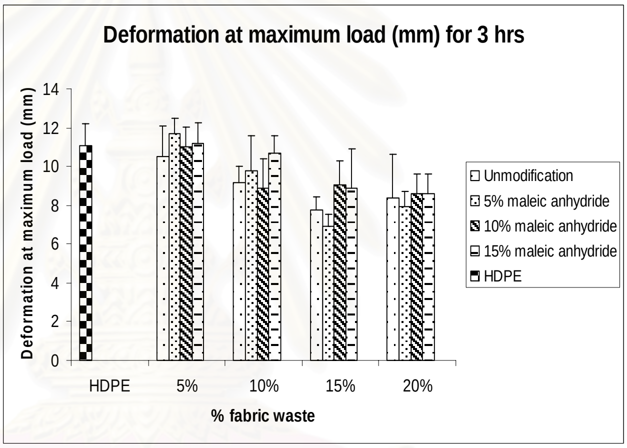


c

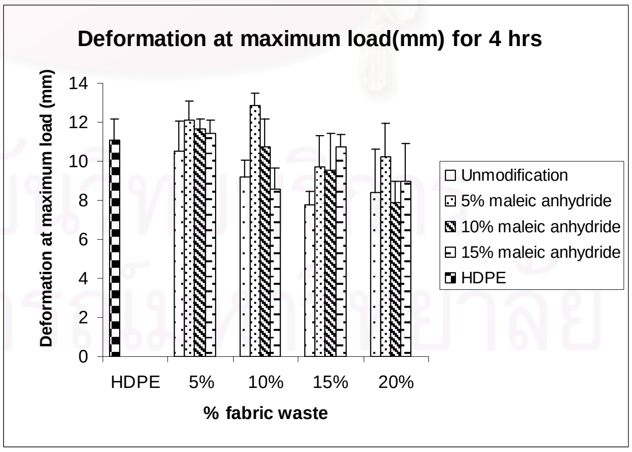
Figure 4.14 Flexural strength of HDPEs filled with unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.



a



b



c

Figure 4.15 Deformation at maximum load of HDPEs filled with unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.

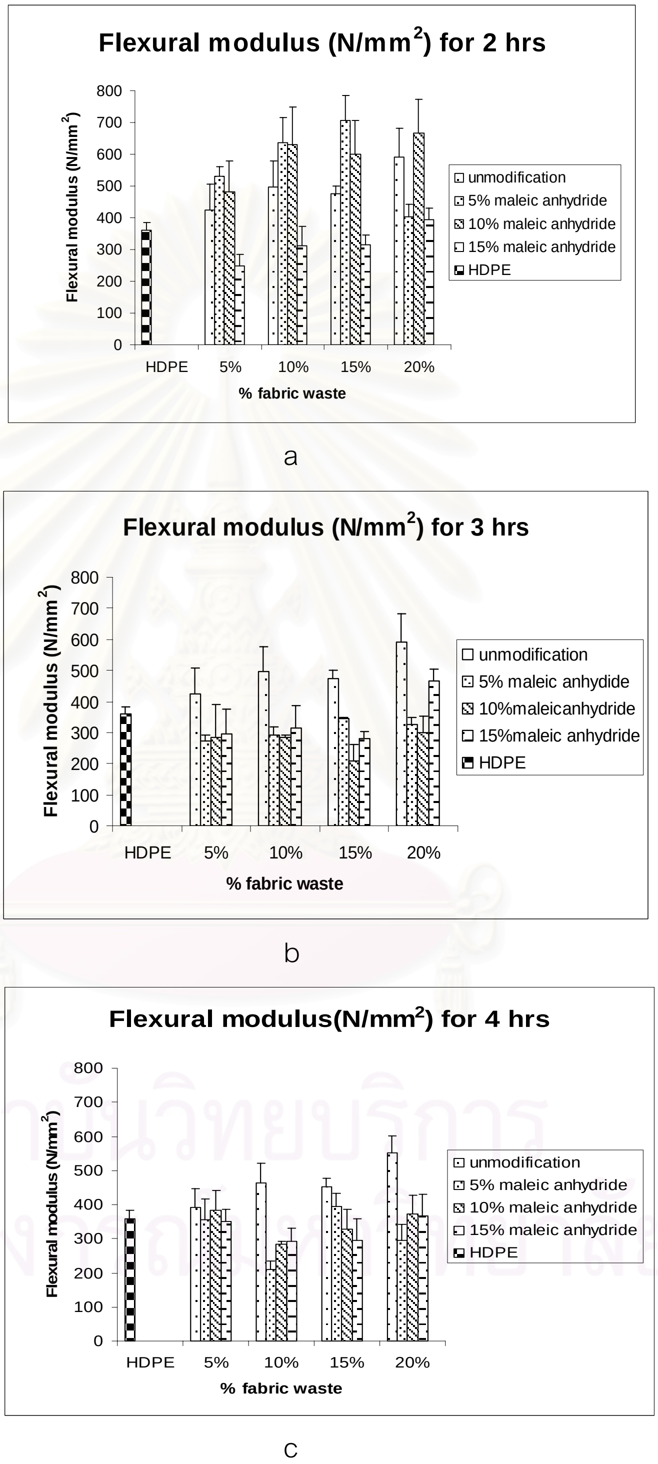


Figure 4.16 Flexural modulus of HDPEs filled with unmodified fabric waste and fabric wastes modified with maleic anhydride 5, 10 and 15%w/w using modification times of (a) 2, (b) 3 and (c) 4 hours.

From Figures 4.8 to 4.16, it can be seen that most mechanical properties of filled HDPE are lower than those of unfilled HDPE. This is a normal phenomenon of non-reinforcing filler [9,15]. However, at some modification conditions, some mechanical properties of filled HDPEs are slightly higher or comparable to those of pure HDPE. This suggests that surface-modified medical gown nonwoven fabric manufacturing waste can be used as filler for HDPE.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Nonwoven fabric waste from medical gown–manufacturing process was recycled as filler for high–density polyethylene (HDPE). Before nonwoven fabric waste were mixed with HDPE, this fabric waste was modified with maleic anhydride at 5, 10 and 15 %w/w using modification time of 2,3 and 4 hour. There sample were prepared by compression molding at 190°C. The fabric waste mixed HDPE were 5,10,15 and 20 %respectively. Conclusions of this work are as follows:

1. The fiber surfaces of fabric waste modified with maleic anhydride were characterized by scanning electron microscopy. SEM micrographs showed that fiber surface of modified fabric waste was rough and disoriented caused by the incorporation of maleic anhydride segments. They also revealed the degradation of the fiber caused by acid hydrolysis at longer reaction time and/or higher amount of maleic anhydride.
2. FT-IR spectra of modified fabric waste exhibited strong C=O stretching of carbonyl groups at 1705 cm^{-1} and H-C=C-H bending at 724 cm^{-1}. This confirmed the incorporation of maleic anhydride segment to cellulose fiber of the fabric waste.
3. Impact strength of filled HDPE was affect by the amount of fabric waste, the degree of modification of fabric waste and the reaction time. It was found that impact strength increased with increasing the amount of fabric waste. Due to acid hydrolysis which was favorable than esterification at longer reaction time and/or higher amount of maleic anhydride; consequently, impact strength of filled HDPE prepared at these conditions were lower than those prepared with other conditions.
4. Tensile properties of filled HDPE were only affected by the amount of fabric waste. It was found that tensile strength and % elongation decreased while Young's modulus increased when increasing the amount of fabric waste.

5. Flexural properties of filled HDPE were only affected by the reaction time. It was found that flexural strength and flexural modulus decreased while deformation increased with increasing the reaction time

The above results indicated that interfacial adhesion between HDPE matrix and polyester/cotton (PET/C) filler was increased by surface modification of cotton of fabric waste maleic anhydride. The results also suggested that HDPE filled with 10% of fabric waste treated by 10% of maleic anhydride for 2 hours exhibited overall mechanical properties better than HDPE filled with unmodified fabric waste or those modified with other conditions. This suggests that surface-modified medical gown nonwoven fabric manufacturing waste can be used as filler for HDPE.

5.2 Recommendations

As the above results indicated that surface modification of cotton in fabric waste can enhance interfacial adhesion between HDPE matrix and polyester/cotton (PET/C) filler, therefore, further experiments can also be studied by using these results as reference. These experiments can possibly be done by changing the type of modifying agent or changing polymer matrix, etc.

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APPENDICES

APPENDIX A

Mechanical Properties of Product

1.Impact Strength of Product

Table 1 Impact strength of HDPE filled with unmodified fabric waste

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	4.59	5.63	5.97*	8.39
2	12.04	4.16*	4.13*	6.78	7.77*
3	13.02	4.49	6.67	10.29	11.85
4	15.24	5.47	5.31	6.82	9.25
5	12.25	5.29	5.06	7.69	9.81
Average	12.01	4.96	5.67	7.9	9.83
SD	1.30	0.49	0.71	1.65	1.47

Table 2 Impact strength of HDPE filled with fabric waste modified with 5%w/w of maleic anhydride using modification time of 2 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	6.38	6.21	9.32	9.94
2	12.04	10.30	4.12*	16.52*	11.53
3	13.02	8.95	11.47	9.41	3.97*
4	15.24	6.16	9.90	9.24	11.69
5	12.25	3.93*	4.48	7.10	6.50
Average	12.01	7.95	8.02	8.78	9.92
SD	1.30	2.02	3.23	1.12	2.41

Table 3 Impact strength of HDPE filled with fabric waste modified with 10%w/w of maleic anhydride using modification of time 2 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	2.92	12.13	4.98*	14.43
2	12.04	2.75*	12.41	11.68	6.53
3	13.02	3.84	7.01	6.48	14.96
4	15.24	3.55	3.19*	5.75	3.32*
5	12.25	3.78	4.93	16.70	13.26
Average	12.01	3.52	9.12	10.15	12.30
SD	1.30	0.42	3.73	5.01	3.91

Table 4 Impact strength of HDPE filled with fabric waste modified with 15%w/w of maleic anhydride using modification time of 2 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	5.09	5.28	16.96	10.87
2	12.04	3.02*	4.95*	6.94	8.32*
3	13.02	3.92	4.94	11.37	12.84
4	15.24	3.62	7.55	12.28	15.28
5	12.25	3.43	6.46	6.52*	11.11
Average	12.01	4.02	6.06	11.89	12.53
SD	1.30	0.74	1.18	4.12	2.04

Table 5 Impact strength of HDPE filled with fabric waste modified with 5 %w/w of maleic anhydride using modification time of 3 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	14.29	24.6*	3.49	9.79
2	12.04	5.7	5.75	6.48	10
3	13.02	5.04*	6.73	5.1*	3.38
4	15.24	9.5	7.08	8.76	11.63
5	12.25	6.06	4.96	9.47	3.96*
Average	12.01	6.58	6.13	7.45	8.85
SD	1.30	1.99	0.96	2.02	3.35

Table 6 Impact strength of HDPE filled with fabric waste modified with 10%w/w of maleic anhydride using modification time of 3 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	5.06	10.38	20.09	8.86
2	12.04	7.03	5.60*	19.47	5.53*
3	13.02	4.11	11.27	6.68*	9.95
4	15.24	3.37*	6.95	8.95	7.87
5	12.25	3.85	9.27	8.75	8.9
Average	12.01	5.01	8.90	9.47	14.32
SD	1.30	1.44	0.85	1.87	2.2

Table 7 Impact strength of HDPE filled with fabric waste modified with 15 %w/w of maleic anhydride using modification time of 3 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	3.8	17.37*	14.53	13.05
2	12.04	5.51	8.91	12.25	10.25*
3	13.02	6.52	15.22	7.93	11.32
4	15.24	3.56*	9.23	5.83*	17.01
5	12.25	7.23	10	10.14	12.2
Average	12.01	5.77	10.84	11.21	13.39
SD	1.30	1.48	2.95	2.82	2.51

Table 8 Impact strength of HDPE filled with fabric waste modified with 5 % w/w of maleic anhydride using modification time of 4 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	6.48	3.32	7.27	15.52*
2	12.04	4.47	9.28	14.43*	6.06
3	13.02	3*	6.12	6.64	7.31
4	15.24	5.33	5.48	11.38	7.35
5	12.25	10.32	2.98*	7.63	8.87
Average	12.01	6.65	6.05	8.23	7.40
SD	1.30	2.58	2.4	2.13	1.14

Table 9 Impact strength of HDPE filled with fabric waste modified with 10 % w/w of maleic anhydride using modification time of 4 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	4.08	3.83	10.05	9.79
2	12.04	4.76	3.85	7.01*	9.31
3	13.02	4.18	8.89	15.54	13.86*
4	15.24	9.21	7	10.53	8.01
5	12.25	9.4*	9.97*	9.73	6.17
Average	12.01	5.55	5.89	11.46	10.24
SD	1.30	2.25	2.49	2.74	2.52

Table 10 Impact strength of HDPE filled with fabric waste modified with 15 %w/w of maleic anhydride using modification time of 4 hours

Sample No.	Impact Strength (KJ/m^2)				
	% fabric waste				
	0	5	10	15	20
1	10.21*	9.32*	6.11	6.82	10.81
2	12.04	5.63	3.79*	4.92*	9.72
3	13.02	4.38	7.29	10.9	10.58
4	15.24	4.32	10.27	5.8	5.19*
5	12.25	5.88	5.52	5.22	8.05
Average	12.01	5.05	7.30	7.19	9.79
SD	1.30	0.82	2.11	2.56	1.25

APPENDIX B

2. Flexural strength

Table 11 Flexural strength of HDPE filled with unmodified fabric waste

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	16.37*	24.31	19.84	22.58*
2	32.32	18.83	15.2*	16.37	18.89
3	26.02*	19.89	19.67	15.03*	17.77
4	31.25	19.89	20.73	17.1	19.39
5	33.31	20.9	20.17	18.27	20.24
Average	30.61	19.88	21.22	17.90	19.07
SD	2.82	0.84	2.11	1.51	1.03

Table 12 Flexural strength of HDPE filled with fabric waste modified with 5 % w/w of maleic anhydride using modification time of 2 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	23.02	15.53*	23.02	16.32
2	32.32	23.36	19.78	13.58	15.48
3	26.02*	21.96	22.3	19.33	16.65
4	31.25	18.55*	24.48	11.18*	14.58
5	33.31	22.13	25.48	25.7	18.5*
Average	30.61	21.8	21.51	18.56	16.74
SD	2.82	0.67	2.52	4.18	1.46

Table 13 Flexural strength of HDPE filled with fabric waste modified with 10 % w/w of maleic anhydride using modification time of 2 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	27.27	20.04	23.86*	25.31*
2	32.32	22.97	19.95	18.83	14.92
3	26.02*	14.42*	22.63	15.53	11.4
4	31.25	20.68	16.37	11.85	13.64
5	33.31	22.63	17.6*	18.83	15.59
Average	30.61	21.59	18.49	17.78	16.17
SD	2.82	1.81	2.78	1.91	0.99

Table 14 Flexural strength of HDPE filled with fabric waste modified with 15 % w/w of maleic anhydride using modification time of 2 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	20.23	21.68	19.05	19.45
2	32.32	21.74	22.46	19.05	19.22
3	26.02*	19.45*	30.73*	20.79	20.51
4	31.25	20.96	20.79	21.79*	21.63*
5	33.31	22.91	23.36	19.17	19.11
Average	30.61	21.46	22.07	19.52	19.57
SD	2.82	1.147	1.09	0.85	0.64

Table 15 Flexural strength of HDPE filled with fabric waste modified with 5 % w/w of maleic anhydride using modification time of 3 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	18.55	14.64	14.64	16.6
2	32.32	18.72*	13.63	12.68*	15.09
3	26.02*	15.26	15.81	16.21	14.92
4	31.25	13.63	7.88*	13.58	9.39*
5	33.31	14.53	18.83	13.63	13.8
Average	30.61	15.49	15.73	14.52	15.10
SD	2.82	2.14	2.25	1.23	1.15

Table 16 Flexural strength of HDPE filled with fabric waste modified with 10 %w/w of maleic anhydride using modification time of 3 hours

Sample of No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	22.97*	15.2	13.86	13.02*
2	32.32	16.37	11.9*	9.27*	14.85
3	26.02*	18.5	14.53	15.05	13.5
4	31.25	16.15	13.36	14.81	13.12
5	33.31	14.7	14.81	19.84	14.23
Average	30.61	16.43	14.48	15.89	13.93
SD	2.82	1.56	0.79	2.68	0.76

Table 17 Flexural strength of HDPE filled with fabric waste modified with 15 %w/w of maleic anhydride using modification time of 3 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	15.09	14.75	14.36	15.25
2	32.32	13.3*	14.53*	15.7	14.88
3	26.02*	19.17	19.78	13.19*	14.87
4	31.25	21.68	16.21	16.04	14.99
5	33.31	16.09	19.67	13.97	14.25*
Average	30.61	18.01	17.60	15.02	15.00
SD	2.82	3.00	2.52	1.00	0.17

Table 18 Flexural strength of HDPE filled with fabric waste modified with 5 %w/w of maleic anhydride using modification time of 4 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	14.53*	14.7*	15.98	15.26
2	32.32	22.74	15.7	12.18	16.43
3	26.02*	20.4	16.93	21.68*	14.81
4	31.25	20.06	15.81	19.17	14.53
5	33.31	18.89	16.32	18.89	20.06*
Average	30.61	20.52	16.19	18.93	15.26
SD	2.82	1.61	0.56	2.33	0.83

Table 19 Flexural strength of HDPE filled with fabric waste modified with 10 %w/w of maleic anhydride using modification time of 4 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	16.15*	14.36	14.64	15.31
2	32.32	21.68	19.38**	21.18*	12.31
3	26.02*	23.47	13.47	17.77	11.62
4	31.25	24.87	13.41	16.37	11.73
5	33.31	24.81	17.94	14.86	17.99*
Average	30.61	23.71	14.80	15.91	13.41
SD	2.82	1.49	2.14	1.45	3.06

Table 20 Flexural strength of HDPE filled with fabric waste modified with 15 %w/w of maleic anhydride using modification time of 4 hours

Sample No.	Flexural strength (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	30.14	20.51	11.62*	16.21	15.81
2	32.32	22.46*	13.41	18.5	12.29
3	26.02*	19.56	16.43	16.04	18.05
4	31.25	18.33	15.7	20.51*	11.18*
5	33.31	19.39	17.99	16.99	17.27
Average	30.61	19.44	15.88	16.93	15.86
SD	2.82	0.89	1.90	1.12	2.55

2. Deformation at maximum load (mm)

Table 21 Deformation at maximum load of HDPE filled with Unmodified fabric waste

Sample of No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	11.18	8.51	8.47	8.97
2	10.25	12.4	6.37*	8.01	8.05
3	12.36	9.19	9	4.92*	10.95
4	10.23	9.31	10.41	6.83	4.88*
5	12.58	7.17*	8.85	7.67	5.53
Average	11.08	10.52	9.19	7.75	8.38
SD	1.11	1.55	0.84	0.69	2.25

Table 22 Deformation at maximum load of HDPE filled with fabric waste modified with 5 % w/w of maleic anhydride using modification time of 2 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	10.83	6.52*	9.46	7.24
2	10.25	10.03	6.68	5.76	5.26
3	12.36	9.95	9.12	5.60*	7.93
4	10.23	8.58*	7.78	7.01	5.34
5	12.58	9.80	9.31	6.52	4.85*
Average	11.08	10.15	8.22	7.19	6.46
SD	1.11	0.46	1.23	1.59	1.36

Table 23 Deformation at maximum load of HDPE filled with fabric waste modified with 10 % w/w of maleic anhydride using modification time of 2 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	9.00	9.46	6.83	5.84*
2	10.25	7.82	9.04	5.68	9.84
3	12.36	6.86*	5.53*	8.85	6.56
4	10.23	10.11	10.41	5.23*	9.01
5	12.58	8.82	9.35	7.78	6.22
Average	11.08	8.95	9.57	7.29	7.91
SD	1.11	0.93	0.59	1.35	1.79

Table 24 Deformation at maximum load of HDPE filled with fabric waste modified with 15 % w/w of maleic anhydride using modification time of 2 hours

Sample of No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	11.52	7.63*	6.68*	6.71
2	10.25	8.77	10.38	6.94	7.32
3	12.36	10.38	9.04	8.51	7.36
4	10.23	8.28	10.3	9.92	6.33*
5	12.58	7.48*	8.85	10.07	6.41
Average	11.08	9.74	9.64	8.86	6.93
SD	1.11	1.48	0.80	1.46	0.49

Table 25 Deformation at maximum load of HDPE filled with fabric waste modified with 5 % w/w of maleic anhydride using modification time of 3 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	11.98	10.87	6.26	7.36
2	10.25	12.63	7.40	6.74	8.09
3	12.36	11.25	9.35	6.03*	5.84*
4	10.23	10.87	3.75*	7.67	7.17
5	12.58	10.38*	11.48	7.06	9.00
Average	11.08	11.68	9.78	6.95	7.91
SD	1.11	0.78	1.81	0.59	0.83

Table 26 Deformation at maximum load of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	10.64	11.06	8.51	8.47
2	10.25	10.53	5.23*	7.97	6.71*
3	12.36	12.74	7.63	8.89	10.11
4	10.23	9.98*	8.81	7.06*	7.82
5	12.58	10.91	8.01	10.8	8.09
Average	11.08	11.21	8.88	9.04	8.62
SD	1.11	1.03	1.53	1.23	1.02

Table 27 Deformation at maximum load of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	12.28	9.537*	7.362	8.469
2	10.25	10.38	9.956	7.057	6.714*
3	12.36	14.38*	11.48	6.866*	10.11
4	10.23	10.19	11.41	10.26	7.82
5	12.58	11.98	9.842	10.99	8.087
Average	11.08	11.20	10.67	8.92	8.62
SD	1.11	1.07	0.89	1.99	1.02

Table 28 Deformation at maximum load of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	11.25*	13.58	11.94	10.41
2	10.25	11.25	13.2	9.65	7.97*
3	12.36	13.05	7.9*	9.04	9.54
4	10.23	12.86	12.4	8.2	8.01
5	12.58	11.33	12.25	7.71*	12.13
Average	11.08	12.12	12.86	9.71	10.02
SD	1.11	0.96	0.63	1.60	1.71

Table 29 Deformation at maximum load of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	9.8*	8.13	7.59	7.97
2	10.25	12.44	11.52	8.81	7.21
3	12.36	11.33	7.13*	9.61	9.36
4	10.23	11.25	8.13	12.09	5.67*
5	12.58	11.56	15.3	6.45*	7.06
Average	11.08	11.65	10.77	9.53	7.9
SD	1.11	0.54	3.4	1.9	1.05

Table 30 Deformation at maximum load of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Deformation at maximum load (mm)				
	% fabric waste				
	0	5	10	15	20
1	10.12*	12.09	6.91*	10.22	7.74
2	10.25	11.22	6.98	11.67*	5.87*
3	12.36	11.79	9.61	10.38	7.06
4	10.23	7.67*	8.62	10.53	11.37
5	12.58	10.6	9	10.38	9.767
Average	11.08	11.43	8.55	10.7	8.98
SD	1.11	0.66	1.12	0.62	1.96

3. Flexural modulus

Table 31 Flexural modulus of HDPE filled with unmodified fabric waste

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	266.1*	614.4	480.1	547.4
2	395.32*	319.4	318.4*	364.7*	488.2
3	336.25	425.5	474.3	507.7	388.3*
4	354.36	428.2	436.4	458.9	640.4
5	341.36	523.4	468	452.2	688.6
Average	359.71	424.13	498.28	474.73	591.15
SD	24.06	83.34	79.1	24.9	90.24

Table 32 Flexural modulus of HDPE filled with fabric waste modified with 5 % w/w of maleic anhydride using modification time of 2 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	539.5	361.7*	569.8*	395.6
2	395.32*	556.6	580.4	641.9	389.9
3	336.25	536	566.7	821.9	366.6
4	354.36	391.2*	735.3	667.2	690.2*
5	341.36	488.2	662.3	687.75	460.2
Average	359.71	530.08	636.18	704.69	403.075
SD	24.06	29.33	78.41	80.36	40.09

Table 33 Flexural modulus of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	456.5	738	777.1	882.3
2	395.32*	477	698.2	594.8	229*
3	336.25	613.4	469.34*	350.6*	762
4	354.36	267.6*	546.1	481	438.8
5	341.36*	376.3	611.25	550.9	579.01
Average	359.71	480.8	629.1975	600.95	665.53
SD	24.06	98.50	118.99	126.43	195.94

Table 34 Flexural modulus of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	238.137	336.43	357.38	377.18
2	395.32*	264.57	221.6	318.18	341.75*
3	336.25	204.21*	368.01	286.14	362.74
4	354.36	288.44	171.41*	247.84*	444.7
5	341.36*	355.47	317.65	301.53	388.28
Average	359.71	248.84	310.92	315.81	393.23
SD	24.06	36.15	63.0	30.64	35.87

Table 35 Flexural modulus of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	293.9	241.2*	355.24*	362.3
2	395.32*	279.7	326.7	340.25	254.4*
3	336.25	198.3*	290.36	345.69	318.3
4	354.36	255.25	288.65	345.21	311.56
5	341.36*	257.69	268.2	345.89	309.21
Average	359.71	271.63	293.48	344.26	325.34
SD	24.06	18.47	24.33	2.69	24.94

Table 36 Flexural modulus of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	302.25	182.26	227.2	227.2
2	395.32*	265.36	220	257.4	257.2
3	336.25	258.36	208.96	376.3	376.3
4	354.36	280.23	204.36	284.36	285.36
5	341.36*	290.32	208.36	286.39	288.01
Average	359.71	284.54	210.42	301.11	301.72
SD	24.06	105.5	6.70	51.83	51.63

Table 37 Flexural modulus of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	181.6*	185.7*	310.4*	325.2*
2	395.32*	299.2	348.5	256.36	512.4
3	336.25	402.3	240	275.26	479.3
4	354.36	207	398.9	250.36	435.23
5	341.36*	274.58	274.36	278.96	438.56
Average	359.71	295.77	315.44	280.25	466.37
SD	24.06	81.04	71.73	22.41	36.65

Table 38 Flexural modulus of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	453*	142.2*	202.5*	269.6
2	395.32*	316	184.2	484.6	349.7
3	336.25	322.1	321.5	457	197.9*
4	354.36	337.8	190.6	436	366.8
5	341.36*	357.25	204.1	395.21	296.32
Average	359.71	367.54	180.28	443.20	320.61
SD	24.06	58.76	26.70	37.68	45.36

Table 39 Flexural modulus of HDPE filled with fabric waste modified with10% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	247*	316.8	455.9*	270.3*
2	395.32*	363.8	250.8*	350.9	476.2
3	336.25	418.3	274.25	222.3	373.26
4	354.36	497.3	283.56	286.8	354.23
5	341.36*	390	291.25	328.45	373.23
Average	359.71	417.35	291.47	297.11	476.2
SD	24.06	57.75	8.5	56.50	55.37

Table 40 Flexural modulus of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Flexural Modulus (N/mm^2)				
	% fabric waste				
	0	5	10	15	20
1	371.26	355.6	243.8*	239.5*	285.4*
2	395.32*	405.3	271.3	309.7	480.3
3	336.25	299.6*	361.2	244.5	336.1
4	354.36	370.3	292.36	394.9	366.56
5	341.36*	321.5	291.36	288.2	367.25
Average	359.71	363.18	304.06	309.33	387.5
SD	24.06	34.73	39.31	63.17	63.51

APPENDIX C

1. Tensile strength

Table 41 Tensile strength of HDPE filled with unmodified fabric waste

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	14.36	17.57	9.75	11.54
2	27.36*	11.54*	4.15*	12.13	9.14
3	22.36	16.45	14.8	13.48	8.87
4	22.1	18.59	15.8	16.19*	7.75
5	24.31	17.72	6.4	9.72	4.73*
Average	24.25	16.78	10.29	10.53	9.33
SD	2.15	1.83	5.87	1.38	1.59

Table 42 Tensile strength of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	13.12	16.36	10.21	3.52
2	27.36*	12.74	13.23	5.72*	8.87
3	22.36	15.1	10.8*	7.83	7.75
4	22.1	8.89*	11.51	10.46	4.83*
5	24.31	16.79	14.62	10.36	9.26
Average	24.25	14.44	12.54	9.72	7.68
SD	2.15	1.87	1.72	1.26	2.00

Table 4 Tensile strength of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	12.6	12.28	2.94*	6.16
2	27.36*	6.88*	8.41	4.94	0.68*
3	22.36	17.18	8.4	7.7	3.39
4	22.1	11.38	10.64	5.9	4.88
5	24.31	13.28	14.03*	9.26	6.15
Average	24.25	13.61	9.94	6.95	5.15
SD	2.15	2.50	1.88	1.91	1.31

Table 44 Tensile strength of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	9.38	17.83	10.86	7.74
2	27.36*	11.6	17.37	9.21	10.32
3	22.36	16.88*	9.9	11.39	8.31
4	22.1	12.58	5.84*	15.29*	4.83*
5	24.31	15.81	12.86	9.85	7.29
Average	24.25	14.22	13.38	10.33	8.42
SD	2.15	2.52	3.76	0.98	1.33

Table 45 Tensile strength of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	18.21	13.39	9.48	5.85
2	27.36*	20.01	7.76*	12.03	5.41
3	22.36	12.21	13.56	3.03*	5.03
4	22.1	7.64*	14.23	6.1	4.1*
5	24.31	14.29	11.97	7.72	4.6
Average	24.25	17.50	13.29	7.77	5.23
SD	2.15	2.92	0.95	1.69	0.53

Table 46 Tensile strength of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	17.34	13.22	11.36	9.7
2	27.36*	16.4	14.99	7.55	4.95*
3	22.36	13.26	11.56	7.42	6.07
4	22.1	13.23	11.39	13.33*	10.95
5	24.31	11.04*	16.41*	12.04	7.59
Average	24.25	15.06	12.79	9.59	8.58
SD	2.15	2.12	1.68	2.44	2.1

Table 47 Tensile strength of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	9.04	14.76	5.62	9.7
2	27.36*	13.76	15.2	5.7	4.95*
3	22.36	11.28	2.49*	10.57	6.07
4	22.1	19.98*	15.85	3.89*	10.95
5	24.31	17.2	12.62	8.34	7.59
Average	24.25	12.82	14.61	7.56	8.58
SD	2.15	3.49	1.39	2.37	2.17

Table 48 Tensile strength of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	10.36	10.33	8.00	9.25*
2	27.36*	11.36	9.25*	10.26	5.21
3	22.36	10.36	12.36	6*	5.01
4	22.1	10.37	10.26	8.65	3.26
5	24.31	12.69*	11.36	10	4.25
Average	24.25	10.61	10.65	9.23	4.43
SD	2.15	0.49	0.61	1.08	0.88

Table 49 Tensile strength of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	20.12*	8.66	6.22	7.89
2	27.36*	15.14	13.17	6.47	7.56
3	22.36	14.36	12.24	3.19*	7.64
4	22.1	19.67	15.74*	10.16	10.76*
5	24.31	17.1	9.27	6.51	8.45
Average	24.25	16.57	10.84	7.62	7.89
SD	2.15	2.36	2.20	2.20	0.40

Table 50 Tensile strength of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Tensile strength (MPa)				
	% fabric waste				
	0	5	10	15	20
1	25.12	18.97*	12.29	9.36	7.26
2	27.36*	11.69	9.93	16.14*	5.88
3	22.36	11.47	14.82*	6.49	7.43
4	22.1	18.12	8.99	9.53	5.41*
5	24.31	11.38	12.71	11.76	7.95
Average	24.25	13.17	10.98	9.29	7.13
SD	2.15	3.30	1.80	2.16	0.88

2. % Elongation

Table 51 %Elongation of HDPE filled with unmodified fabric waste

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	15.76	15.72	11.24	12.03
2	27.36*	15.35	7.62*	16.09	15.37*
3	27.36	16.15	10.44	18.07	12.37
4	24.36	13.1*	12.79	14.48	10.25
5	24.36	15.1	8.17	9.66*	12.56
Average	25.76	15.59	9.76	14.97	1.05
SD	1.51	0.46	2.36	2.88	1.05

Table 52 %Elongation of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 2 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	10.18	10.26	9	7.05
2	27.36*	10.23	9.59	14.07*	10.28*
3	27.36	10.49	8.75*	8.71	7.47
4	24.36	8.79*	10.23	8.39	6.88
5	24.36	10.72	10.75	9.18	7.91
Average	25.76	10.45	10.21	8.82	7.33
SD	1.51	0.25	0.47	0.34	0.46

Table 53 %Elongation of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 2 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	9.11	10.07	6.71	11.08
2	27.36*	11.65	6.86*	6.62*	4.03*
3	27.36	10.92	9.14	7	6.61
4	24.36	8.11*	12.15	7.89	8.71
5	24.36	10.85	9.96	7.06	8.83
Average	25.76	10.63	10.33	7.16	7.05
SD	1.51	1.07	1.28	0.50	2.25

Table 54 %Elongation of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 2 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	8.87	12.77	11.45	9.63
2	27.36*	21.87*	12.23	8.65*	13.94
3	27.36	12.19	7.17*	12.79	10.04
4	24.36	11.11	8.19	10.21	12.47
5	24.36	12.89	12.86	13.3	8.17*
Average	25.76	11.27	10.11	10.10	10.08
SD	1.51	1.75	2.85	1.40	1.78

Table 55 %Elongation of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 3 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	12.26	7.78	8.98	7.94
2	27.36*	12.6	10.63	11.15	9.87
3	27.36	8.75	12.05	5.68*	10.74
4	24.36	9.09	13.87*	12.05	20.04*
5	24.36	14.59*	7.75	10.35	8.26
Average	25.76	10.63	10.14	9.55	9.20
SD	1.51	2.13	2.14	1.30	1.32

Table 56 %Elongation of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 3 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	11.59	14.58*	9.76*	10.3
2	27.36*	12.87	10.14	10.25	9.24
3	27.36	8.93*	9.49	11.9	13.01*
4	24.36	10.89	11.56	12.13	8.78
5	24.36	10.77	11.94	11.98	10.22
Average	25.76	11.53	11.21	11.56	9.63
SD	1.51	0.96	1.85	0.88	0.74

Table 57 %Elongation of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 3 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	15.32*	11.2	12.37*	13.3*
2	27.36*	9.36	9.57*	10.46	10.26
3	27.36	12.09	12.29	8.69	6.29
4	24.36	11.64	16.12	10.77	7.33
5	24.36	12.37	15.69	11.21	12.33
Average	25.76	11.37	11.02	10.81	9.05
SD	1.51	1.37	1.36	0.37	2.75

Table 58 %Elongation of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 4 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	10.26	9.57	10.26	8.26
2	27.36*	11.25	9.52	11.25	8.25
3	27.36	9.56*	10.25	8.56*	7.23
4	24.36	10.25	11.03	9.25	7.26
5	24.36	10.26	8.25*	9.65	9.24*
Average	25.76	10.51	10.09	10.10	7.75
SD	1.51	0.49	0.70	0.87	0.58

Table 59 %Elongation of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 4 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	14.34	6.16	6.22	10.3
2	27.36*	11.95	8.4	6.47	9.24
3	27.36	17.52	7.85	3.19*	13.01*
4	24.36	21.6*	13.19*	10.16	8.77
5	24.36	11.23	6.61	9.56	10.22
Average	25.76	12.51	7.26	7.14	9.63
SD	1.51	1.62	1.04	1.60	0.75

Table 60 %Elongation of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 4 hours

Sample No.	% Elongation				
	% fabric waste				
	0	5	10	15	20
1	25.36	16.36*	12.35*	8.6	7.26
2	27.36*	9.63	7.66	11.47*	11.11
3	27.36	14.4	9.11	8.84	10.02
4	24.36	11.61	10	6.75	6.87*
5	24.36	7.3	7.81	7.4	12.93
Average	25.76	13	9.81	7.89	7.06
SD	1.51	2.97	1.91	0.99	0.27

3. Young ‘ s Modulus

Table 61 Young’s Modulus of HDPE filled with unmodified fabric waste

Sample No.	Young’s Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	246.87	247.63	204.03*	205.36*
2	447.36*	214.49	215.56	264.84	264.36
3	365.36	155.17*	323.73*	229.53	228.36
4	389.36	356.44	272.09	276.42	250.36
5	425.36	273.03	213.3	267.95	268.36
Average	403.36	272.70	237.14	259.68	252.85
SD	32.61901	60.74	28.08	20.69	18.06

Table 62 Young’s Modulus of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Young’s Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	219.87	220.25	270.17	157.46*
2	447.36*	260.68	254.35	153.35*	366.4
3	365.36	351.03*	268.25	211.63	354.28
4	389.36	241.09	280.21	281.61	394.96
5	425.36	307.39	211.56*	240.3	318.25
Average	403.36	257.26	255.76	250.93	358.41
SD	32.61	37.34	25.92	31.45	31.77

Table 63 Young's Modulus of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	327.53	345.98	154.24*	255.9
2	447.36*	294.04	263.84	247.64	62.67*
3	365.36	349.44	259.2	289.37	174.2
4	389.36	351.18	375.48	284.21	125.73
5	425.36	269.6*	432.4*	243.25	224.41
Average	403.36	330.54	311.12	266.11	154.62
SD	32.61	26.61	58.56	24.03	81.50

Table 64 Young's Modulus of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 2 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	375.64*	267.15	180.78	205.46
2	447.36*	194.78	284.91	429.48*	387.52*
3	365.36	187.36	324.22*	131.69	167.57
4	389.36	120.19	185.88	280.13	85.734
5	425.36	283.67	222.85	222.59	245.07
Average	403.36	196.5	240.19	203.79	175.95
SD	32.61	67.10	44.63	63.00	67.96

Table 65 Young's Modulus of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	333.49	349.57	277	192.56
2	447.36*	265.56	322.5	249.77	171.27*
3	365.36	223.74	161.61*	100.43*	207.71
4	389.36	452.45*	204.24	145.97	228.1
5	425.36	267.93	276.78	239.6	220.15
Average	403.36	272.68	288.27	228.08	212.13
SD	32.61	45.33	63.56	56.97	15.51

Table 66 Young's Modulus of HDPE filled with fabric waste modified with 10% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	212.92	159.67*	182.74	211.6*
2	447.36*	173.85	320.41	156.21*	289.5
3	365.36	304.25*	344.74	189.38	228.1
4	389.36	241.83	253.31	252.54	238.97
5	425.36	152.9	324.75	172.1	274.27
Average	403.36	233.21	310.80	175.10	257.71
SD	32.61	54.94	39.76	14.46	28.94

Table 67 Young's Modulus of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 3 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	105.3*	362.46	232.125	105.6*
2	447.36*	321.42	306.8	141.38	152.47
3	365.36	220.83	99.526*	295.97	207.42
4	389.36	293.33	177.57	114.17*	164.98
5	425.36	223.38	181.97	228.26	213
Average	403.36	264.74	222.11	217.63	184.46
SD	32.61	50.55	73.37	75.64	30.24

Table 68 Young's Modulus of HDPE filled with fabric waste modified with 5% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	250.26	250.36	230.36	210.256*
2	447.36*	241.26	224.15	205.25	195.25
3	365.36	262.35	225.25	215.26	180.25
4	389.36	222.36*	200.35*	211.25	145.32
5	425.36	265.56	245.26	201.23*	111.23
Average	403.36	254.85	236.25	215.53	158.01
SD	32.61	11.20	13.51	10.70	37.55

Table 69 Young's Modulus of HDPE filled with fabric waste modified with10% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	333.66	343.79	299.61	211.6*
2	447.36*	374.75	353.37	189*	289.1
3	365.36	182.28	433.5*	254.7	228.1
4	389.36	170.86	311.27	202.96	238.97
5	425.36	401.41*	310.75	220.36	274.27
Average	403.36	320.17	329.79	244.40	257.61
SD	32.61	103.36	22.04	42.62	28.79

Table 70 Young's Modulus of HDPE filled with fabric waste modified with 15% w/w of maleic anhydride using modification time of 4 hours

Sample No.	Young's Modulus (MPa)				
	% fabric waste				
	0	5	10	15	20
1	389.36	389.71	241.66	274.26	361.84*
2	447.36*	356.45	281.5	287.57	127.17
3	365.36	367.52	433.13*	181.06*	235.86
4	389.36	458.32	255.78	411.02	156.9
5	425.36	277.14*	312.47	443.34	121.6
Average	403.36	393	272.85	247.63	160.38
SD	32.61	45.68	31.13	58.03	52.65

* not include in the figure

VITAE

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