ผลของสารเสริมสภาพเข้ากันได้ต่อสมบัติกายภาพและสัณฐานวิทยาของเอบีเอส/ยูเอชเอ็มดับบลิวพีอีเบล็นด์

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EFFECT OF COMPATIBILIZERS ON PHYSICAL PROPERTIES AND MORPHOLOGY OF ABS/UHMWPE BLENDS

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กานต์ อังกาบสี : ผลของสารเสริมสภาพเข้ากันได้ต่อสมบัติกายภาพและสัณฐานวิทยาของเอบีเอส/ยูเอชเอ็มดับบลิวพีอีเบลนด์ (EFFECT OF COMPATIBILIZERS ON PHYSICAL PROPERTIES AND MORPHOLOGY OF ABS/UHMWPE BLENDS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. ดร. ภัทรพรรณ ประศาสน์สารกิจ, 74 หน้า.

งานวิจัยนี้เป็นการศึกษาผลของปริมาณสารเสริมสภาพเข้ากันได้และปริมาณของ UHMWPE ต่อสมบัติกายภาพและสัณฐานวิทยาของพอลิเมอร์เบลนด์ ABS/UHMWPE โดยศึกษาประสิทธิภาพของสารเสริมสภาพ PE-g-MAH และ SEBS ในพอลิเมอร์เบลนด์ ABS/UHMWPE โดยเตรียมตัวอย่างด้วยการใช้เครื่องอัดรีดแบบเกลียวคู่ตามด้วยเครื่องอัดแบบฉีด ศึกษาสมบัติทางสัณฐานวิทยาและสมบัติเชิงความร้อนของพอลิเมอร์เบลนด์โดยใช้กล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด (SEM) และเครื่องดิฟเฟอเรนเชียลสแกนนิงแคลอริมิเตอร์ (DSC) ตามลำดับ เมื่อตรวจสอบสัณฐานวิทยาพบว่าพอลิเมอร์เบลนด์มีความเข้ากันได้ดีขึ้นเมื่อเพิ่มปริมาณของ SEBS สำหรับการตรวจสอบสมบัติเชิงความร้อนของพอลิเมอร์ผสมพบว่าสารเสริมสภาพเข้ากันไม่ส่งผลต่อการเปลี่ยนแปลงในสมบัติเชิงความร้อน ในส่วนของสมบัติการทนต่อแรงดึงพบว่ามีค่าลดลงในขณะที่การยืดตัวเมื่อขาดและสมบัติการทนต่อแรงกระแทกเพิ่มขึ้นเมื่อเพิ่มปริมาณของ SEBS ผลจากการศึกษาพบว่า SEBS สามารถทำหน้าที่เป็นสารเสริมสภาพเข้ากันได้ที่ดีของพอลิเมอร์เบลนด์ ABS/UHMWPEโดยให้ผลที่ดีขึ้นเมื่อมีการเพิ่มปริมาณของ SEBS สำหรับการเปรียบเทียบสมบัติเชิงกล ศึกษาผลของปริมาณ UHMWPE ที่อัตราส่วนร้อยละ 5 – 25 โดยน้ำหนักของ ABS/UHMWPE ในพอลิเมอร์เบลนด์ที่ใช้ SEBS 5 ส่วนต่อพอลิเมอร์ผสมร้อยส่วนพบว่าสมบัติการทนต่อแรงดึง, การยืดตัวเมื่อขาด, สมบัติการทนต่อแรงกระแทก, สมบัติของความแข็ง, การทนต่อความสึกหรอ และการทนต่อสภาวะแวดล้อมมีสมบัติดีที่สุดที่อัตราส่วน 95:5 ของพอลิเมอร์เบลนด์ ABS/UHMWPE

สาขาวิชา ปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์ ลายมือชื่อนิสิต ....

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KARN UNGKABSEE: EFFECT OF COMPATIBILIZERS ON PHYSICAL PROPERTIES AND MORPHOLOGY OF ABS/UHMWPE BLENDS. ADVISOR: PROF. PATTARAPAN PRASASSARAKICH, Ph.D., 74 pp.

This research evaluates the effect of compatibilizer and UHMWPE content on physical properties and morphology of ABS/UHMWPE blends. The effectiveness of PE-g-MAH and SEBS compatibilizers in ABS/UHMWPE blends was investigated. The sample preparation was carried out in a twin screw extruder followed by an injection molding machine. Scanning Electron Microscope (SEM) and Differential Scanning Calorimeter (DSC) were utilized to assess the morphological and thermal properties of the blends, respectively. Morphology observation of the blends indicated the better compatibility of the blends with increasing SEBS content. For thermal analysis, the ABS/UHMWPE blends with compatibilizer did not show any significant difference in thermal properties. The tensile strength decreased while the elongation at break and the impact strength increased with SEBS compatibilizer content. The results indicated that SEBS acted as a good compatibilizer in ABS/UHMWPE blends and its effect was more pronounced in blends with a higher SEBS content. The mechanical properties of the ABS/UHMWPE blends at 5 phr of SEBS with UHMW content in the range of 5 to 25 wt% were compared. The results indicated that the ABS/UHMWPE blend at ratio of 95:5 exhibited the highest value of tensile strength, elongation, impact strength, hardness, abrasion resistance and stability against degradation by accelerated weathering.

Field of Study:	Petrochemistry and Polymer Science	Student's Signature Advisor's Signature	....
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LIST OF ABBREVIATIONS

ABS	: Acrylonitrile-Butadiene-Styrene
ASTM	: American Society for Testing and Materials
CSTR	: Continuous Stirred-tank Reactor
DIN	: German Institute for Standardization
DSC	: Differential Scanning Calorimetry
HDPE	: High Density Polyethylene
MW	: Molecular Weight
MWD	: Molecular Weight Distribution
PE-g-MAH	: The graft copolymer of polyethylene onto skim maleic anhydride
phr	: Parts per Hundred of Rubber
PP	: Polypropylene
PS	: Polystyrene
RH	: Relative Humidity
rpm	: Round per Minute
SAN	: Styrene Acrylonitrile
SBM	: Styrene-Butadiene-Maleic anhydride copolymer
SBR-g-MAH	: The graft copolymer of styrene-butadiene rubber onto skim maleic anhydride
SEBS	: styrene/ethylene-butylene/styrene
SEBS-g-MAH	: The graft copolymer of styrene/ethylene-butylene/styrene onto skim maleic anhydride
SEM	: Scanning Electron Microscope
T_g	: Glass Transition Temperature
UHMWPE	: Ultra-high Molecular Weight
UV	: Ultraviolet
wt%	: Weight Percent

CHAPTER 1
INTRODUCTION

1.1 The Purpose of the Investigation

Blending of polymers is a convenient way which improves the material properties for the proper applications. The development of new polymers from polymer blends is far less costly and faster than the development of new polymers from synthesis. Therefore, blends are economically attractive and experiencing significant growth. However, most polymer blends are immiscible. The incompatibility of polymeric blends is responsible for poor mechanical properties because of a defective of physical and chemical interactions across the phase boundaries and poor interfacial adhesion. Therefore, compatibilization is demanded to obtain a blend with desired properties. A common way to improve the compatibility and interfacial adhesion of polymer blends is to add compatilizers or interfacial agents [1].

Acrylonitrile-butadiene-styrene (ABS) is a widely used thermoplastic material due to its good mechanical properties, chemical resistance and easy processing characteristics. ABS as a typical heterogeneous polymer is composed of a styrene acrylonitrile (SAN) copolymer matrix phase, with grafted polybutadiene particles. Butadiene has the character of rubber toughness, and styrene offers glossiness and process ability [2]. The composition of the various components can be controlled to meet the requirements of a variety of applications. However, the overall mechanical properties of ABS are lower than those of most engineering plastics, and the heat distortion temperature of general grades of ABS is lower than 100 ^{o}C [3]. In order to upgrade the use of ABS, one simple way is to blend ABS resin with other high performance engineering plastics such as ultra-high molecular weight polyethylene (UHMWPE). UHMWPE, one type of polyethylene which possesses high impact strength, has been widely used in bearing applications due to its good chemical stability, biocompatibility, and friction reducing and antiwear ability. It has also been used as some components or parts of machines in chemical engineering, textile engineering, transportation engineering, agricultural engineering, food processing, and the paper making industry, because of its excellent chemical corrosion resistance [4]. However, the high molecular weight of UHMWPE (in the range of 3–10 million g/mol) gives it a very high viscosity, which prevents its flow in conventional techniques of polymer processing. This is because in practice this material does not flow, thereby limiting its applications [5].

The purpose of this work is to study the effect of compatibilizers on physical properties and morphology of ABS/UHMWPE blends with polyethylene-grafted maleic anhydride (PE-g-MAH) and styrene/ethylene-butylene/styrene (SEBS) as compatibilizers. In addition, the effect of the ABS/UHMWPE ratio (5-20 wt% UHMWPE) in blends at 5 phr of SEBS was focused.

1.2 Objective of the Research Work

To study the properties of ABS/UHMWPE blends with polyethylene-grafted maleic anhydride (PE-g-MAH) and styrene/ethylene-butylene/styrene (SEBS) as compatibilizers.

1.3 Scope of the Research Work

1. Study the principle and theory of work and review the literatures.
2. Prepare the ABS/UHMWPE blends using laboratory twin screw co-rotating extruder. Effect of polyethylene-grafted maleic anhydride (PE-g-MAH) contents (0, 3, 5, and 7 phr) on the mechanical properties of ABS/UHMWPE (90/10) blends was studied.
3. Prepare the ABS/UHMWPE blends using laboratory twin screw co-rotating extruder. Effect of styrene/ethylene-butylene/styrene (SEBS) contents (0, 3, 5, and 7 phr) on the mechanical properties of ABS/UHMWPE (90/10) blends was studied.
4. The ABS/UHMWPE blends with styrene/ethylene-butylene/styrene (SEBS) 5 phr were prepared. The effect of UHMWPE content (0, 5, 10, 15, 20 and 25 wt%) on the properties of ABS/UHMWPE blends was studied.

5. Evaluate the blend miscibility and the morphology using the techniques of differential scanning calorimetry (DSC) and scanning electron microscopy (SEM).
6. Study the accelerated weathering effects by using sunshine weathering meter (open flame carbon arc) and Xenon weathering meter (Xenon arc lamp) for 100, 250, 500 and 1000 h.
7. Summarize and conclude the results.

CHAPTER 2

THEORY AND LITERATURE REVIEWS

2.1 Acrylonitrile Butadiene Styrene

Acrylonitrile-Butadiene-Styrene (ABS) is one of the most widely used thermoplastic in the world because of the wide range of available properties. The product has excellent surface appearance, strength and stiffness, toughness and chemical resistance. ABS is a terpolymer of acrylonitrile, butadiene and styrene: acrylonitrile (A), butadiene (B) and styrene (S), where acrylonitrile improves the chemical resistance and thermal enhancements, butadiene contributes increased toughness and impact strength, and styrene gives good processability and stiffness to the ABS plastic. These three monomers are typically added together in specific proportions: 15-35% acrylonitrile, 5-30% butadiene and 40-60% styrene on average [6]. A small change in even one of the monomers can create drastic changes in the mechanical and physical properties of ABS. The structure of ABS is shown in Figure 2.1.

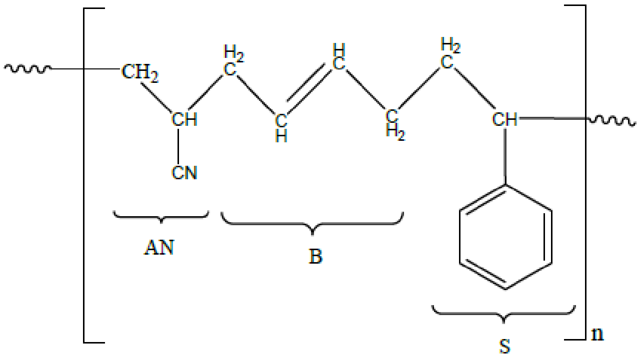


Figure 2.1 Acrylonitrile-butadiene-styrene copolymers [7]

ABS polymers consist of elastomer dispersed as a grafted particulate phase in a thermoplastic matrix of styrene and acrylonitrile copolymer (SAN). Grafting SAN onto the elastomer, which is usually polybutadiene, compatabilizes the rubber and

SAN components and imparts excellent toughness, good dimensional stability, good processability, and chemical resistance.

A chemical connection between elastomer and the styrene acrylonitrile copolymer is created by polymerizing styrene and acrylonitrile in the presence of polymerized elastomer. The resulting grafts serve to compatibilize the rubber and SAN copolymer phases.

2.1.1 Production of ABS [6]

The commercial ABS is accomplished by a number of various process based on free radical polymerization**.** The currently polymerization are used for production of ABS classified into five major polymerization processes used, and are the emulsion, suspension, continuous bulk, hybrid emulsion/bulk and expandable ABS processes, where continuous and emulsion and mass suspension method have been generally used in industry's production.

a) Bulk Polymerization

The continuous bulk process is seen as the preferred route because it is cost-effective and involves the least contamination. The bulk process for ABS production is based on the polymerization of styrene-acrylonitrile mixtures in the presence of a rubber substrate dissolved in this monomer phase. This is in contrast to the emulsion process, which takes place in an aqueous phase that affords lower viscosity of the reaction medium and better heat transfer. Rubber is usually introduced to the process in large bales or slabs, which are ground into small particles and dissolved in a mixture of styrene and acrylonitrile monomers. The process can be separated into three steps. Initial step, the rubber substrate is dissolved in the monomer mixture. For the second step, the rubber monomer mixture is prepolymerized with continuous mixing. Finally, the polymer-monomer mixture is polymerized further by bulk polymerization or by continuous bulk polymerization in a high viscosity reactor cascade.

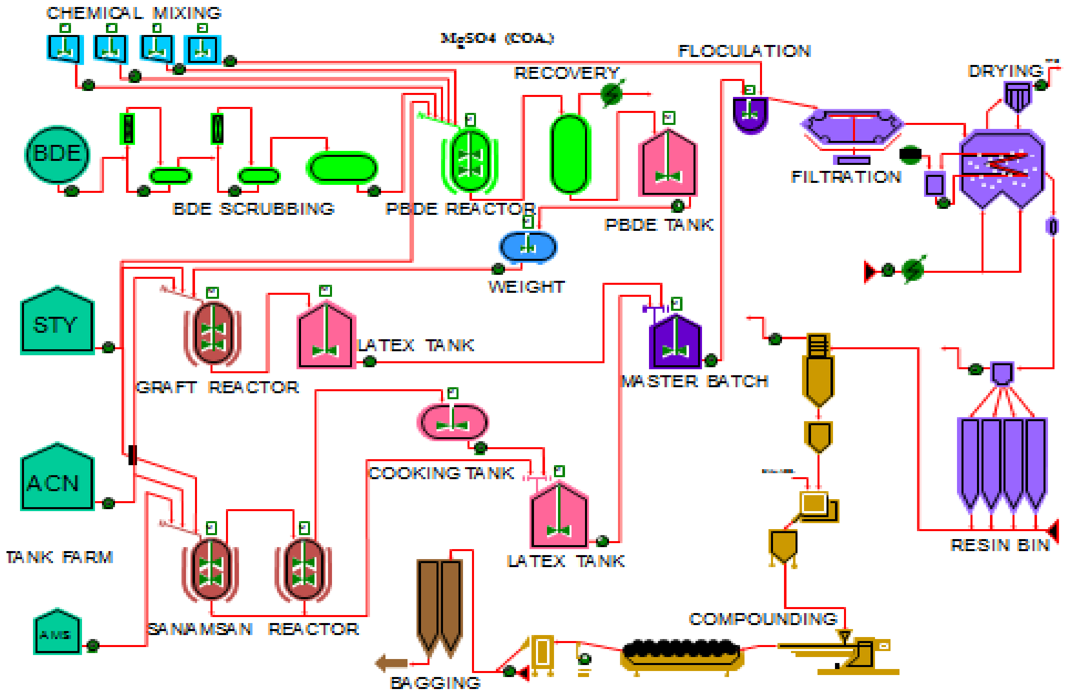


Figure 2.2 Process flow scheme of ABS by continuous bulk polymerization [7]

b) Emulsion Polymerization [6]

The emulsion process is more flexible, and was the original ABS production process but the principle of this method has also been applied to other rubber-modified. However, the emulsion polymerization process has been generally used for manufacturing in ABS plants, which provides more flexibility, dimensional stability and results in excellent toughness, processibility and chemical resistance properties in the produced ABS resin. The advantages of emulsion process are easy control of heat transfer, rubber crosslinking, rubber particle size, and graft morphology. The batch emulsion is used in the production of high impact grades.

A typical commercial emulsion process is shown in Figure 2.3. The process involves five major steps: rubber polymerization, agglomeration, graft polymerization, polymer recovery, and compounding.

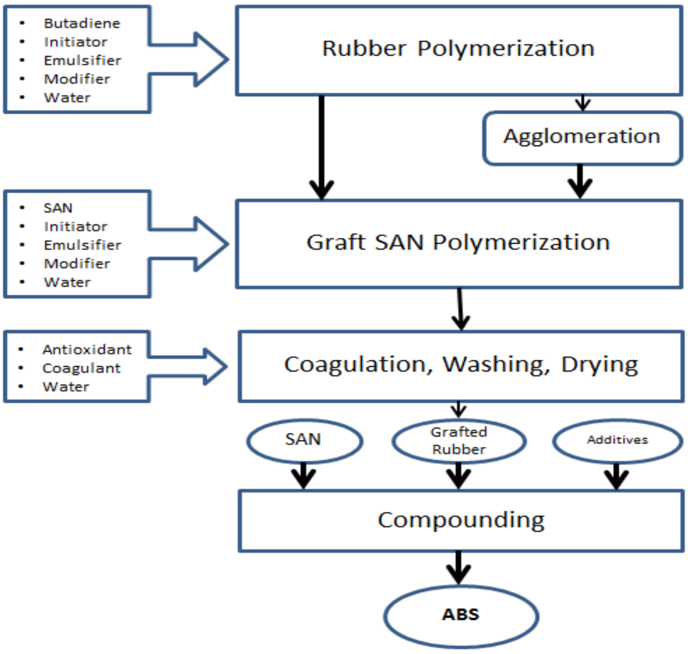


Figure 2.3 Emulsion ABS polymerization process [6]

c) Hybrid Emulsion/Bulk Polymerization

A hybrid emulsion/mass process has also been developed. It combines the features of the emulsion process, which forms polybutadiene latex and grafts styrene and acrylonitrile, and the mass process, which makes the styrene acrylonitrile component. This approach permits the production of a wide range of ABS products.

2.1.2 Applications of ABS

ABS is an alternative material for many applications and one of the widely used as engineering thermoplastics. In addition, there are many different grades and a wide range of properties for customer required. ABS is often used as the cost and performance dividing line between standard plastics (polystyrene, PVC, polyolefins, ,etc.) and engineering plastics (acrylic, nylon, acetal, etc.). ABS is light weight and ability to be injection molded and extruded make it useful in manufacturing products such as drain-waste-vent (DWV) pipe systems, automotive application, medical devices, enclosures for electrical and electronic assemblies, protective headgear, small kitchen appliances, including toys and household. In the automotive industry, ABS often competes with modified polypropylenes, but in the other applications, it also replaces industrial thermoplastics and thermoplastic blends.

2.2 UHMWPE [8]

Ultra-high molecular weight polyethylene (UHMWPE) is a polyolefin resin closely related to high density polyethylene (HDPE) that can be classified as a specialty engineering plastic. UHMWPE has an outstanding combination of physical properties, particularly for toughness and abrasion resistance, combined with the excellent chemical properties of conventional HDPE. UHMWPE is substantially different from these common PE grades. It is defined as a linear polyethylene homopolymer having an average molecular weight of over about 3.1 million (ASTM D4020-05), with commercial products having MW ranging from about 3 million to over 10 million.

UHMWPE has been in use since 1962. There have been many attempts to improve the performance of this material. These attempts include adding fiber reinforcement, recrystallizing the material to higher crystallinity levels, modifying sterilization methods, modifying methods of manufacture and most recently, elevating the level of crosslinking. UHMWPE has chemical, electrical and other physical properties similar to HDPE with the exception of its abrasion resistance, impact strength, low temperature performance and self-lubricating properties, which are all exceptional. The physical properties of HDPE and UHMWPE are shown in Table 2.1.

Table 2-1 Typical average physical properties of HDPE and UHMWPE [9]

Property	HDPE	UHMWPE
Molecular Weight (10^6 g/mole)	0.05 – 0.25	2 - 6
Melting Temperature (^{o}C)	130 - 137	125 - 138
Poisson’s Ratio	0.40	0.46
Specific Gravity	0.952 – 0.956	0.932 – 0.945
Tensile Modulus of Elasticity* (GPa)	0.4 – 4.0	0.8 – 1.6
Tensile Yield Strength* (MPa)	26 - 33	21 - 28
Tensile Ultimate Strength* (MPa)	22 - 31	39 - 48
Tensile Ultimate Elongation* (%)	10 - 1200	350 - 525
Impact Strength, Izod* (J/m of notch; 3.175 mm thick specimen)	21 - 214	>1070 (No Break)
Degree of Crystallinity (%)	60 - 80	39 - 75

*Testing conducted at 23°C.

Like all polyethylene polymers, UHMWPE has good resistance to aggressive chemical media, except for strong oxidizing acids. Aromatic and halogenated hydrocarbons that dissolve regular polyethylene (e.g. decahydronaphthalene) cause only slight swelling in contact with UHMWPE at moderate temperatures. Stress crack resistance is also very good, as might be expected with its very high MW. Resistance to UV is similar to HDPE and light stabilizers must be added for out-door or exposed applications. Heat stabilizers are also used for parts exposed to continuous use at elevated temperature. At low mechanical stress, UHMWPE can be used at 80-100 ^{o}C without significant deformation. Brief excursions up to 200 ^{o}C can also be tolerated.

In abrasion resistance, UHMWPE outperforms abrasion resistant steel and many other lower molecular weight plastics and other materials. Resistance to wear increases somewhat with molecular weight. Its impact strength is extremely high, such that the standard ASTM D256 Izod test gives “no breaks” due to its high energy absorption characteristics.

UHMWPE usually also offer PE grades of lower MW in the range of 600,000 to 2.5 million g/mol. These have many of the desirable properties of UHMWPE. Some may be compounded with UHMWPE powder as an additive to impart more of the desirable surface properties of UHMWPE. They may also form the base resin for filled grades, for example where thermally conductive compounds are required for better heat dissipation in bearings etc. Specialty UHMWPE powders, when added to elastomers such as NBR and SBR, have designed morphologies that improve energy dissipation to the matrix, resulting in sound/noise reduction. They can also prolong service life of rubber parts, improve chemical resistance, reduce crack propagation, and provide abrasion resistance and a lower coefficient of friction.

2.2.1 Production of UHMWPE [9]

UHMWPE is synthesized from monomer of ethylene, which are bonded together to form the base polyethylene product. These UHMWPE are several orders of magnitude longer than those of familiar HDPE due to a synthesis process based on metallocene catalysts, resulting in UHMWPE molecules typically having 100,000 to 250,000 monomer units per molecule each compared to HDPE's 700 to 1,800 monomers.

UHMWPE is processed variously by compression molding, ram extrusion, gel spinning, and sintering. Gel-spinning arrived much later and was intended for different applications. In gel spinning a precisely heated gel of UHMWPE is extruded through a spinneret. The extrudate is drawn through the air and then cooled in a water bath. The end-result is a fiber with a high degree of molecular orientation, and therefore exceptional tensile strength. Gel spinning depends on isolating individual chain molecules in the solvent so that intermolecular entanglements are minimal. Entanglements make chain orientation more difficult, and lower the strength of the final product.

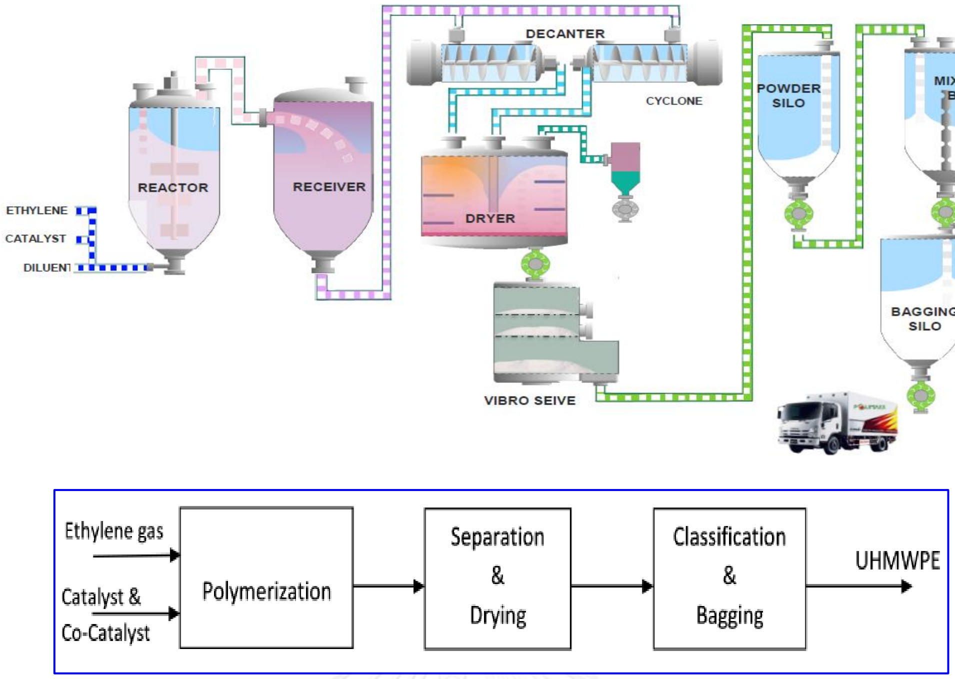


Figure 2.4 Process flow scheme of UHMWPE by polymerization [8]

The process used by all UHMWPE plants worldwide is a CSTR diluent slurry process operating in either batch or continuous mode, and all currently use Ziegler catalysts. (Patent information indicates that some producers may begin to use single-site or metallocene catalysts in the short-to-medium term future.) In the 1960s and 1970s most UHMWPE plants operated in batch mode, but by the early 1980s there were using continuous polymerization processes. However, continued to use batch mode until 1989/90 when it built a semi-continuous plant, only converting to continuous mode in 1996/97. Some smaller plants may still be operating in batch mode, but at capacities of 10 Kiloton or more, a continuous process is probably more effective.

2.2.2 Applications of UHMWPE

The outstanding impact, wear and sliding properties of UHMWPE, in combination with machinability, make it a cost-effective material for use in a wide variety of industries and applications. It competes in many applications with acetal and nylon resins, as well as with steel, PTFE, PVC, HDPE, and PP. UHMWPE is widely utilized in the textile, chemical processing, pulp and paper, mining, maritime, steel, water and sewage treatment, bulk material handling and agriculture industries. The typical applications for UHMWPE are shown in Table 2.2.

Table 2-2 The typical applications for UHMWPE [9]

Industrial sector	**Typical applications**
Bulk material handing	Liners for silos, hoppers, dump trucks, railcars and mining chutes, wear strips, slide plates, unlubricated bearings and bushings.
Cold weather and cryogenics	Snowmobile drive sprockets, snow blower impellers, ski and snowboard bottom surfaces, scales, pistons, pumps and other items for liquid gases.
Papermaking	Doctor blades, suction box covers and chain conveyor wear plates.
Chemical processing	Pump impellers and housings, valve seats, gaskets and filter media.
Textiles	Loom pickers, shuttles, sticks, straps, caps, buffers, gears and pinions.
Food, beverage, pharmaceutical	Meat-cutting surfaces, conveyor surfaces, rollers, bottling line timing augers and wear strips; contact wear surfaces in artificial hip & knee joints.
Water/wastewater treatment	Filter media, bearings, dewatering plates and siding shoes.
Batteries	Electrode separators in lead-acid batteries.
Fiber applications	Sails, nautical rope, fishing line and personal protective clothing (e.g. bulletproof vests and cut resistant gloves), synthetic ligaments in orthopedic surgery.
Miscellaneous	Maritime dock fenders, linings in earth-moving equipment, golf ball cores, porous pen nibs, table saw slides and guide rails.

2.3 Polymer Blends [10]

Polymer blending is a convenient route for the development of new polymeric materials, which combine the excellent properties of more than one existing polymer. This strategy allows for savings in research and development of new materials with equivalent properties, as well as versatility, simplicity, relatively low cost and faster development time of new materials. The polymer blends can be obtained basically in two ways, by polymer dissolution in a good solvent, common to them, and subsequently letting the solvent evaporate or in a mixing by the working temperature that enough to melt or modify the polymeric components, without causing degradation of the same.

Polymer blends accounted for 30 – 40% proportion of the total plastic products, and are increasingly research in a wide variety of materials and designs. Among the reasons for the popularity of polymer blends are synergistic combinations of blend ingredients to optimize properties such as high modulus with toughness, effective diffusional barriers with good mechanical properties, low investment costs in new materials design and lower cost than copolymer solutions [11].

The characterization of polymer blends can be achieved by their phase behavior as being either miscible or immiscible. Miscible blends exhibit fine phase morphology that has the properties of mixtures in only one homogeneous phase. Therefore, miscibility of polymer blends influences the poor mechanical properties, rheological, thermal and other properties of a polymer blends. Miscibility in polymer blends is always the result of specific interactions between the blend components. These interactions include hydrogen bonding interactions, dipole-dipole interactions, Van der Waals interactions (such as dispersion forces), and trans-reaction reactions. There are some polymer pairs that exhibit miscibility even without any specific interactions. The variation of the properties for polymer blends is shown in Figure 2.5.

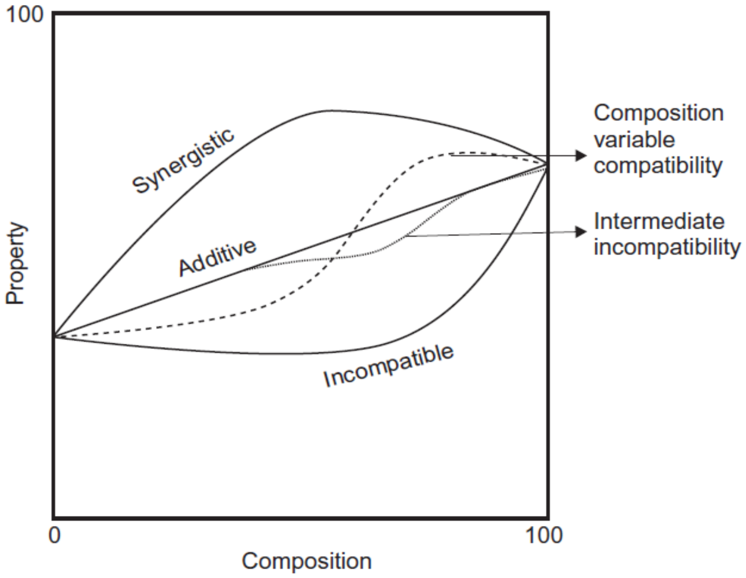


Figure 2.5 Variation of the properties of polymer blends as a function of composition. [10]

Compatibilization is the addition of a substance to an immiscible blend of polymers that will increase their stability. Polymer blends are described generally by coarse, unstable phase morphologies. This results in poor mechanical properties. Compatibilizing the system will make more stable and better blended phase morphology by creating interactions between the two previously immiscible polymers [12].

The strategies for blend, compatibilization is usually cheaper and less time-consuming than the development of new monomers or new polymerization routes, as the basis for entirely new polymeric materials. Polymer blending usually takes place in processing machines, such as twin-screw extruders, which are considered standard industrial equipment. There are several methods of compatibilization as modification of blends to provide a desirable set of properties, such as (a) Achievement of thermodynamic miscibility, (b) addition of block or graft copolymer, (c) addition of functional/reactive polymer and (d) in situ grafting/polymerization (reactive blending) [28].

2.3.1 Achievement of Thermodynamic Miscibility

Compatibilization by the achievement of thermodynamic miscibility is a comprehension from thermodynamic theory. When two polymers are mixed the most frequent result will be a system with complete phase separation due to unsuitable interactions between the blend components. Complete miscibility can be achieved when Equation (2.1) is satisfied.

$$\Delta G_m = \Delta H_m - T\Delta S_m \tag{2.1}$$

Where ΔG_m is the free energy of mixing, and ΔH_m and ΔS_m are the enthalpy and entropy of mixing and T is temperature. For miscibility to occur, ΔG_m must be smaller than 0, and so

$$\Delta H_m - T\Delta S_m < 0 \tag{2.2}$$

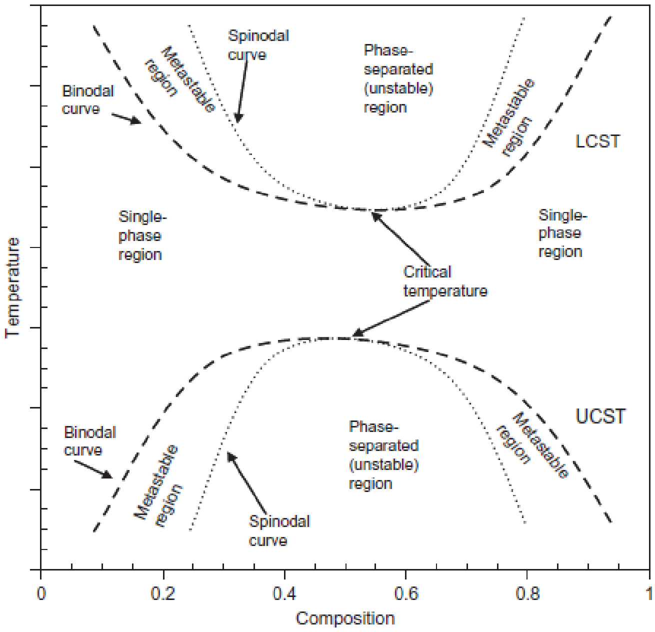


Figure 2.6 Phase diagram showing LCST and UCST behavior for polymer blends. [12]

For two – component blends that is possible to interpret a phase diagram, which may exhibit lower critical solution temperatures (LCST) and upper critical solution temperatures (UCST) (Figure 2.6). The negative values of Equation 2.2 can yield an area of the phase diagram where the mixture will separate into a phase rich in component 1 and 2. The UCST behavior is obtained when phase separation occurs upon cooling. Phase diagrams exhibiting the LCST behavior are for solutions which phase separate upon heating. In all cases, phase separation occurs when the interaction parameter exceeds its critical value. It is often seen that LCST behavior originates in the existence of specific interactions between the polymer and the solvent. Therefore, controlling the phase behavior becomes a key factor in converting these immiscible blends into useful polymeric products [13].

2.3.2 Addition of Block or Graft Copolymer [14]

The extensively method to manipulate the interface properties of polymer blends is adding of suitable block or graft copolymer, which contains a segment miscible with one blend component and another segment with the other blend component as compatibilizers. The investigation of block copolymer is frequently more than the graft copolymer and especially its contain blocks chemically and molecular weight same as the blend polymers component. In general, the copolymer segments are not necessarily identical with the respective blend components. Significant amounts of the copolymer are expected to locate at the interface between immiscible blend phases, reducing the interfacial tension between blend components, reducing the resistance to minor phase breakup during melt mixing thus reducing the size of the dispersed phase, and stabilizing the dispersion against coalescence. The finer morphology and the increased interfacial adhesion usually result in improved physical properties. The effects of a copolymer on the morphology of polymer blends, interfacial adhesion between blend phases, and blend properties depend on such parameters as the type and molecular weight of the copolymer segments, blend compositions, blending conditions. Summary, the added copolymers are compatible with both phases, thereby segregating preferentially at the interface and ensuring strong interfacial adhesion [14].

2.3.3 Addition of Functional/Reactive Polymer

Several researcher have described the compatibilizer by addition of functional polymers that a chemically polymer identical to the one component of blends is modified to contain functional group, which have some affinity for the second blend component. This technique has certain advantages over the addition of premade block or grafted copolymers. Usually reactive polymers can be generated by free radical copolymerization or by melt grafting of reactive groups on to chemically inert polymer chains. Furthermore, reactive polymers only generate block or grafted copolymers at the site where they are needed, i.e. at the interface of an immiscible polymer blend. Although grafted and (especially) block copolymers may form micelles after being added to or formed in a blend, the chance that the critical micelle concentration is exceeded is actually higher in the case of pre-made structures. This is a drawback with respect to the efficiency of the compatibilizer. Finally, the melt viscosity of a (linear) reactive polymer is lower than that of a pre-made block or grafted copolymer, at least if the blocks of the pre-made copolymer and the reactive “blocks” are of similar molecular weights. Lower molecular weight polymers will diffuse at a higher rate towards the interface. This is of utmost importance in view of the short processing times used in reactive blending which may be on the order of a minute or less [14].

In order to successfully apply reactive polymers as block or grafted copolymer precursors, the functionalities must have a suitable reactivity in order to react across the melt phase boundary during the short blending time. In addition, the generated covalent bond must be sufficiently stable to survive subsequent processing conditions.

2.3.4 Reactive Blending [15]

Reactive blending is the new method for producing the compatible thermoplastic blends, which relies on the formation of in situ copolymers or interacted polymers. This technique is different from other compatibilization technique in that its blend components are either chosen or modified, and the reaction occurs during the melt blending with not required the addition of compatibilizer. This technique is usually founded in chemical application.

In reactive blending, a chemical reaction occurs between the functionalized and unfunctionalized components during melt blending. The reactive mechanism results in in situ formation of small interacting polymers resulting in fine dispersion and adhesion between the two phases, which identifies a number of reaction blending mechanisms as follows:

- An in situ formation of graft or block copolymers by chemical bonding reactions between reactive groups on component polymers or by addition of a free radical initiator during blending.
- Formation of a block copolymer by an interchange reaction in the backbone bonds of the components. This is most likely to arise in the condensation reaction.
- Mechanical scission and recombination of component polymers to form graft or block copolymers, which may be induced by high shear levels during processing.
- Promotion of the reaction by catalysis [15].

For thermoplastics, these techniques are applied in particular and the chemical modification in twin-screw extruders gained a lot of attention in recent years as an advantageous route for the production of new materials. There are several methods for blending the different polymers to obtain the desirable properties such as, mechanical blending, solution blending, mechanochemical blending, latex blending and chemical blending which are widely used in reactive processing technology [16].

2.4 Literature Reviews

Mei-Lin et al. [17] studied the miscibility and compatibilization of the poly trimethylene terephthalate)/acrylonitrile–butadiene–styrene (PTT/ABS) blends was prepared by melt processing with and without epoxy or styrene‑butadiene‑maleic anhydride copolymer (SBM) as a reactive compatibilizer. The miscibility and compatibilization of the PTT/ABS blends were investigated by differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), capillary rheometer and scanning electron microscopy (SEM). The existence of two separate composition-dependent glass transition temperatures (T_g) indicated that PTT was partially miscible with ABS over the entire composition range. In the presence of the compatibilizer, both the cold crystallization and glass transition temperatures of the PTT phase shifted to higher temperatures, indicating their compatibilization effects on the blends. The PTT/ABS blends exhibited typical pseudoplastic flow behavior. The rheological behavior of the epoxy compatibilized PTT/ABS blends showed an epoxy content-dependence. In contrast, when the SBM content was increased from 1 wt% to 5 wt%, the shear viscosities of the PTT/ABS blends increased and exhibited much clearer shear thinning behavior at higher shear rates. The SEM micrographs of the epoxy or SBM compatibilized PTT/ABS blends showed a finer morphology and better adhesion between the phases.

Vesna et al. [18] studied the influence of styrene/ethylene-butylene/styrene (SEBS) compatibilizer on the morphology and properties of atactic polystyrene/high density polyethylene (aPS/HDPE) blends. The rheological behavior of the blends melt during processing was followed. The concentration of SEBS did not significantly influence the processing parameters. The morphology was determined by SEM and TEM. The aPS/HDPE/SEBS blends exhibited fine dispersion of HDPE or aPS particles in the matrix and better adhesion at the interface. Higher concentration of SEBS resulted in better compatibility. Transmission electron micrographs confirmed the existence of the SEBS interfacial layer between the aPS and the HDPE phase. This effect was stronger in the blends with higher SEBS concentration and HDPE as matrix. From the mechanical properties, the tensile strength decreased while the elongation at break and the impact strength increased with the SEBS content. The results proved that SEBS acted as a compatibilizer in aPS/HDPE blends and its effect was more expressed in blends with a higher SEBS content and HDPE as matrix.

Jiansong et al. [4] studied the effect of the compatibilizer on the properties of ultra-high-molecular-weight polyethylene/liquid crystalline (UHMWPE/LCP) polymer composites compatibilized with polyethylene-grafted maleic anhydride (PE-g-MAH) prepared by compression molding. The effect of the compatibilizer on the mechanical, thermal, and tribological properties of the UHMWPE/LCP composites was investigated, based on the evaluation of the composite properties and examination of the fracture sections by means of scanning electron microscopy. It was found that the incorporation of the PE-g-MAH contributed to decrease the melting points of the composites and decrease their crystallinity to some extent. Moreover, the inclusion of the PE-g-MAH compatibilizer helped to greatly increase the tensile rupture strength and tensile modulus of the composites, which was beneficial to improving the wear resistance. Such improvements in the tensile and tribological behavior of the UHMWPE–matrix composites by the PE-g-MAH compatibilizer could be closely related to the enhanced cross-linking function of the composites in the presence of the compatibilizer.

Sani et al. [19] studied the effect of styrene/ethylene-butylene/styrene (SEBS) and blend ratio on the chemical resistance of polystyrene/polypropylene (PS/PP) blends. Using a twin-screw extruder, blends of PS rich PS/PP (composition ranging of 90–60 wt% PS) containing different amount of SEBS were prepared and injection moulded to be evaluated for chemical resistance. The results showed that the chemical resistance of PS to acetone and tetrahydrofuran (THF) increased with increasing PP content. The chemical resistance of PS/PP blends increased with increasing SEBS content at relatively lower PP content but decreased with increasing SEBS content at higher PP content. Dynamic mechanical analysis showed that 60/40/25 PS/PP/SEBS blends had better miscibility than 60/40/5 PS/PP/SEBS blends. However better miscibility did not result in enhanced chemical resistance since SEBS itself was affected by the chemicals.

Alessandra et al. [20] studied the properties of high density polyethylene/ ultra-high molecular weight polyethylene (HDPE/UHMWPE) blends prepared by mixing in a melted state at concentrations ranging from 10 to 30 wt% UHMWPE in an intermeshing co-rotating twin screw extruder (ICTSE). For abrasive resistance of the blends, the volumetric loss of the blends decreased with increasing concentration of UHMWPE. The mechanical properties of the blends in terms of flexural, tensile, and impact strength; in general, the HDPE/UHMWPE blends had a good set of properties, most of which were better than the properties of pure HDPE. From thermal analysis of samples by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA), no significant difference was observed between the blends and pure HDPE. The morphological analysis conducted by scanning electron microscopy (SEM) showed that the UHMWPE was present in the HDPE matrix as a second phase, but there was a good interface between the two phases.

Azman Hassan, et al. [3] investigated the effect of blend ratio on mechanical properties of high impact acrylonitrile-butadiene-styrene/polycarbonate (ABS/PC). Blends of ABS and PC were prepared in different ratios by melt blending technique using a twin screw extruder. A super high impact ABS at different weight ratios was incorporated into the blends to study the effects of blend ratio on the properties of the blend. This study focused upon tensile, flexural, impact and creep properties of ABS/PC blends. PC offered an improvement in tensile properties for this blend. With the increasing content of PC in ABS/PC blends, both the tensile strength and Young's Modulus of the blends were increased. Both the flexural strength and modulus show a marked increase with increasing PC content. In general, impact strength increased with increasing PC content. However, sudden drop in the impact strength value occurred when small amount of PC (20 wt%) was added to the blends. The creep resistance of neat PC exhibited the highest value while neat ABS has the lowest value. The optimum formulation for the ABS/PC blends based on the mechanical properties and cost was 40: 60 ABS/PC blend ratio.

Sanchez-Solis, et al. [21] evaluated the processing and properties of poly ethylene terephthalate/styrene-butadiene rubber (PET/SBR) blend. The mixing of incompatible polymers such as PET and SBR produced a blend with a poor mechanical, due to polymeric phase interact weakly with each other and segregate. The use of SBR grafted with maleic anhydride (MAH) increased the compatibility of SBR-PET system by generating higher interactions and chemical link between ingredients of the blend. The induced compatibility was reflected in the impact resistance of the blend as compared to that of pure PET. The grafting reaction to produce SBR-g-MAH was carried out by reactive extrusion using a reaction initiator, benzoyl peroxide (BPO), and the extent of the reaction depended on the content of MAH and BPO. Results indicated the close relationship between processing conditions and microstructural parameters, such as particle diameter and interparticle distances of the dispersed rubber phase, necessary to achieve the optimum impact resistance.

Shi-Ai Xu, et al. [22] studied the compatibilization of polystyrene /high density polyethylene (PS/HDPE) blends by using a tri-block copolymer styrene/ethylene-butylene/styrene (SEBS) as a compatibilizer. The blends were prepared by a twin-screw extruder. The mechanical properties of the blends were greatly improved after addition of SEBS, suggesting the compatibilizing role of the tri-block copolymer in the immiscible PS/HDPE system. From the morphology of the blends observed by scanning electron microscopy (SEM), the copolymer was very efficient in reducing the size of the dispersed phase, and that a co-continuous two-phase structure appeared as the content of SEBS increased to 4 wt%. The results of a SEM study of the fracture surfaces of the tensile bars showed that the unmodified and modified blends exhibited different fracture characteristics. From the melt rheology of the blends investigated by capillary rheometry, the melt viscosity of the blends increased after the addition of 4 wt% SEBS. The thermal properties of these blends measured by a differential scanning calorimeter (DSC) indicated that the SEBS content did not affect the glass transition temperature of the polystyrene phase and the melting point of the polyethylene phase in the blends.

CHAPTER 3
EXPERIMENTAL

3.1 Materials

1. Powder of ABS with a melt flow index of 0.28 g/10 min of 220 °C/10 kg (ASTM D1238) was supplied by Thai ABS Co., Ltd..
2. UHMW resin with a molecular weight of 3.2 x 10^6g/mol and a mean particle size of about 122 μm. was supplied by IRPC Public Co. Ltd., Rayong, Thailand.
3. The polyethylene-grafted maleic anhydride compatibilizer, PE-g-MAH, of grafting degree 1.6 wt%, was supplied by the Chemtura Corp Co..
4. Triblock copolymer, poly styrene/ethylene-butylene/styrene (SEBS), G 1650 (with the content of 29 wt% of PS and ethylene/butylene, EB as rubbery middle block) was purchased from Shell Chemicals, (USA).

3.2 Instruments

1. Sieve shakers: (Model 200LS-N, Hosokawa Alpine)
2. High speed mixer: (Model 3L, Lab Tech Engineering)
3. Twin screw co-rotating extruder: (Model LTE 22-32, Lab Tech Engineering)
4. Grinder: (Mode LZ-120/VS, LAB TECH Engineering)
5. Injection mold machine (For test specimen): (Mode NEX80, Nissei plastic)
6. Tensile strength: (Model 5565, Instron)
7. Izod impact testing: (Model Im pactor, Ceast)
8. Hardness testing: (Model SHR-150CP, M & L Testing Equipment)
9. Differential scanning calorimetry (DSC): (Model DSC1, Mettler Toledo)
10. Scanning electron microscope (SEM): (Model JSM-6400, JEOL)
11. Xenon weather o-meter: (Model Atlas ci 65A, Primary Supply)
12. Abrasion tester: (Model 5155, Taber Industries)

3.3 Experimental

3.3.1 Preparation of UHMWPE Powder

A representative weighed sample of UHMWPE powder was poured into the top sieve which has the largest screen openings. After the shaking was completed, the material on each sieve was weighed. The size of the average particles on each sieve was analysed to get the cut-point or specific size range captured on screen. The suitable size required on the range 100 - 200 μm was obtained for testing.

3.3.2 Preparation of ABS/UHMWPE Blends

The ABS/UHMWPE (90/10 w/w) blends were prepared at various amount of compatibilizer (PE-g-MAH and SEBS). The effect of various compatibilizer in the composites based on the phr of compatibilizer (0, 3, 5, 7) and the weight ratio of ABS and UHMWPE (0-25 wt% UHMWPE) in form of powder are presented in Table 3.1.

The effect of compatibilizer (PE-g-MAH and SEBS) contents on the properties of ABS/UHMWPE blends were studied (formulation no. 1-7). The effect of various UHMWPE ratio of the blends (100/0, 95/5, 90/10, 85/15, 80/20, and 75/25) with 5 phr of SEBS block copolymer added to blends was also studied. Then, all materials were prepared by direct blending at room temperature by high speed mixer at 500 rpm for 5 minutes and continuously at 700 rpm for 20 seconds for each formulation.

Figure 3.1 High speed mixer for mixing powder of ABS/UHMWPE blends

Table 3-1 Formulation of ABS/UHMWPE blends

Polymer blends		Compatibilizer (phr)	
No.	Formulation	PE-g-MAH	SEBS
1	90/10 (w/w) ABS/ UHMWPE	0	0
2	90/10 (w/w) ABS/ UHMWPE	0	3
3	90/10 (w/w) ABS/ UHMWPE	0	5
4	90/10 (w/w) ABS/ UHMWPE	0	7
5	90/10 (w/w) ABS/ UHMWPE	3	0
6	90/10 (w/w) ABS/ UHMWPE	5	0
7	90/10 (w/w) ABS/ UHMWPE	7	0
8	ABS	0	5
9	95/5 (w/w) ABS/ UHMWPE	0	5
10	90/10 (w/w) ABS/ UHMWPE	0	5
11	85/15 (w/w) ABS/ UHMWPE	0	5
12	80/20 (w/w) ABS/ UHMWPE	0	5
13	75/25 (w/w) ABS/ UHMWPE	0	5

3.3.3 Extrusion

The ABS/UHMWPE blends were extruded by using vented screw extruder Nissei Mode NEX80. A Twin screw co-rotating extruder has a screw diameter of 45 mm and L/D ratio of 32:1. The temperature profiles were 180, 190, 195, 200 and 210 ^{o}C for feed zone, the compression zone, the metering and die end, respectively. The screw speed was held at 120 rpm. The extrudate was pelletized. After passing through cooling water at 30 ^{o}C, using a strand cutter. These pellet samples were dried at 85 ^{o}C for 2 hours and then molded to form test specimens for mechanical testing by injection molding.

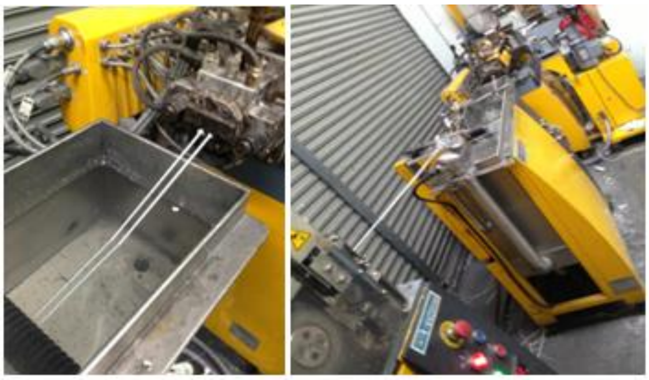


Figure 3.2 Twin screw extruder for pelletizing of ABS/UHMWPE blends

3.3.4 Specimen Preparation

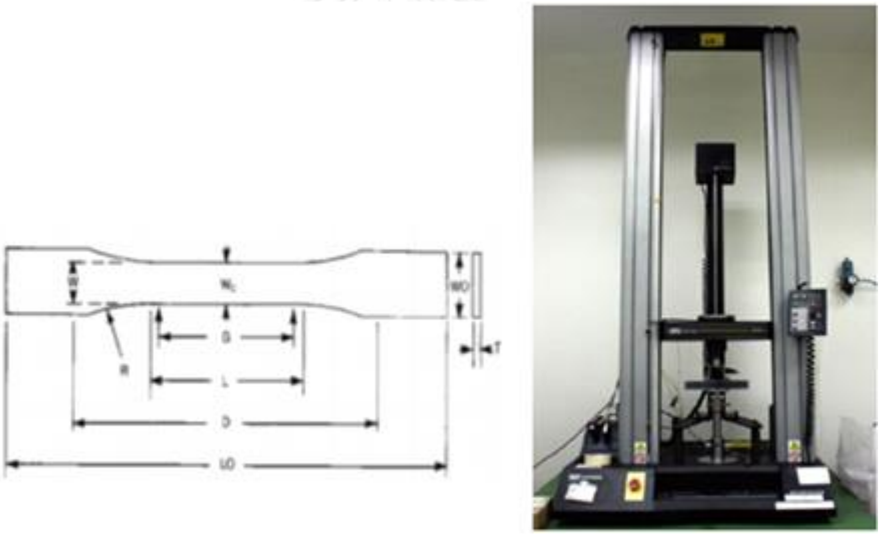
Test specimens for mechanical testing were prepared by injection molding (Nissei Mode NEX80) at 300 kg/cm^3 injection pressure, with 3 and 5 seconds of injection and cooling times, serially, followed by cooling at ambient temperature. The temperature profiles were 190, 200, 210 and 220 ^{o}C for the feed zone, the compression zone, the metering and nozzle end respectively. The screw speed was held at 200 rpm.

Figure 3.3 Injection molding for specimen preparation of ABS/UHMWPE blends

3.4 Physical Properties Testing

3.4.1 Tensile Testing (ASTM D638) [23]

The tensile test was carried out on a Universal testing machine (LLOYD Instrument LR 10K Plus) with crosshead speed of 5 mm/min at the test condition of 23 ± 2 ^{o}C and 50 ± 5 % relative humidity. The width and thickness of test specimen were measured by using digital micrometer with the resolution 0.001 mm. An average of five specimens was considered as a representative value. The results of tensile properties were determined as an average. The dumb-bell specimens are shown in Figure 3.4.

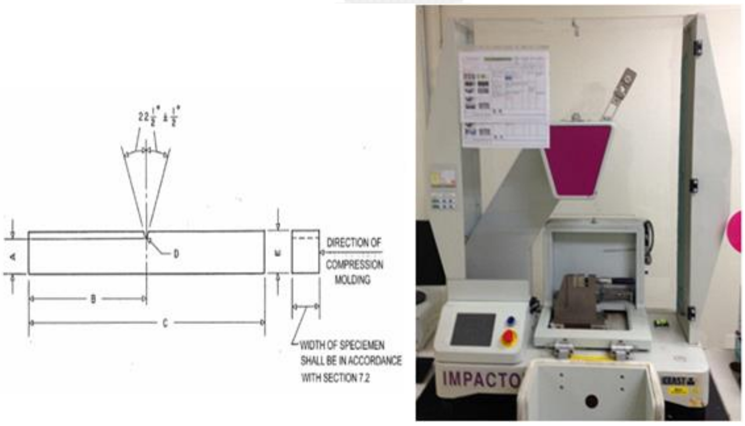


W : 13 mm WO : 19 mm G : 50 mm R : 76 mm
L : 57mm LO : 165 mm D : 115 mm T : 4 mm or under

Figure 3.4 Tensile test specimen (type I) [23] and tensile tester

3.4.2 Impact testing (ASTM D256) [24]

The test specimen is conformed to the dimensions and geometry as shown in Figure 3.5. Impact properties were studied using an Izod-Charpy Impact Tester (Impact tester GOTECH GT 7045). Impact test was performed according to notched Izod impact strength (ASTM D256). The total impact energy of 2.7 J was selected. The width of each specimen was measured in the region of the notch with a micrometer caliper and recorded its average width along with its identifying marking. The test specimen was put in a horizontal position so that it would be impacted edgewise at its center on the face opposite the notch for notched specimens. The breaking energy of the specimen was estimated and a pendulum of suitable energy was selected. The pendulum was released and the excess energy remaining in the pendulum was recorded after breaking the specimen, together with a description of the appearance of a broken specimen. The average impact energy was calculated in the group of specimens. The impact resistance was reported as impact strength (kg-cm/cm^2) that was the failure energy divided by the cross section area of the sample.



Unit: mm

A : 10.16 ± 0.05 B : 31.8 ± 1.0 C : 63.50 ± 2.0
D : 0.25 ± 0.05 E : 12.70 ± 0.20

Figure 3.5 Dimensions of simple, impact test specimen [24] and Impact tester

3.4.3 Hardness Testing (ASTM D785) [25]

The hardness was measured by Rockwell hardness tester SHR-150CP at standard laboratory atmosphere of 23 ± 2 °C (73.4 ± 3.6 °F) and 50 ± 5 % relative humidity. The test specimen had a minimum thickness of 2 mm. The specimen was prepared by injection molding. Care was taken that the test specimen had parallel flat surface to ensure good seating on the anvil and thus avoid the deflection that would be caused by poor contact. Data were averaged over six different positions.

3.4.4 Abrasion Test (Din 53516) [26]

The abrasion test was used to determine the resistance of material with relation to the frictional loss of a specimen by Taber Industries Model 5155. The abrasion resistance was measured by moving a test specimen across the surface of an abrasive sheet mounted to a revolving drum and expressed as volume loss. For volume loss, a smaller number indicates better abrasion resistance. The test specimen (10x10 cm. in square size and minimum thickness of 2 mm) are abraded in pure sliding motion against an abrasive paper grade 3M adhesive 200MP, rotating at 72 rev/min (revolutions/minute). The specimen holder arm moved parallel to cylinder axis, providing a contact normal force. After rotating of 1000 rev was reached, the specimen was automatically lifted from the equipment and weighted. Five test specimens of each composition were tested. The volumetric loss was averaged to abrasion resistance index in percent.

Figure 3.6 Abrasion tester

3.5 Thermal Properties of ABS/UHMWPE Blends

Differential scanning calorimetry (DSC) is a technique used to study thermal transitions of a polymer. Thermal transitions are the changes that take place in a polymer when it is heated or cooled at a controlled rate. The melting temperatures (T_m) of ABS/UHMWPE blends were obtained from a differential scanning calorimeter (DSC1, METTLER TOLEDO, Figure 3.7). The sample in aluminium pan was heated up to 200 ^{o}C with a constant heating rate of 10 ^{o}C/min under nitrogen of 50 mL/min atmosphere. The melting temperatures (T_m) are taken as the maximum of two endothermic peaks from the midpoint of the baseline shift of DSC thermogram.

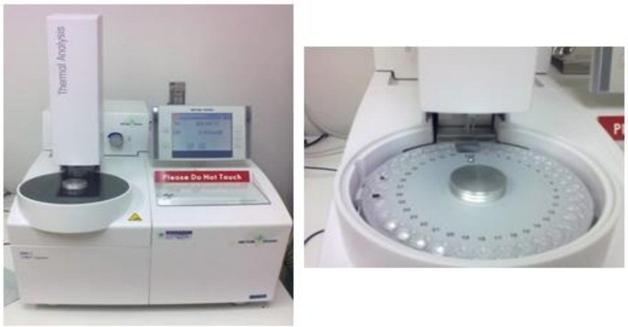


Figure 3.7 Differential Scanning Calorimeter (DSC)

3.6 Morphological Study of ABS/UHMWPE Blends

The morphology of the ABS/UHMWPE blends was observed with a SEM (JEOL JSM-6400 SEM) at an accelerating voltage of 15 kV and a magnification of 5000. All the samples were fractured after immersion in liquid nitrogen for about 10 min. The fracture surface was then coated with a thin layer of gold.

3.7 Accelerated Weathering Test (ASTM G155) [27]

The Weathering test is the basic principles to simulate the direct natural exposure by using xenon arc light and water apparatus intended to reproduce the weathering effect that occur when materials are exposed to sunlight. The one set of test specimen was placed in Xenon weathering (Model Atlas ci 65A, Primary Supply, Fig 3.8) with Xenon arc lamp source for 100, 250, 500 and 1000 h. The radiant energy was filtered to provide a spectral power distribution closely to the earthly daylight. The conditions were as follows, temperature = 63 ± 3 ^{o}C, RH = 50 ± 5 %, irradiance 0.35 w/m^{2}, UV wavelength = 340 nm, spraying time = 18 min and dry interval between spraying time = 102 min, according to ASTM G155. This experimental have appeared with focus on the effect of accelerated weathering testing in term of % retention of tensile strength and impact resistant.

For accelerated weathering, the retention rate is defined as follows;

$$\text{Retention (\%)} = \frac{\text{Properties after weathering}}{\text{Properties before weathering}} \times 100 \qquad (3.1)$$

Figure 3.8 Xenon weather o-meter

CHAPTER 4
RESULTS AND DISCUSSION

This research work was divided into two parts. The effectiveness of compatibilizer types PE-g-MAH and SEBS and contents are primarily determined by comparing the compatibility of the ABS/UHMWPE blends. This study focused on the properties of blend at various contents (3, 5 and 7 phr) of SEBS and PE-g-MAH. The ABS/UHMWPE blends without compatibilizers is the representative of the initial properties.

The second part focused on the effect of UHMWPE compositions in ABS/UHMWPE blends. The properties of blends with 5 phr of SEBS at various content of UHMWPE (0, 5, 10, 15, 20 and 25 wt%) were studied. The mechanical properties, the morphology, the thermal properties and the effect by accelerated weathering were investigated.

4.1 Effect of Compatibilizers Types and Contents

4.1.1 Physical Properties of ABS/UHMWPE Blends

The mechanical properties were determined mainly to investigate the behavior of ABS/UHMWPE blends at various content, of PE-g-MAH and SEBS. The mechanical properties of the polymer blends without compatibilizers and with different contents, of compatibilizer are summarized in Table 4.1.

Table 4-1 Effect of PE-g-MAH or SEBS content on tensile strength (TS), elongation at break (EB), impact strength (IS), hardness (HD) and abrasion (AR) of ABS/UHMWPE blends.

Polymer blends	Compatibilizer		Mechanical properties				
ABS/UHMWPE (w/w)	PE-g-MAH	SEBS	TS (MPa)	EB (%)	IS (kg-cm/cm^2)	HD (R-scale)	AR (%)
90/10	0	0	180	85	12.8	40	0.86
			(3.78)	(2.59)	(0.36)	(4.64)	(0.02)
90/10	0	3	168	68	15.3	43	0.64
			(4.93)	(3.36)	(0.43)	(2.59)	(0.02)
90/10	0	5	165	73	16.4	45	0.53
			(3.74)	(2.41)	(0.24)	(2.07)	(0.01)
90/10	0	7	160	76	18.1	46	0.36
			(6.69)	(1.95)	(0.35)	(1.22)	(0.02)
90/10	3	0	155	64	13.2	40	0.78
			(7.23)	(2.30)	(0.48)	(2.30)	(0.02)
90/10	5	0	154	70	14.1	41	0.71
			(8.63)	(2.07)	(0.64)	(2.28)	(0.02)
90/10	7	0	150	73	15.3	43	0.55
			(7.92)	(1.95)	(0.43)	(4.12)	(0.03)
ABS (Reference)			182	86	13.1	38	0.89

4.1.1.1 Effect of Compatibilizers on Tensile Properties

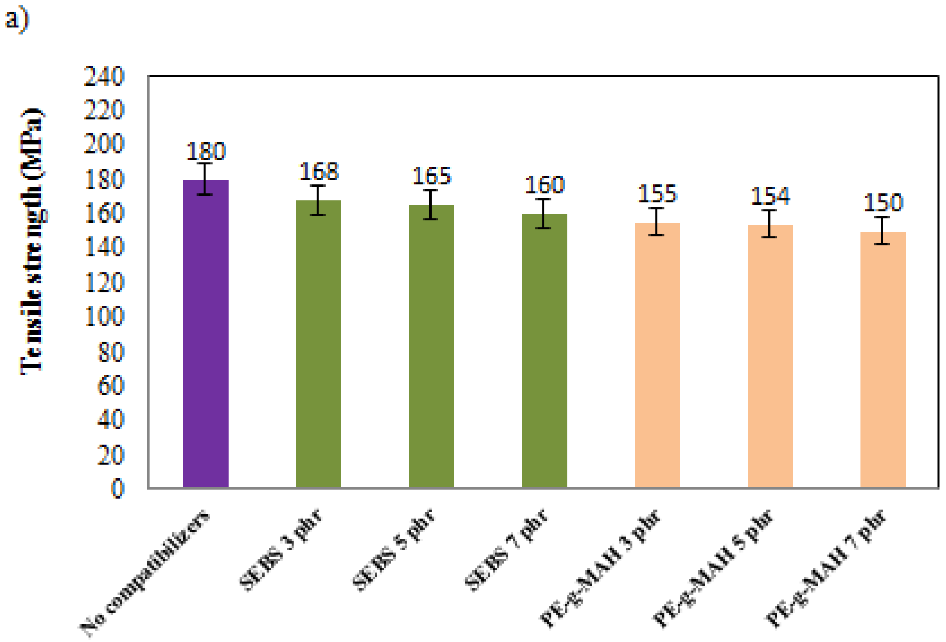
The mechanical properties of the 90/10 (w/w) ABS/UHMWPE blends at various content of SEBS and PE-g-MAH compatibilizers are summarized in Table 4.1.

The tensile strength (TS) and elongation at break (EB) of ABS/UHMWPE blends with compatibilizer were lower than that of the blend without compatibilizer. The low mechanical properties of the blends may be due to the heterogeneous UHMWPE distribution in ABS, as can be seen from morphology from SEM micrographs (section 4.1.2). It can be observed that the blends had a two-phase morphology of the immiscibility of UHMWPE which was a uniform distribution phase in the ABS matrix [29].

The tensile strength decreased while the elongation at break increased with increasing SEBS and PE-g-MAH content. After the addition of compatibilizers to the blend, a completely different tensile behavior was observed. The addition of compatibilizers slightly reduced the tensile strength. This suggests that the tensile strength of compatibilized blends is determined not only by the interfacial adhesion but also by the strength of the matrix that is highly affected by the amount of the compatibilizer [18].

In contrast to the tensile strength, the ABS/UHMWPE blend displayed an elastic behavior as indicated by the high value of elongation at break, which exhibited the characteristics of partially miscible UHMWPE with ABS matrix [22]. The result was confirmed by the morphology observed from SEM micrographs (section 4.1.2).

The ABS/UHMWPE blend with SEBS compatibilizer provided higher tensile strength and elongation at break than the blends with PE-g-MAH compatibilizer. The effect of compatibilizer content on the tensile strength and elongation at break is shown in Figure 4.1. The UHMWPE/ABS blends with SEBS had a higher tensile strength and elongation at break than the blends with PE-g-MAH. This can be explained that the SEBS provided a better compatibility and better adhesion of ABS/UHMWPE blends than PE-g-MAH. The increase in the elongation at break could be due to the good compatibility between the two polymers, which was be evidenced by the good interfacial adhesion observed in the SEM micrographs [22].



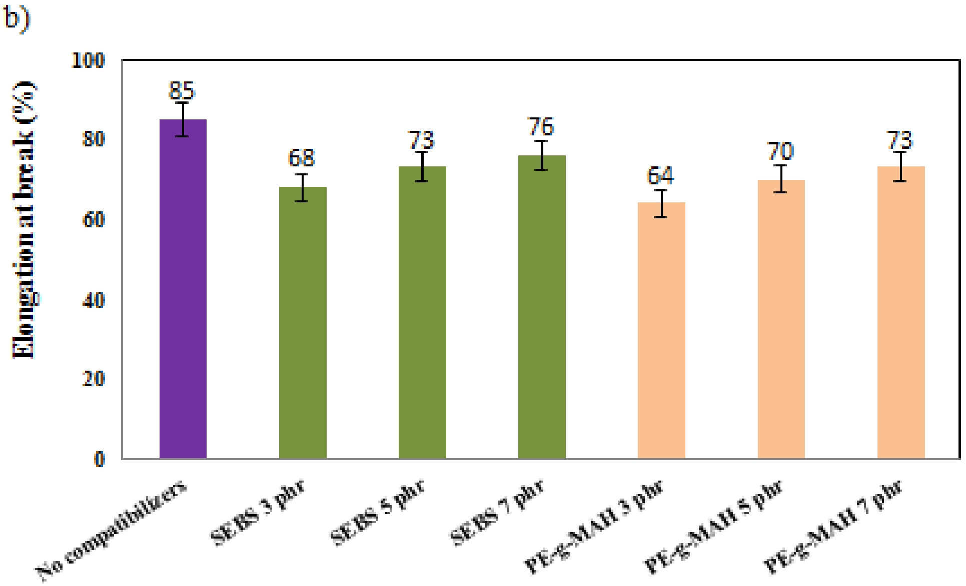


Figure 4.1 Effect of compatibilizers on: a) tensile strength b) elongation at break of 90/10 (w/w) ABS/UHMWPE blends

4.1.1.2 Effect of Compatibilizers on Impact Strength

UHMWPE is an engineering plastic that has very high impact strength about five times of ABS [25]. For ABS, the major factors on the impact strength include rubber-matrix adhesions, matrix molecular weight, matrix composition, glass transition temperature of the rubber, test temperature, strain rate, and orientation [7]. As a result, the impact strength of the polymer blends depends on dispersed particle size and interfacial adhesion. As can be seen in SEM micrographs, the impact strength of the blends was strongly dependent upon the blend morphology.

Figure 4.2 represents the effect of compatibilizers on the impact strength of the ABS/UHMWPE blends. The results revealed that the impact strength of blends increased when compatibilizer were added and tended to increase with increasing compatibilizer content. The results of the impact strength and the elongation at break indicated that the properties of modified ABS/UHMWPE blends were not improved unless the compatibilizer was used. It can be explained by weak interfacial adhesion and poor dispersion of the components, which is characteristic for incompatible polymer blends and documented by SEM micrographs. The presence of compatibilizer leads to an increase in the adhesion between the UHMWPE particles and the ABS matrix and a decrease in the dispersed phase size. In the latter case, it is known that the size of dispersed particles has a dramatic effect on the deformation behavior. The ductility increases with finer phase dispersions due to the lower resultant stress concentration when a small particle cracks [18].

For the effect of SEBS and PE-g-MAH compatibilizers, the improvement in the impact strength upon addition of SEBS more than PE-g-MAH was confirmed by the higher impact strength. The similar result was earlier reported by Xu, et al. [22].

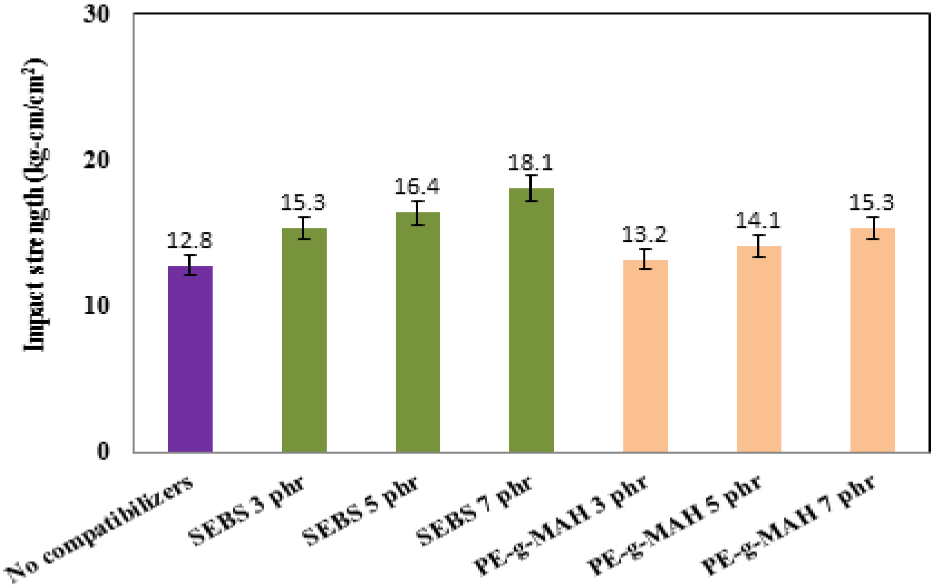


Figure 4.2 Effect of compatibilizers on impact strength of 90/10 (w/w) ABS/UHMWPE blends

4.1.1.3 Effect of Compatibilizers on Hardness and Abrasion Resistance

UHMWPE has the remarkable properties of excellent abrasion resistance, impact resistance, fatigue resistance, and chemical resistance, and it is commonly compared to engineering polymers. The hardness and abrasive wear is caused by hard asperity on the counterface and/or hard particles that move over the polymer surface [9].

Figure 4.3 and 4.4 show the effect of compatibilizers on hardness and abrasion of ABS/UHMWPE blends. Likewise the impact property, the addition of compatibilizer to the ABS/UHMWPE blends provided an increase in its hardness and abrasion properties and tended to increase with increasing compatibilizer content. It can be explained by the good compatibility between the two polymers, which can be evidenced by the good interface observed in the SEM micrographs (section 4.1.2). The compatibilizers addition could improve the distribution and the pullout of

UHMWPE particles in ABS matrix, allowing this phase to contribute to the excellent resistance of the material to abrasive wear [20].

For the effect of SEBS and PE-g-MAH compatibilizers, the improvement in the hardness and abrasive wear upon addition of SEBS could be observed more than PE-g-MAH and this could be explained similarly to the impact strength improvement.

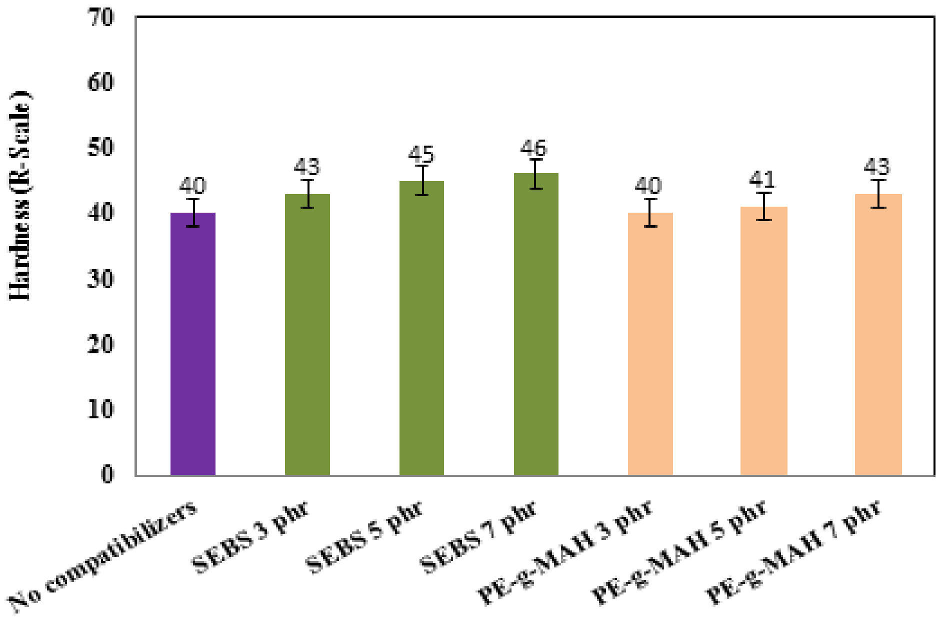


Figure 4.3 Effect of compatibilizers on hardness of 90/10 (w/w) ABS/UHMWPE blends

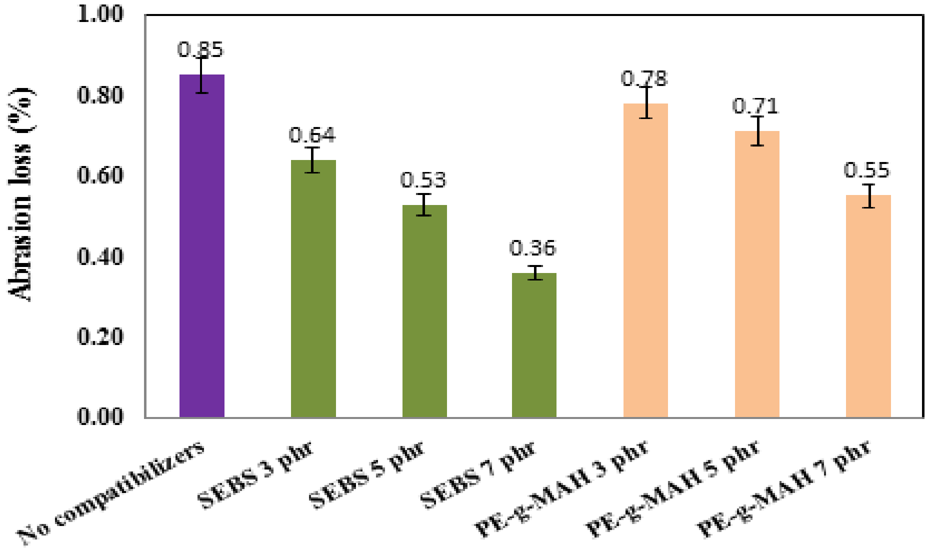


Figure 4.4 Effect of compatibilizers on abrasion resistance of 90/10 (w/w) ABS/UHMWPE blends

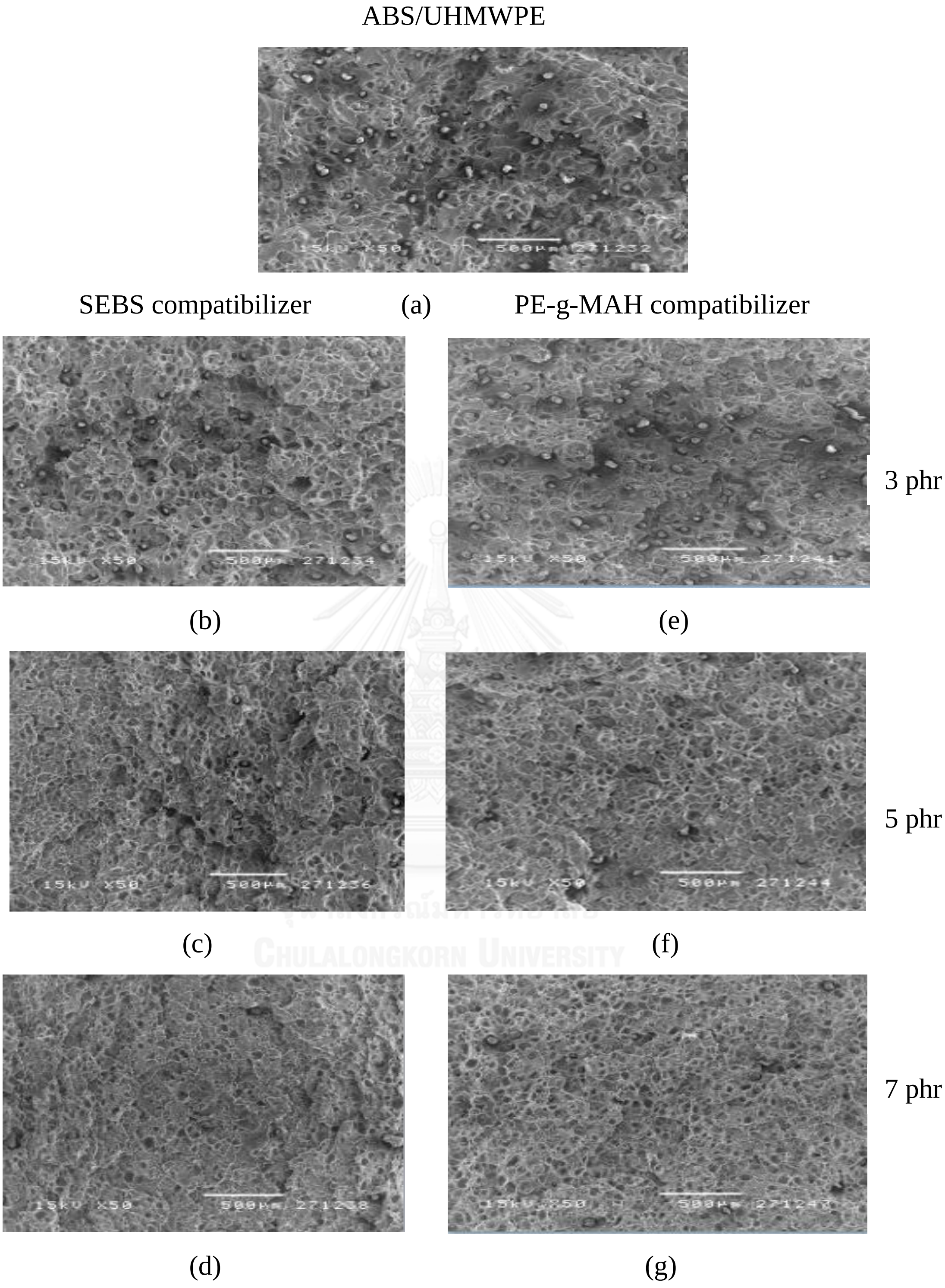
4.1.2 Morphology of ABS/UHMWPE Blends

The scanning electron microscope was employed to investigate morphology and compatibility of 90/10 (w/w) ABS/UHMWPE blends. The SEM micrographs revealing the fracture surface of ABS/UHMWPE blend without compatibilizer are shown in Figure 4.5(a) and 4.6(a). Representative SEM micrographs of ABS/UHMWPE blends with various ratios of compatibilizers are shown in Figure 4.5(b-g) and 4.6(b-g).

From the morphology of pure ABS/UHMWPE blends without compatibilizers (Figures 4.5 a and 4.6 a), there exists a presence of two phases with the sharp edges of particles and holes on the fracture surface indicating the poor interfacial adhesion. The coarse morphology of the blends and the detachment of dispersed UHMWPE particles in ABS matrix confirmed the poor adhesion at the interface between the homopolymers [18].

From the morphology of ABS/UHMWPE blends with SEBS and PE-g-MAH (Figures 4.5 b-g and 4.6 b-g), the binary blends exhibited coarsely dispersed UHMWPE particles in the ABS matrix. This incident can be observed from the increase in diameter of dispersed phase size and higher rough fracture surfaces.

The addition of compatibilizer to the ABS/UHMWPE blends provided more compatibility and tended to increase compatibility with increasing compatibilizer content. Certainly for the addition of SEBS as a compatibilizer, the blends showed a finer and more homogeneous dispersion of UHMWPE particles than the addition of PE-g-MAH. It also indicated that SEBS addition provided a better compatibility in ABS/UHMWPE blends than PE-g-MAH addition that has been verified by the good impact resistance and other mechanical properties of the ABS/UHMWPE/SEBS blends [19].



(a)

(b) (e)

(c) (f)

(d) (g)

Figure 4.5 SEM micrographs of fracture surface of 90/10 (w/w) ABS/UHMWPE blends: (a) without compatibilizer and with compatibilizer (b) SEBS 3 phr; (c) SEBS 5 phr; (d) SEBS 7 phr; (e) PE-g-MAH 3 phr; (f) PE-g-MAH 5 phr; and (g) PE-g-MAH 7 phr (500x magnification).

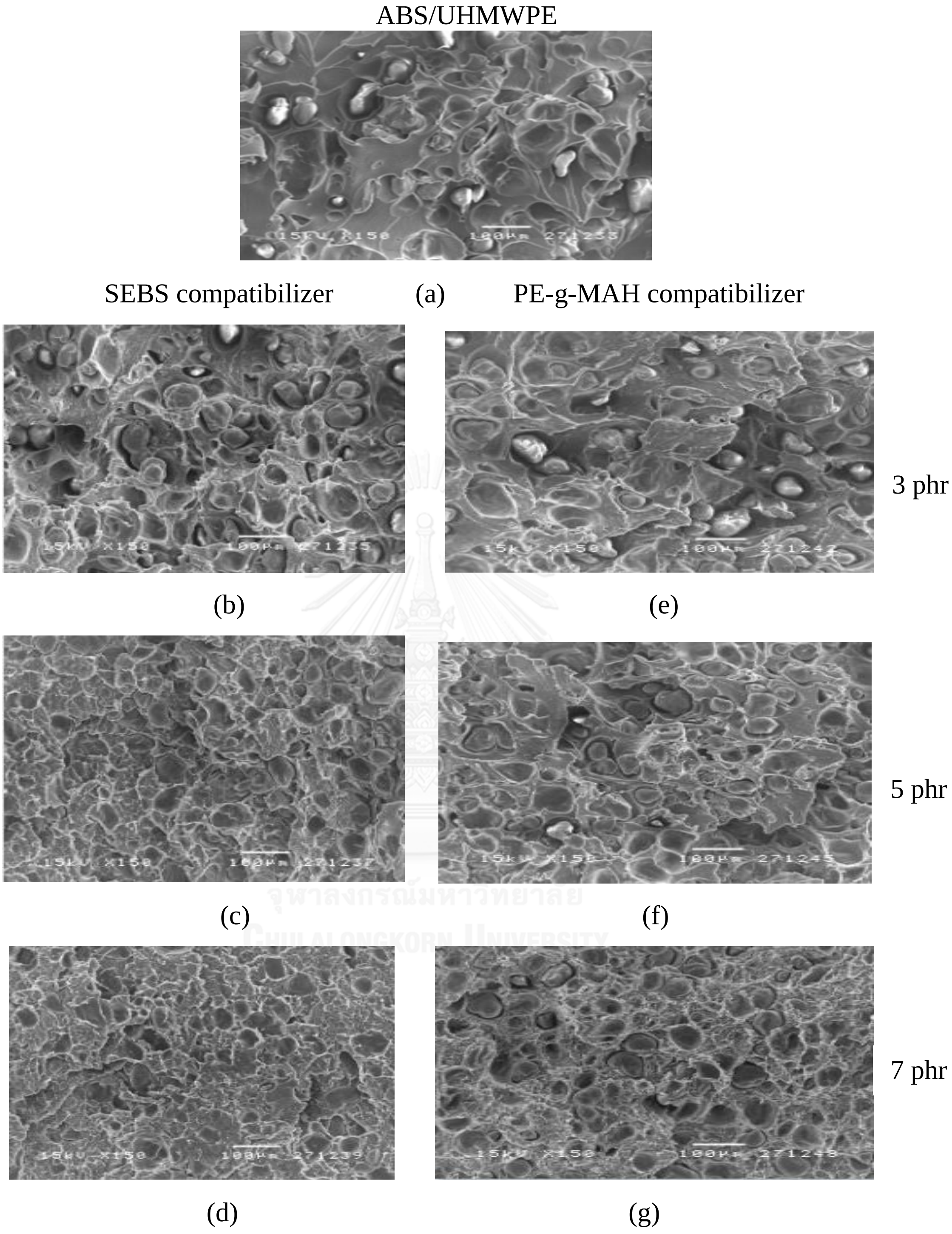


Figure 4.6 SEM micrographs of fracture surface of 90/10 (w/w) ABS/UHMWPE blends: (a) without compatibilizer and with compatibilizer (b) SEBS 3 phr; (c) SEBS 5 phr; (d) SEBS 7 phr; (e) PE-g-MAH 3 phr; (f) PE-g-MAH 5 phr; and (g) PE-g-MAH 7 phr (1000x magnification).

4.1.3 Thermal Properties of ABS/UHMWPE Blends

The thermal properties of ABS/UHMWPE blends were investigated by DSC in the temperature range 50 – 200 ^{o}C. The effect of temperature on the thermal behavior of ABS/UHMWPE blends, which focus on the melt temperature of UHMWPE is shown in Figure 4.7.

The pure UHMWPE and the ABS/UHMWPE blends without compatibilizers revealed the melt temperature 136 ^{o}C in DSC thermograms. All the blends expressed the same melt temperature with only one melting peak, which was attributed to the backbone structure of the UHMWPE and did not change with the compatibilizers content [4]. This may be due to that both SEBS and PE-g-MAH did not affect the melt temperature of the blends. This behavior was normally observed for immiscible polymer blends in melt state.

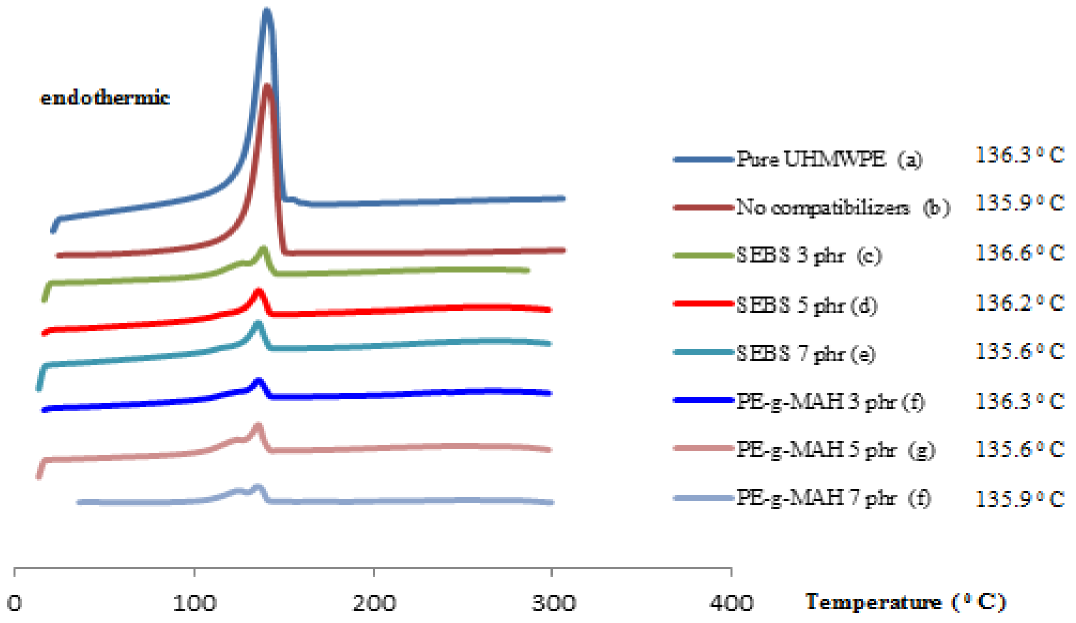


Figure 4.7 DSC thermograms of 90/10 (w/w) ABS/UHMWPE blends: (a) without compatibilizer and with compatibilizer (b) SEBS 3 phr; (c) PE-g-MAH 3 phr; (d) SEBS 5 phr; (e) PE-g-MAH 5 phr; (f) SEBS 7 phr; and (g) PE-g-MAH 7 phr.

4.1.4 Weathering Test of ABS/UHMWPE Blends

Environmental exposure can affect almost any material, including plastics, rubbers, composites, paints and coatings, metals, textiles and much more. Certain accelerated weathering testing is required to ensure materials or products meet regulatory standards in environmental exposure. Accelerated weathering allows manufacturers to evaluate performance of their products under extreme conditions, providing a documented basis of comparison and detailed information that can be critical to production planning and specifications.

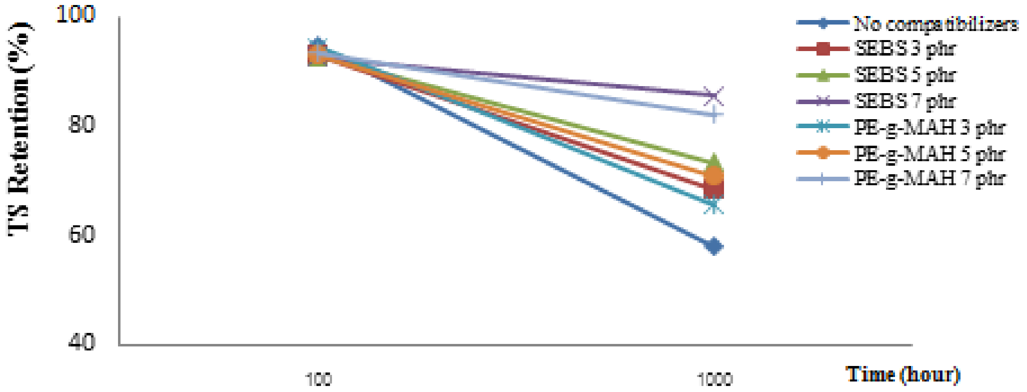
In this work, the effect of accelerated weathering via Xenon weathering on the mechanical properties of ABS/UHMWPE blends at various contents of compatibilizers are studied and the result of Xenon weathering at 100, 250, 500, and 1000 h are presented in the Table 4.2. This study focused on the effect of accelerated weathering testing in term of retention of tensile strength and impact resistance. The % retention of blend with SEBS and PE-g-MAH compatibilizers at 0-7 phr are plotted versus time, 100 and 1000 h as shown in Figure 4.8.

From Figure 4.9, the % retention of tensile strength, elongation at break and impact strength of ABS/UHMWPE blends with compatibilizer was higher than that without compatibilizer. For the effect of compatibilizer content, % retention increased with increasing compatibilizer content indicating the improvement of weathering resistance. It also convinced that the addition of SEBS gave longer term stability against degradation by irradiation than that of PE-g-MAH.

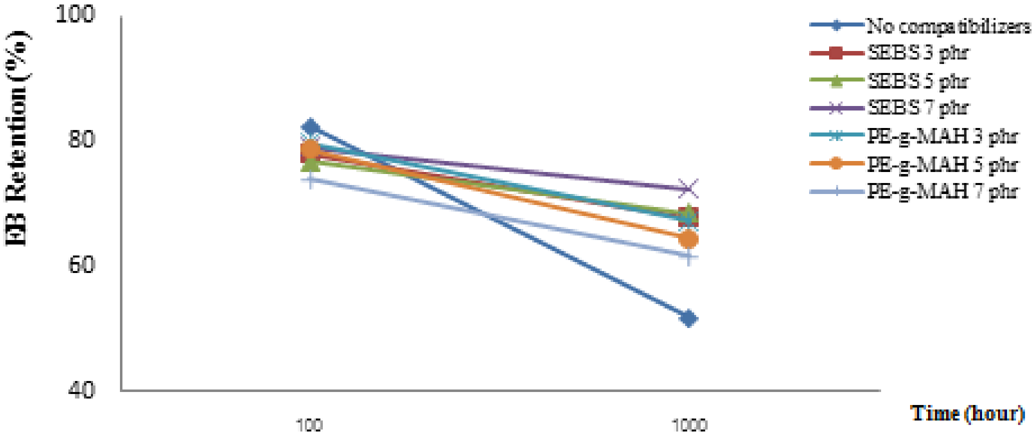
Table 4-2 Effect of compatibilizer on mechanical properties after accelerated weathering in Xenon weathering meter.

Polymer blends		Mechanical properties after accelerated weathering					
		TS	Retention	EB	Retention	IS	Retention
ABS/UHMWPE/Compat.	Time (hr)	(MPa)	(%)	(%)	(%)	(kJ/m^2)	(%)
ABS	100	170 (2.88)	94.4	70 (2.95)	82.4	10.8 (0.18)	84.4
	250	163 (1.82)	90.6	61 (3.11)	71.8	9.8 (0.16)	76.6
	500	132 (2.07)	73.3	53 (1.34)	62.4	8.5 (0.27)	66.4
	1000	104 (1.58)	57.8	44 (1.52)	51.8	7.3 (0.15)	57.0
90/10/3 SEBS	100	156 (1.64)	92.9	53 (2.00)	77.9	15.1 (0.16)	98.7
	250	155 (1.82)	92.3	52 (3.29)	76.5	13.9 (0.16)	90.8
	500	145 (1.41)	86.3	46 (1.67)	67.6	12.8 (0.17)	83.7
	1000	115 (2.59)	68.4	42 (1.67)	61.7	12.4 (0.22)	81.0
90/10/5 SEBS	100	153 (2.45)	92.7	56 (1.34)	76.7	16.0 (0.35)	97.6
	250	150 (2.68)	90.9	55 (1.00)	75.3	15.6 (0.13)	95.1
	500	148 (2.17)	89.7	50 (1.58)	68.5	14.7 (0.15)	89.7
	1000	121 (1.67)	73.3	47 (1.52)	64.4	13.5 (0.22)	82.3
90/10/7 SEBS	100	148 (2.07)	92.5	60 (1.87)	78.9	17.7 (0.26)	97.8
	250	143 (1.22)	89.4	58 (1.41)	76.3	17.0 (0.29)	93.9
	500	140 (1.14)	87.5	55 (1.79)	72.4	16.5 (0.33)	91.2
	1000	137 (1.79)	85.6	50 (0.84)	65.8	15.2 (0.13)	84.0
90/10/3 PE-g-MAH	100	146 (1.82)	94.2	51 (2.07)	79.7	12.6 (0.18)	95.5
	250	142 (1.64)	91.6	50 (2.05)	78.1	12.5 (0.19)	94.7
	500	130 (2.59)	79.9	43 (1.00)	67.2	11.3 (0.13)	85.6
	1000	103 (1.58)	70.8	41 (1.64)	64.1	10.7 (0.21)	81.1
90/10/5 PE-g-MAH	100	143 (1.87)	92.9	55 (1.52)	78.6	13.5 (0.11)	95.7
	250	141 (2.55)	91.6	50 (0.71)	71.4	13.3 (0.38)	94.3
	500	123 (1.92)	79.9	50 (2.28)	71.4	12.1 (0.18)	85.8
	1000	109 (1.52)	70.8	45 (1.58)	64.3	11.6 (0.18)	82.3
90/10/7 PE-g-MAH	100	140 (2.30)	93.3	54 (1.48)	74.0	14.9 (0.25)	97.4
	250	139 (1.30)	92.7	51 (2.07)	69.9	14.5 (0.17)	94.8
	500	130 (4.02)	86.7	47 (1.30)	64.4	13.9 (0.22)	90.8
	1000	123 (1.64)	82.0	45 (1.48)	61.6	12.7 (0.20)	83.0

a)


TS Retention (%)
100
80
60
40
100
1000
Time (hour)
No compatibilizers
SEBS 3 phr
SEBS 5 phr
SEBS 7 phr
PE-g-MAH 3 phr
PE-g-MAH 5 phr
PE-g-MAH 7 phr

b)


EB Retention (%)
100
80
60
40
100
1000
Time (hour)
No compatibilizers
SEBS 3 phr
SEBS 5 phr
SEBS 7 phr
PE-g-MAH 3 phr
PE-g-MAH 5 phr
PE-g-MAH 7 phr

c)

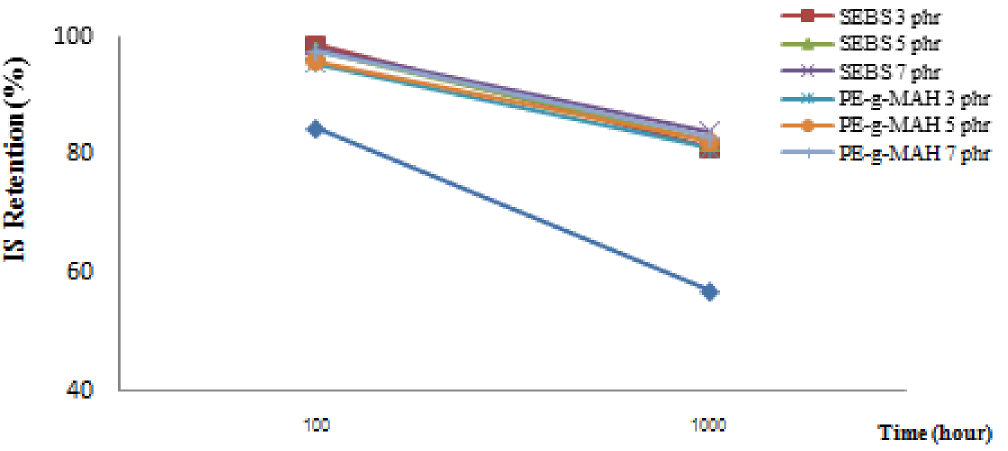

IS Retention (%)
100
80
60
40
100
1000
Time (hour)
No compatibilizers
SEBS 3 phr
SEBS 5 phr
SEBS 7 phr
PE-g-MAH 3 phr
PE-g-MAH 5 phr
PE-g-MAH 7 phr

Figure 4.8 Effect of compatibilizer content on accelerated weathering on: (a) tensile strength; (b) elongation at break; (c) impact strength of 90/10 (w/w) ABS/UHMWPE blends

4.2 Effect of UHMWPE on Physical Properties and Morphology of ABS/UHMWPE Blends

4.2.1 Physical Properties of ABS/UHMWPE Blends

The mechanical properties of ABS/UHMWPE blends with 5 phr SEBS compatibilizer were determined to investigate the effect of ABS/UHMWPE ratio on blend behavior and compatibility and the results are summarized in Table 4.3.

Table 4-3 Effect of ABS/UHMWPE ratio on the mechanical properties of ABS/UHMWPE blends, tensile strength (TS), elongation at break (EB), impact strength (IS), hardness (HD) and abrasion resistance (AR).

Polymer blends ABS/UHMWPE	Compatibilizer	Mechanical properties				
	SEBS (phr)	TS (MPa)	EB (%)	IS (kg-cm/cm^2)	HD (R-scale)	AR (%)
ABS	5	182	86	13.1	38	0.89
		(1.64)	(1.22)	(0.23)	(0.89)	(0.02)
95/5	5	175	80	17.9	48	0.49
		(1.34)	(1.64)	(0.14)	(1.64)	(0.02)
90/10	5	165	73	16.4	45	0.53
		(1.22)	(1.92)	(0.08)	(1.92)	(0.02)
85/15	5	150	55	16.0	43	0.56
		(2.05)	(1.92)	(0.32)	(2.41)	(0.02)
80/20	5	148	53	15.7	42	0.65
		(0.84)	(1.30)	(0.27)	(1.64)	(0.01)
75/25	5	144	52	15.6	42	0.66
		(1.48)	(1.10)	(0.28)	(1.14)	(0.01)

4.2.1.1 Effect of UHMWPE on Tensile Properties

Table 4.3 and Figure 4.9 represent the effect of UHWPE on the tensile strength and elongation at break of the ABS/UHMWPE blends.

The tensile strength and elongation at break of ABS/UHMWPE blends was lower than that of ABS. The low mechanical properties of blends may be due to the heterogeneous UHMWPE distribution in ABS, as can be seen from morphology from SEM micrographs (section 4.2.2). The explanation is similar to that for blends with various contents of compatibilizers which already discussed earlier in section 4.1.2.

The tensile strength and elongation at break of blends (5 phr SEBS compatibilizer) decreased with increasing UHMUPE content. According to these results, the addition of UHMWPE higher than 5 wt% in ABS/UHMWPE blends did not improve the mechanical properties of blends. Moreover, the addition of more UHMWPE showed the decreasing tensile strength and elongation at break. This could be related to the effect of the compatibilizer on the interfacial bonding of the composites. Thus, the optimized interfacial bonding was realized at 5 wt% UHMWPE, whilst an excess amount of UHMWPE led to weakened interfacial bonding and more severe structural inhomogeneity of the blend, resulting in lower tensile strength and elongation at break.

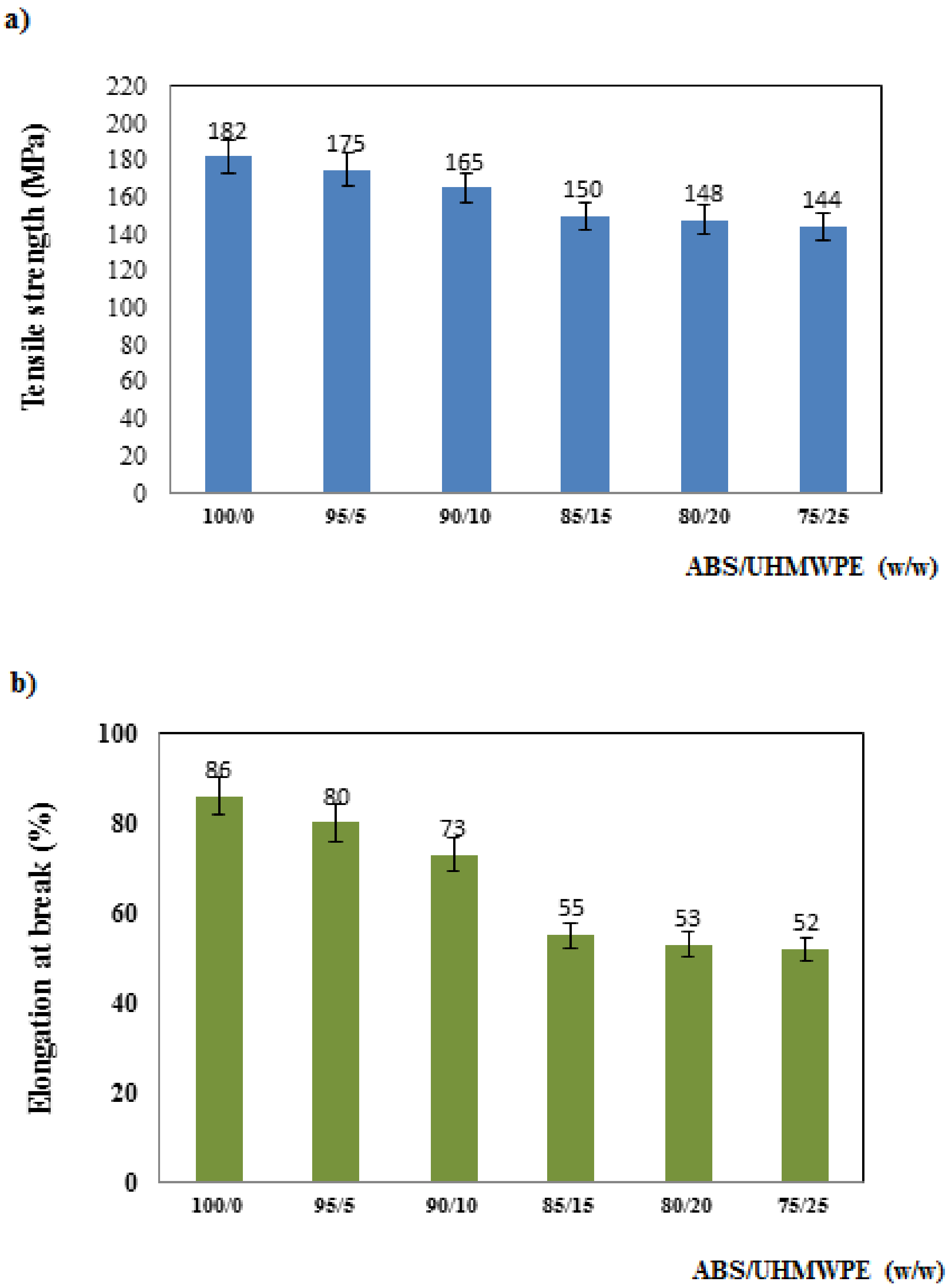


Figure 4.9 Effect of ABS/UHMWPE ratio on: (a) tensile strength; (b) elongation at break of blends with 5 phr SEBS**.**

4.2.1.2 Effect of UHMWPE on Impact Strength

Figure 4.10 shows the effect of UHMWPE content on the impact strength of the ABS/UHMWPE blends. The impact strength of ABS/UHMWPE blends was improved when UHMWPE were added. It could be clearly seen that ABS/UHMWPE blends had higher impact strength than pure ABS. This might be explained that the higher impact property of UHMWPE could lower the stiffness of ABS that it contained rubber in their molecules.

Considering the impact strength of blends at various UHMWPE content, the impact strength of ABS/UHMWPE blend was highest at 5 wt% UHMWPE content and was gradually decreased with increasing UHMWPE content. It should be noted that the stiffness of ABS/UHMWPE blends exhibited a small change at high UHMWPE content (15 – 25 wt%). It can be explained that an excess UHMWPE led to weak interfacial adhesion and poor dispersion of the components, and this was confirmed by the morphology from SEM micrograph (section 4.2.2).

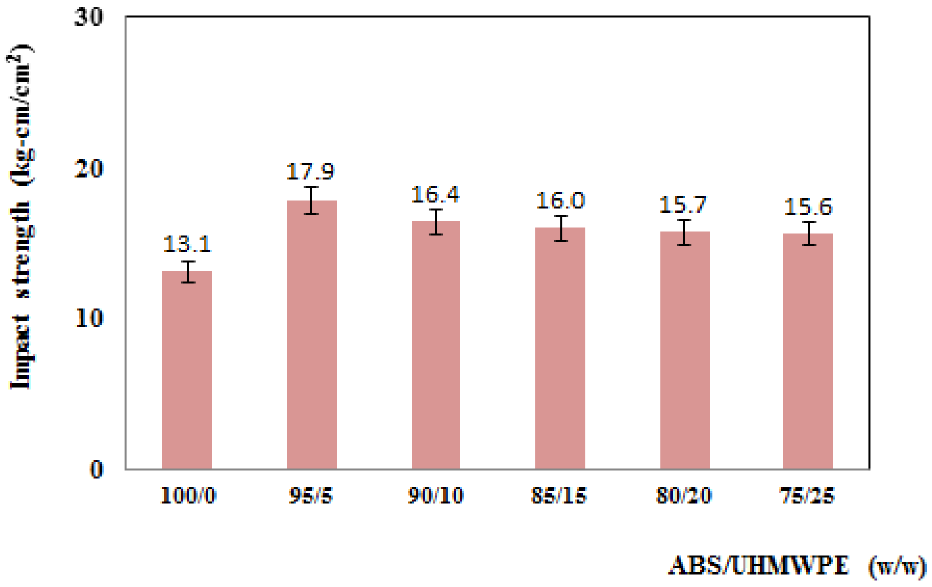


Figure 4.10 Effect of UHMWPE content on impact strength of ABS/UHMWPE blends (5 phr SEBS)

4.2.1.3 Effect of UHMWPE on Hardness and Abrasion Resistance

The effect of UHMWPE content on hardness and abrasion resistance of the ABS/UHMWPE blends was investigated by varying the UHMWPE content of 5, 10, 15, 20 and 25 wt%. The hardness and abrasion resistance of ABS/UHMWPE blends (with 5 phr SEBS) are shown in Figure 4.11 and Figure 4.12. From these Figure, the hardness and abrasion resistance of ABS/UHMWPE blends were enhanced when UHMWPE were added. This can be explained by the stiffness from UHMWPE. Furthermore, the hardness of blends decreased with increasing UHMWPE content and exhibited a small change at high UHMWPE content (15 – 25 wt%). These results could be explained similar to the impact property improvement.

The optimum content of the UHMWPE in the ABS/UHMWPE blends (with 5 phr SEBS) was 5 wt%. Higher content of the UHMWPE did not offer further significant improvement in the mechanical properties. This is simply due to the fact that incorporation of the appropriate amount of UHMWPE and SEBS in ABS blend resulting in good compatibility.

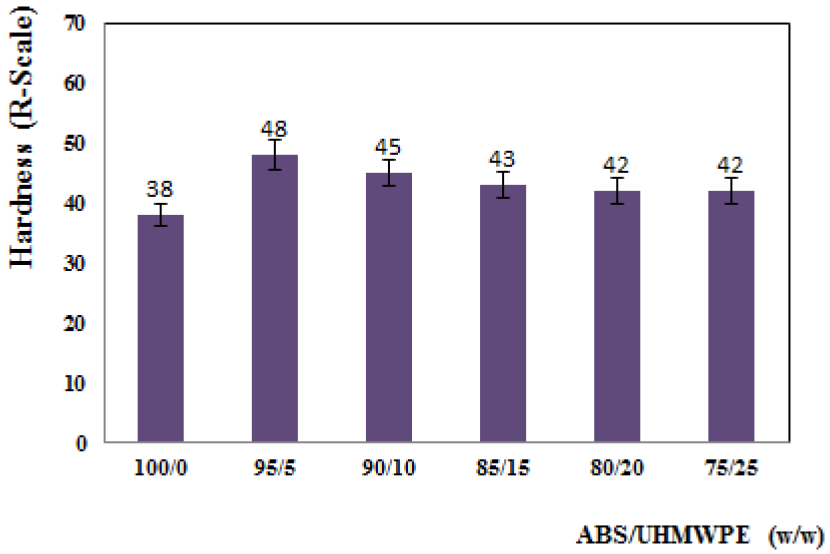


Figure 4.11 Effect of UHMWPE content on hardness of ABS/UHMWPE blends (5 phr SEBS)

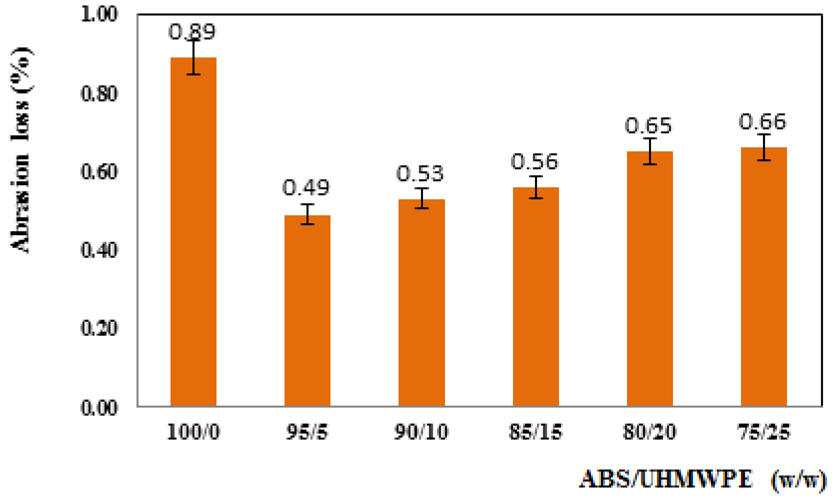
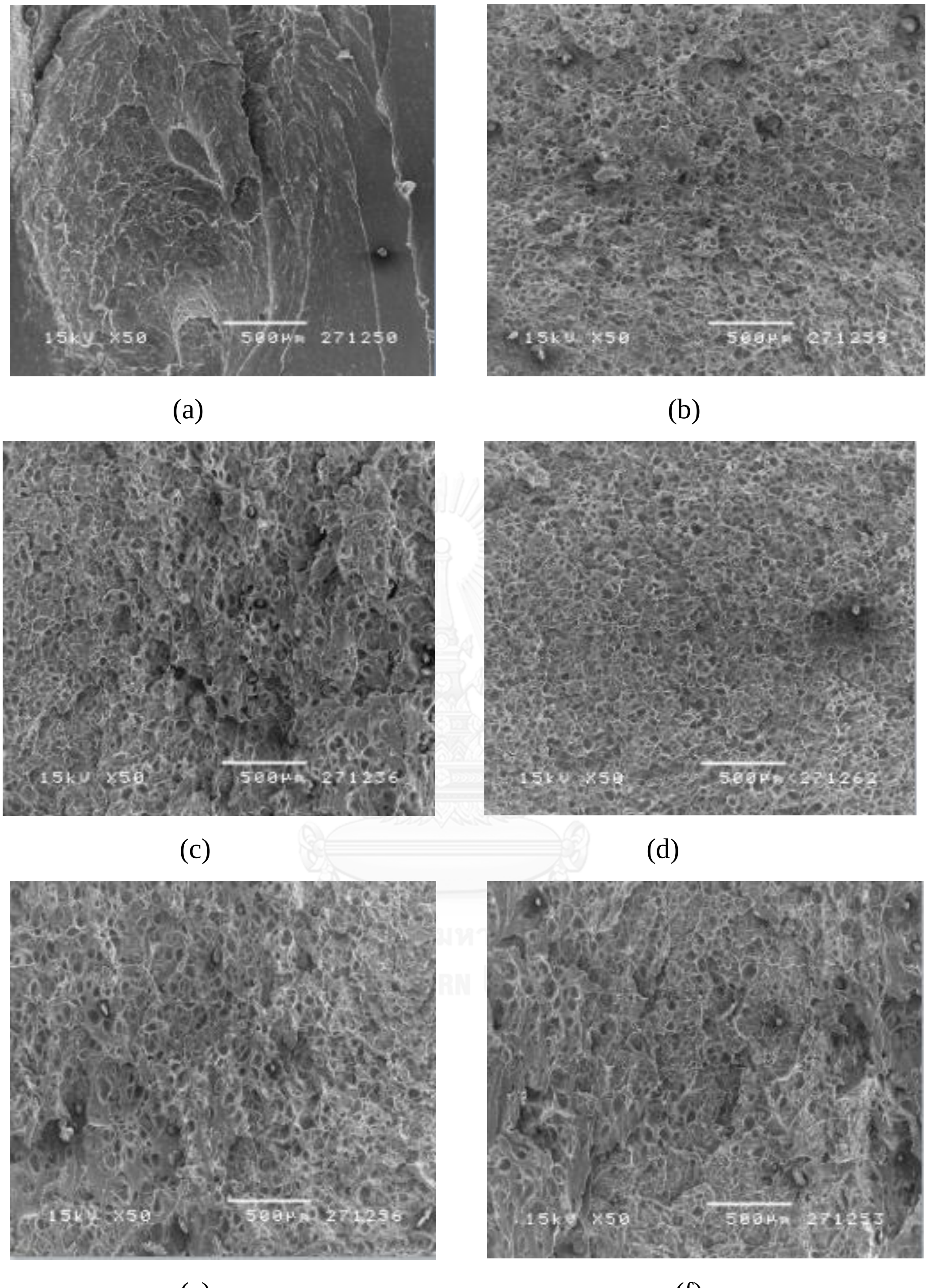


Figure 4.12 Effect of UHMWPE content on abrasion resistance of ABS/UHMWPE blends (5 phr SEBS)

4.2.2 Morphology of ABS/UHMWPE Blends

The SEM micrographs revealing the fracture surface of ABS without UHMWPE are shown in Figure 4.13(a) and 4.14(a). Representative SEM micrographs of ABS/UHMWPE blends at various ratios of ABS/UHMWPE are shown in Figure 4.13(b-g) and 4.14 (b-g). The presence of two phases was clearly observed that the particles of UHMWPE dispersed in the ABS matrix. The incompatibility between ABS and UHMWPE increased with increasing UHMWPE content from 5 to 25 wt%. This incident could be observed from the increasing diameter of dispersed phase size and higher rough fracture surface. The smooth fracture surface implied the brittle property of blend as well as the rough surface referred to the ductility of the dispersed UHMWPE phase [30].

Moreover, the addition of more UHMWPE showed a heterogeneous dispersion of UHMWPE particles. It also indicated that an excess UHMWPE content led to the damage to the interfacial bonding of the ABS/UHMWPE blends [4].

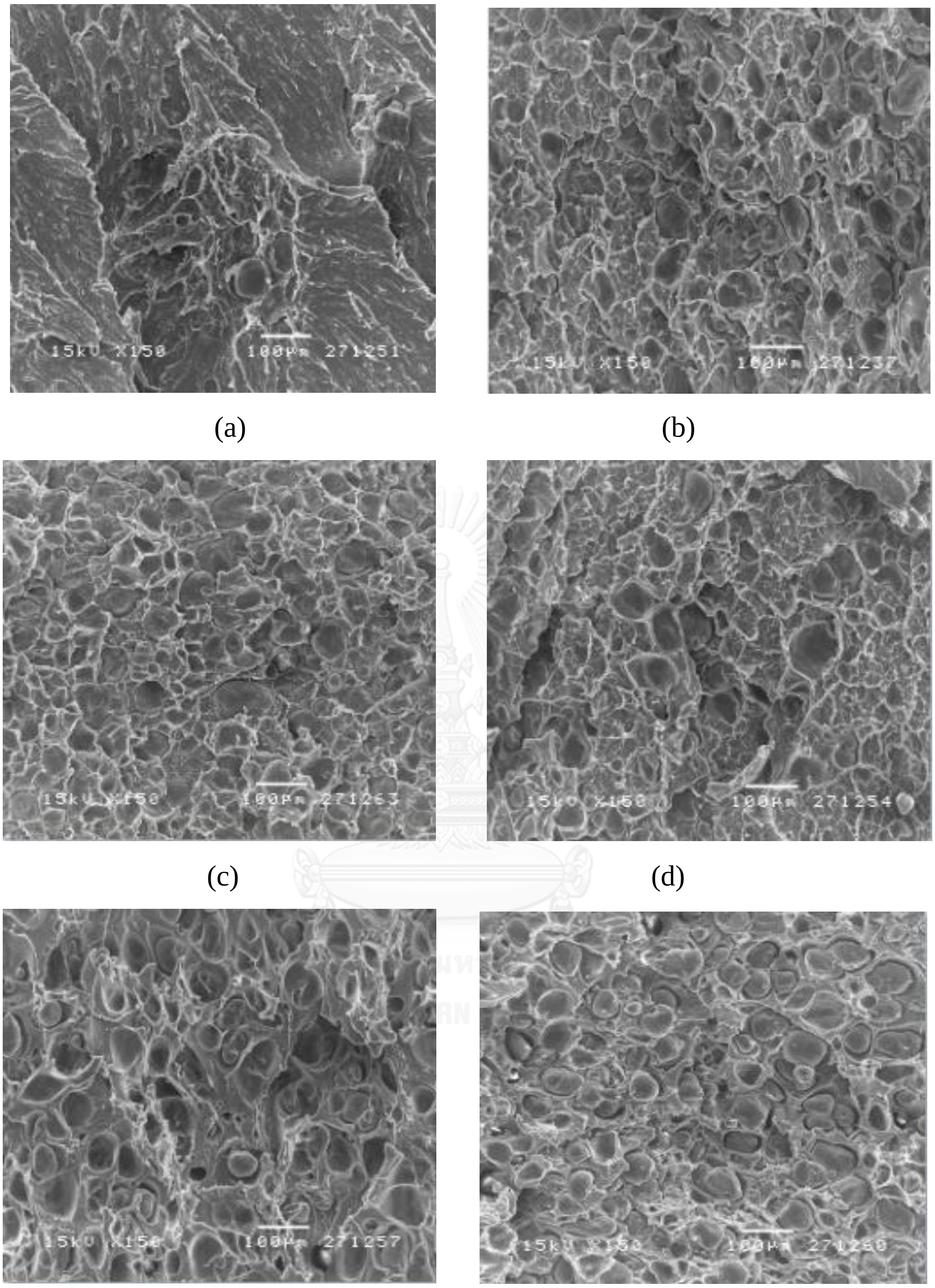


(a) (b)

(c) (d)

(e) (f)

Figure 4.13 SEM micrographs of fracture surface of ABS/UHMWPE blends (with 5 phr SEBS): (a) ABS; (b)-(f) ABS/UHMWPE blends, (b) 95/5; (c) 90/10; (d) 85/15; (e) 80/20 and (f) 75/25 (500x magnification).



(a) (b)

(c) (d)

(e) (f)

Figure 4.14 SEM micrographs of fracture surface of ABS/UHMWPE blends (with 5 phr SEBS): (a) ABS; (b)-(f) ABS/UHMWPE blends, (b) 95/5; (c) 90/10; (d) 85/15; (e) 80/20 and (f) 75/25 (1000x magnification).

4.2.3 Thermal Properties of ABS/UHMWPE Blends

The effect of UHMWPE content on thermal properties of ABS/UHMWPE blends were investigated by DSC in the temperature range 50 – 200 °C. The effect of temperature on the thermal behavior of ABS/UHMWPE blends focused on the melt temperature of UHMWPE was investigated.

Figure 4.15 presents the melt temperature of ABS/UHMWPE blends (with 5 phr SEBS) at various ABS/UHMWPE ratios in DSC thermograms. All the blends expressed only one melting peak at 136 °C on the DSC curves which implied that the amount of UHMWPE did not affect the melt temperature. The explanation is similar to that of compatibilizer effect (section 4.1.3).

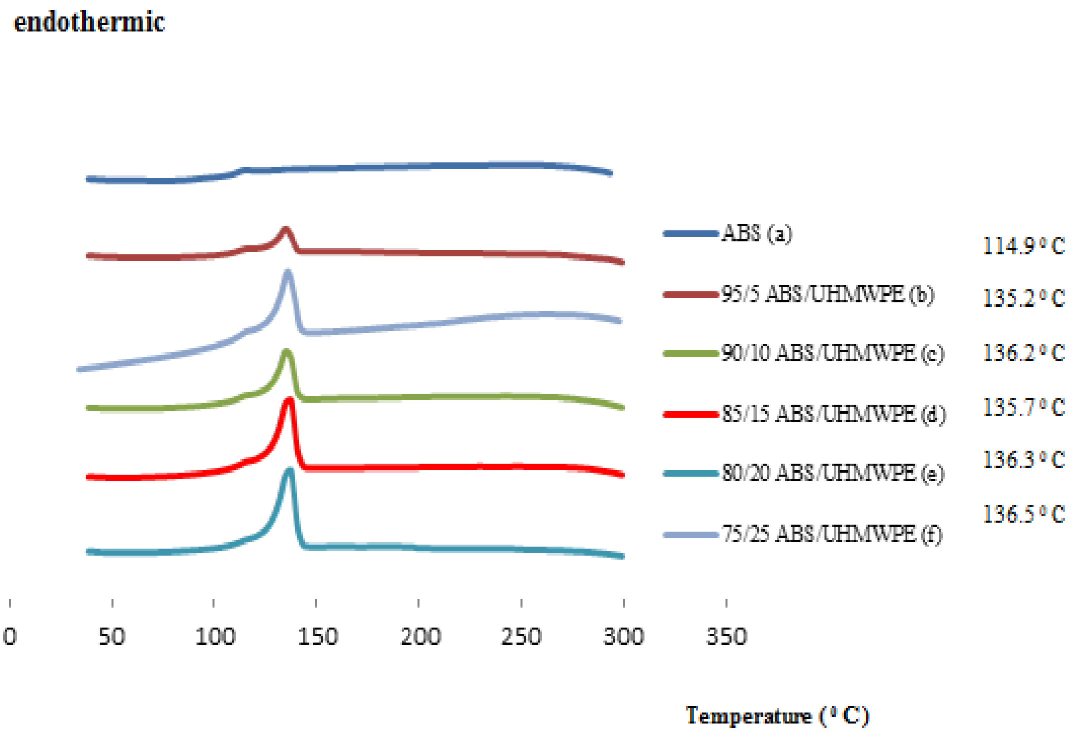


Figure 4.15 DSC thermograms of ABS/UHMWPE blends (with 5 phr SEBS): (a) ABS; (b)-(f) ABS/UHMWPE blends, (b) 95/5; (c) 90/10; (d) 85/15; (e) 80/20 and (f) 75/25

4.2.4 Weathering Test of ABS/UHMWPE Blends

In this section, the effect of accelerated weathering via Xenon weathering on the mechanical properties of ABS/UHMWPE blends at various ABS/UHMWPE ratios were investigated at Xenon weathering time of 100, 250, 500, and 1000 h. This study was focused on the % retention of tensile strength and impact strength.

Table 4.4 presents the mechanical properties after accelerated weathering of ABS/UHMWPE blends (5 phr SEBS) with various ABS/UHMWPE ratios. The % properties retention of blends with various compositions were plotted versus time, 100 and 1000 h as shown in Figure 4.16.

From Figure 4.16, % retention of tensile strength, elongation at break and impact strength of ABS/UHMWPE blends after accelerated weathering with UHMWPE was higher than that without UHMWPE. It should be noted that UHMWPE had good resistance to aggressive condition and high wear resistance whereas ABS had lower heat distortion temperature than 100 ^{o}C. This might be explained that the addition of UHMWPE improved the stability against degradation of ABS. In the other hand, it was found that all the blends with various ABS/UHMWPE ratios exhibited a little change in the % retention and it may be due to that UHMWPE was partially miscible with ABS matrix. This can be explained by the observed morphology from SEM micrographs (Fig. 4.13 (b) – (f), 4.14 (b) – (f)).

Table 4-4 Effect of UHMWPE on mechanical properties after accelerated weathering in Xenon weathering meter

Polymer blends ABS/UHMWPE (5phr SEBS)	Time (hour)	Mechanical properties after accelerated weathering					
		TS (MPa)	Retention (%)	EB (%)	Retention (%)	IS (kJ/m^2)	Retention (%)
ABS	100	139 (2.35)	76.4	63 (2.30)	73.7	9.0 (0.39)	68.7
	250	123 (2.07)	67.6	59 (1.58)	68.6	8.8 (0.25)	67.2
	500	96 (1.14)	52.7	51 (0.84)	59.3	8.4 (0.40)	64.1
	1000	86 (1.30)	47.3	45 (1.48)	52.3	7.3 (0.11)	55.7
95/5	100	162 (1.79)	92.6	65 (1.64)	81.3	17.4 (0.13)	97.2
	250	160 (2.24)	91.4	63 (1.00)	78.8	16.8 (0.09)	93.9
	500	155 (1.52)	88.6	59 (1.87)	73.8	16.1 (0.27)	89.9
	1000	129 (2.86)	73.7	53 (2.28)	66.3	15.3 (0.17)	85.5
90/10	100	153 (2.30)	92.7	56 (1.48)	76.7	16.0 (0.28)	97.6
	250	150 (1.58)	90.9	55 (1.22)	75.3	15.6 (0.22)	95.1
	500	148 (1.64)	89.7	50 (1.48)	68.5	14.7 (0.23)	89.6
	1000	121 (0.71)	73.3	47 (1.67)	64.4	13.5 (0.36)	82.3
85/15	100	140 (3.42)	93.3	46 (0.84)	83.6	15.6 (0.23)	97.5
	250	138 (2.17)	92.0	42 (1.10)	76.4	15.0 (0.32)	93.8
	500	135 (1.58)	90.0	40 (1.48)	72.7	14.9 (0.33)	93.1
	1000	109 (2.41)	72.7	34 (1.82)	61.8	13.6 (0.13)	85.0
80/20	100	139 (1.95)	93.9	44 (2.55)	83.0	15.2 (0.24)	96.8
	250	134 (1.52)	90.5	43 (2.77)	81.1	14.8 (0.17)	94.3
	500	130 (2.39)	87.8	40 (2.59)	75.5	13.4 (0.23)	85.4
	1000	108 (1.14)	73.0	33 (1.48)	62.3	12.7 (0.19)	80.6
75/25	100	133 (1.95)	92.4	42 (1.67)	80.8	14.4 (0.44)	92.3
	250	130 (2.07)	90.3	42 (1.64)	80.8	13.9 (0.19)	89.1
	500	139 (1.64)	89.69	38 (1.82)	71.1	13.1 (0.15)	84.0
	1000	109 (1.95)	75.7	34 (1.30)	65.4	12.9 (0.13)	82.7

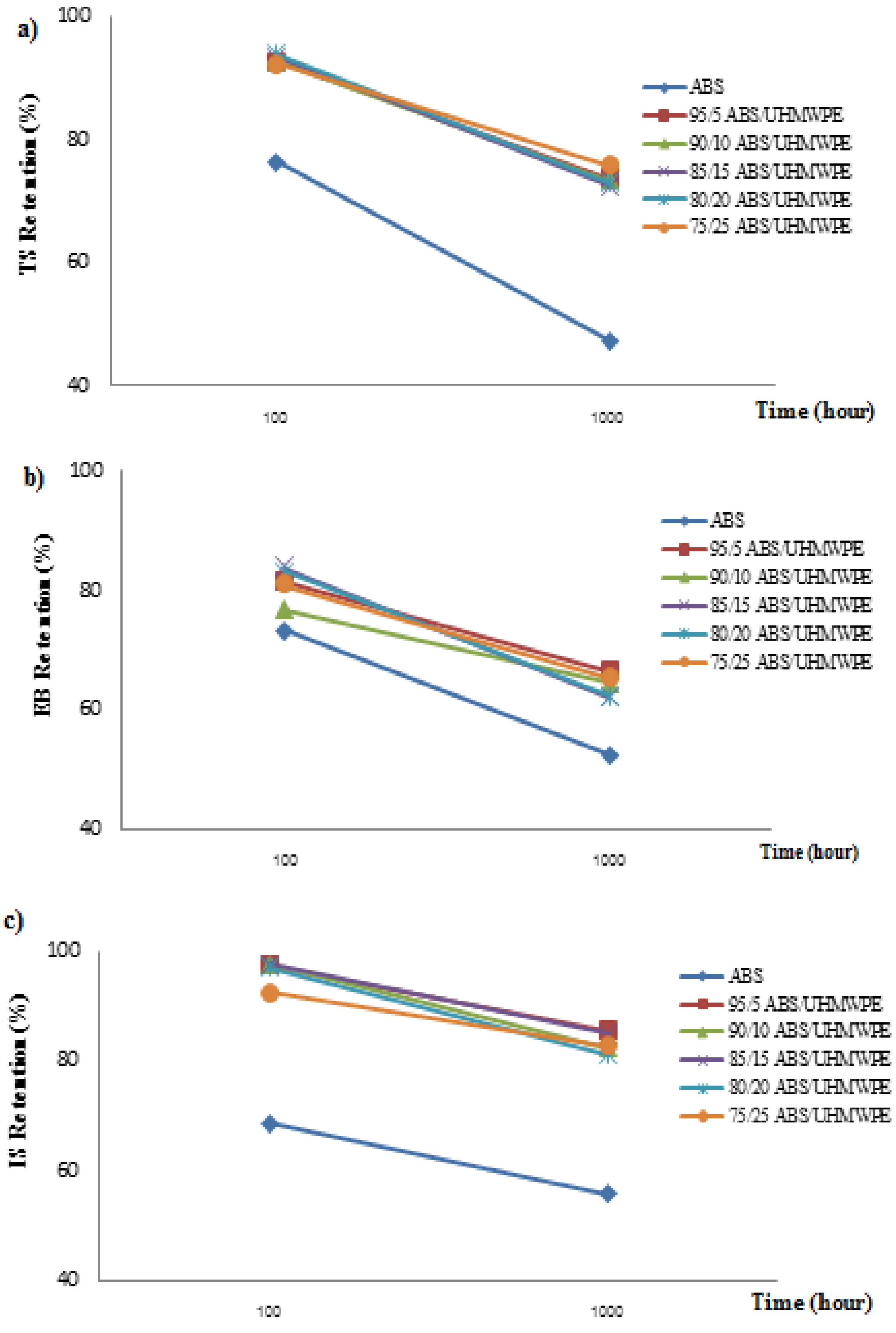


Figure 4.16 Effect of UHMWPE content on accelerated weathering of ABS/UHMWPE (a) Tensile strength; (b) Elongation at Break; (c) Impact Strength

4.3 Economic aspects of production

The Cost analysis of raw materials used in this research, which is a reference in June, 2015 are shown in table 4.5 and 4.6

Table 4-5 Cost of raw materials

Raw Materials	Price (baht/kg)
ABS	50
UHMWPE	120
PE-g-MAH	522
SEBS	170

Table 4-6 Cost of ABS/UHMWPE blends

Polymer blends Formulation	Price (baht/kg)					
	PE-g-MAH (phr)			SEBS (phr)		
	3	5	7	3	5	7
95/5 (w/w) ABS/ UHMWPE	69.2	79.6	90.0	58.6	62.0	65.4
90/10 (w/w) ABS/ UHMWPE	72.7	83.1	93.5	62.1	65.5	68.9
85/15 (w/w) ABS/ UHMWPE	76.2	86.6	97.0	65.6	69.0	72.4
80/20 (w/w) ABS/ UHMWPE	79.7	90.1	100.5	69.1	72.5	75.9
75/25 (w/w) ABS/ UHMWPE	83.2	93.6	104.0	72.6	76.0	79.4

CHAPTER 5

CONCLUSION AND SUGGESTION

5.1 Conclusions

The physical properties and morphology of ABS/UHMWPE blends were investigated. The work was divided into two parts. Firstly, the effectiveness of PE-g-MAH and SEBS compatibilizer of blends were studied. Secondly, the effect of UHMWPE content on physical properties of ABS/UHMWPE blends was studied. The results were concluded as the following:

Part one: The physical properties and morphology of ABS/UHMWPE blends with PE-g-MAH and SEBS compatibilizer.

- The tensile strength and elongation at break of blends with compatibilizers were lower than that of the blends without compatibilizers.
- The tensile strength of blends decreased while the elongation at break increased with increasing SEBS and PE-g-MAH content.
- The blend with SEBS provided higher tensile strength and elongation at break than the blends with PE-g-MAH.
- The impact strength, hardness and abrasion of blend increased when compatibilizer were added and tended to increase with increasing compatibilizer content.
- The blends with SEBS provided higher impact strength, hardness and abrasion than the blends with PE-g-MAH.
- Scanning electron microscope showed the partially miscible UHMWPE in ABS matrix and SEBS provided the compatibilization effects on the blends more than PE-g-MAH.
- The blends with compatibilizer had long term stability against degradation by irradiation of extended-UV exposure than the blends without compatibilizer.

Part two: The physical properties and morphology of ABS/UHMWPE blends (5 phr SEBS) with various ABS/UHMWPE ratios.

- The tensile strength and elongation at break of ABS/UHMWPE were lower than that of the pure ABS.
- The tensile strength and elongation at break of blends decreased with increasing UHMWPE content.
- The blend with 5 wt% UHMWPE provided the highest tensile strength and elongation at break.
- The impact strength, hardness and abrasion of blend increased when UHMWPE were added and the highest values were at 5 wt% UHMWPE content.
- Scanning electron microscope showed more incompatibility of blends with increasing UHMWPE content.
- The ABS blends with UHMWPE had long term stability against degradation by irradiation of extended-UV exposure than the pure ABS.

Therefore, UHMWPE was partially miscible with ABS matrix. Both PE-g-MAH and SEBS provided the compatibilization effects on the ABS/UHMWPE blends. The 95/5 ABS/UHMWPE blends with 5 phr SEBS was the appropriate formulation with the highest physical properties.

5.2 Suggestions for the Future Work

A future investigation of ABS/UHMWPE blends should be studied with the following aspects:

1. The effect of particle size of UHMWPE should be investigated.
2. The ABS/UHMWPE blends with other compatibilizer such as styrene/ethylene-butylene/styrene grafted maleic anhydride (SEBS-g-MAH) should be investigated.

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APPENDICES

Appendix A

Effect of Compatibilizers Types and Contents on Mechanical Properties of ABS/UHMWPE Blends

Table A-1 Tensile strength, elongation at break, impact strength, hardness and abrasion of ABS/UHMWPE blends

Polymer blends	**SEBS (phr)**				**PE-g-MAH (phr)**		
ABS/UHMWPE 90/10 (w/w)	**0**	**3**	**5**	**7**	**3**	**5**	**7**
TS (MPa)	183	164	170	160	159	143	146
	175	167	162	165	158	158	149
	176	172	163	151	149	156	163
	182	175	168	167	162	165	142
	182	164	162	155	145	148	149
Mean	**180**	**168**	**165**	**160**	**155**	**154**	**150**
SD	**3.78**	**4.93**	**3.74**	**6.69**	**7.23**	**8.63**	**7.92**
EB (%)	89	64	70	77	63	72	72
	82	68	72	75	64	73	74
	86	66	76	79	68	68	72
	84	73	74	77	62	69	70
	85	67	71	74	65	70	75
Mean	**85**	**68**	**73**	**76**	**64**	**70**	**73**
SD	**2.59**	**3.36**	**2.41**	**1.95**	**2.30**	**2.07**	**1.95**
IS (kg-cm/cm2)	12.4	16.0	16.1	17.6	13.2	13.5	15.9
	12.9	15.1	16.3	17.9	12.6	14	15.2
	13.2	15.2	16.2	18.3	13.9	15.2	15.5
	12.5	15.5	16.7	18.1	12.9	13.9	14.9
	13.1	14.9	16.5	18.5	13.2	14.0	14.9
Mean	**12.8**	**15.3**	**16.4**	**18.1**	**13.2**	**14.1**	**15.3**
SD	**0.36**	**0.43**	**0.24**	**0.35**	**0.48**	**0.64**	**0.43**
HD (R-cale)	39	46	45	46	39	43	50
	38	45	42	45	42	42	43
	48	42	46	45	37	41	40
	36	41	47	48	42	41	40
	39	40	43	46	42	37	42
Mean	**40**	**43**	**45**	**46**	**40**	**41**	**43**
SD	**4.64**	**2.59**	**2.07**	**1.22**	**2.30**	**2.28**	**4.12**
AR (%)	0.84	0.63	0.54	0.36	0.75	0.72	0.58
	0.86	0.62	0.54	0.33	0.80	0.74	0.54
	0.88	0.66	0.52	0.35	0.76	0.69	0.53
	0.85	0.65	0.51	0.36	0.77	0.70	0.52
	0.85	0.64	0.53	0.38	0.80	0.70	0.57
Mean	**0.86**	**0.64**	**0.53**	**0.36**	**0.78**	**0.71**	**0.55**
SD	**0.02**	**0.02**	**0.01**	**0.02**	**0.02**	**0.02**	**0.03**

Appendix B

Effect of Compatibilizers Types and Contents on Mechanical Properties of ABS/UHMWPE Blends after Accelerated Weathering in Weathering Meter

Table B-1 Tensile strength of ABS/UHMWPE blends

Polymer blends ABS/UHMWPE/Compat.	Tensile strength (MPa) in each exposed time in hour			
	100	**250**	**500**	**1000**
ABS	174	164	130	102
	173	162	134	105
	168	165	133	103
	168	165	129	106
	169	161	132	104
Mean	**170**	**163**	**132**	**104**
SD	**2.88**	**1.82**	**2.07**	**1.58**
90/10/3 SEBS	158	153	143	113
	155	153	144	114
	157	157	146	117
	154	154	146	118
	155	156	146	112
Mean	**156**	**155**	**145**	**115**
SD	**1.64**	**1.82**	**1.41**	**2.59**
90/10/5 SEBS	155	148	146	124
	156	154	145	121
	152	152	150	122
	150	148	149	120
	152	149	149	120
Mean	**153**	**150**	**148**	**121**
SD	**2.45**	**2.68**	**2.17**	**1.67**
90/10/7 SEBS	145	145	138	138
	149	143	141	139
	146	142	140	135
	148	143	139	135
	150	142	140	137
Mean	**148**	**143**	**140**	**137**
SD	**2.07**	**1.22**	**1.14**	
90/10/3 PE-g-MAH	146	140	128	105
	146	144	132	101
	148	143	133	102
	143	141	129	103
	145	141	127	104
Mean	**146**	**142**	**130**	**103**
SD	**1.82**	**1.64**	**2.59**	**1.58**
90/10/5 PE-g-MAH	140	145	122	108
	143	142	123	109
	143	140	125	107
	144	139	120	108
	145	139	124	111
Mean	**143**	**141**	**123**	**109**
SD	**1.87**	**2.55**	**1.92**	**1.52**
90/10/7 PE-g-MAH	144	138	126	121
	139	139	135	122
	138	140	134	125
	140	137	128	124
	141	140	128	124
Mean	**140**	**139**	**130**	**123**
SD	**2.30**	**1.30**	**4.02**	**1.64**

Table B-2 Elongation at break of ABS/UHMWPE blends

Polymer blends ABS/UHMWPE/Compat.	Elongation at break (%) in each exposed time in hour			
	100	**250**	**500**	**1000**
ABS	74	58	51	45
	71	64	52	44
	69	63	54	42
	66	57	54	45
	69	62	52	46
Mean	**70**	**61**	**53**	**44**
SD	**2.95**	**3.11**	**1.34**	**1.52**
90/10/3 SEBS	50	51	45	39
	54	48	47	41
	52	49	43	43
	55	55	47	43
	54	55	46	42
Mean	**53**	**52**	**46**	**42**
SD	**2.00**	**3.29**	**1.67**	**1.67**
90/10/5 SEBS	55	54	50	48
	57	54	51	48
	57	55	52	49
	54	56	48	47
	55	56	49	45
Mean	**56**	**55**	**50**	**47**
SD	**1.34**	**1.00**	**1.58**	**1.52**
90/10/7 SEBS	61	57	57	50
	62	57	57	49
	58	59	53	50
	58	60	55	49
	61	57	54	51
Mean	**60**	**58**	**55**	**50**
SD	**1.87**	**1.41**	**1.79**	**0.84**
90/10/3 PE-g-MAH	49	48	43	43
	53	48	44	43
	54	49	42	40
	51	52	44	40
	50	52	42	40
Mean	**51**	**50**	**43**	**41**
SD	**2.07**	**2.05**	**1.00**	**1.64**
90/10/5 PE-g-MAH	54	50	52	44
	55	49	48	43
	54	50	47	47
	53	51	52	45
	57	50	50	46
Mean	**55**	**50**	**50**	**45**
SD	**1.52**	**0.71**	**2.28**	**1.58**
90/10/7 PE-g-MAH	54	51	48	44
	54	53	47	43
	56	52	48	45
	55	49	45	45
	52	48	46	47
Mean	**54**	**51**	**47**	**45**
SD	**1.48**	**2.07**	**1.30**	**1.48**

Table B-3 Izod impact strength of ABS/UHMWPE blends

Polymer blends ABS/UHMWPE/Compat.	Izod impact strength (kg-cm/cm^2) in each exposed time in hour			
	100	**250**	**500**	**1000**
ABS	10.9	9.8	8.9	7.5
	11.1	9.7	8.7	7.5
	10.7	9.9	8.3	7.2
	10.7	10.0	8.4	7.3
	10.7	9.6	8.3	7.2
Mean	**10.8**	**9.8**	**8.5**	**7.3**
SD	**0.18**	**0.16**	**0.27**	**0.15**
90/10/3 SEBS	14.9	14.0	12.8	12.4
	15.3	13.7	12.9	12.3
	15.2	13.8	12.9	12.7
	15.2	14.1	12.5	12.1
	15.0	14.0	12.9	12.3
Mean	**15.1**	**13.9**	**12.8**	**12.4**
SD	**0.16**	**0.16**	**0.17**	**0.22**
90/10/5 SEBS	15.5	15.6	14.7	13.4
	16.4	15.4	14.7	13.2
	15.8	15.7	14.9	13.8
	15.9	15.5	14.5	13.5
	16.2	15.7	14.6	13.6
Mean	**16.0**	**15.6**	**14.7**	**13.5**
SD	**0.35**	**0.13**	**0.15**	**0.22**
90/10/7 SEBS	17.7	17.4	16.0	15.1
	17.3	17.1	16.8	15.2
	17.5	16.8	16.8	15.3
	17.9	16.8	16.4	15.3
	17.9	16.7	16.5	15.0
Mean	**17.7**	**17.0**	**16.5**	**15.2**
SD	**0.26**	**0.29**	**0.33**	**0.13**
90/10/3 PE-g-MAH	12.7	12.2	11.3	10.8
	12.8	12.6	11.2	10.9
	12.5	12.5	11.4	10.7
	12.4	12.7	11.1	10.4
	12.4	12.6	11.4	10.5
Mean	**12.6**	**12.5**	**11.3**	**10.7**
SD	**0.18**	**0.19**	**0.13**	**0.21**
90/10/5 PE-g-MAH	13.7	13.0	12.3	11.5
	13.6	13.0	12.1	11.4
	13.5	13.2	12.1	11.4
	13.4	13.7	11.8	11.7
	13.5	13.8	12.0	11.8
Mean	**13.5**	**13.3**	**12.1**	**11.6**
SD	**0.11**	**0.38**	**0.18**	**0.18**
90/10/7 PE-g-MAH	14.7	14.7	14	12.8
	15.3	14.7	14	12.8
	15.0	14.3	13.6	12.4
	15.0	14.5	13.7	12.6
	14.7	14.5	14.1	12.9
Mean	**14.9**	**14.5**	**13.9**	**12.7**
SD	**0.25**	**0.17**	**0.22**	**0.20**

Appendix C

Effect of UHMWPE on Mechanical Properties of ABS/UHMWPE Blends

Table C-1 Tensile strength, elongation at break, impact strength, hardness and abrasion of ABS/UHMWPE blends

Polymer blends (5phr SEBS)	**ABS/UHMWPE (w/w)**					
	ABS	**95/5**	**90/10**	**85/15**	**80/20**	**75/25**
TS (MPa)	183	174	166	148	147	144
	184	174	165	148	147	144
	180	176	166	149	149	145
	183	176	163	152	148	146
	181	173	165	152	148	142
Mean	**182**	**175**	**165**	**150**	**148**	**144**
SD	**1.64**	**1.34**	**1.22**	**2.05**	**0.84**	**1.48**
EB (%)	87	82	72	54	52	52
	84	78	73	58	52	52
	86	79	70	53	54	54
	87	79	74	55	55	52
	86	81	75	56	53	51
Mean	**86**	**80**	**73**	**55**	**53**	**52**
SD	**1.22**	**1.64**	**1.92**	**1.92**	**1.30**	**1.10**
IS (kg-cm/cm2)	13.2	17.9	16.4	16.1	15.7	15.7
	13.3	17.9	16.3	16.5	15.4	15.4
	13.4	17.7	16.5	15.7	15.9	15.3
	12.9	17.9	16.3	15.8	16.1	15.9
	12.9	18.1	16.4	15.9	15.6	15.9
Mean	**13.1**	**17.9**	**16.4**	**16.0**	**15.7**	**15.6**
SD	**0.23**	**0.14**	**0.08**	**0.32**	**0.27**	**0.28**
HD (R-cale)	37	49	45	46	43	42
	39	49	44	42	43	42
	38	50	42	41	44	41
	39	46	47	40	41	40
	39	47	46	44	40	43
Mean	**38**	**48**	**45**	**43**	**42**	**42**
SD	**0.89**	**1.64**	**1.92**	**2.41**	**1.64**	**1.14**
AR (%)	0.88	0.50	0.55	0.59	0.64	0.65
	0.87	0.50	0.52	0.55	0.67	0.65
	0.90	0.47	0.51	0.56	0.65	0.67
	0.91	0.52	0.54	0.55	0.64	0.65
	0.87	0.47	0.53	0.55	0.66	0.67
Mean	**0.89**	**0.49**	**0.53**	**0.56**	**0.65**	**0.66**
SD	**0.02**	**0.02**	**0.02**	**0.02**	**0.01**	**0.01**

Appendix D

Effect of UHMWPE on Mechanical Properties of ABS/UHMWPE Blends after Accelerated Weathering in Weathering Meter

Table D-1 Tensile strength of ABS/UHMWPE blends

Polymer blends ABS/UHMWPE (5phr SEBS)	Tensile strength (MPa) in each exposed time in hour			
	100	**250**	**500**	**1000**
ABS	141	120	96	84
	142	125	96	85
	137	124	94	87
	137	125	95	86
	138	123	97	87
Mean	**139**	**123**	**96**	**86**
SD	**2.35**	**2.07**	**1.14**	**1.30**
95/5	163	159	154	132
	163	157	153	131
	159	163	154	129
	161	160	155	127
	163	161	157	125
Mean	**162**	**160**	**155**	**129**
SD	**1.79**	**2.24**	**1.52**	**2.86**
90/10	153	152	147	121
	152	148	147	122
	157	149	146	121
	154	150	150	120
	151	151	149	121
Mean	**153**	**150**	**148**	**121**
SD	**2.30**	**1.58**	**1.64**	**0.71**
85/15	145	140	134	108
	136	141	133	110
	139	137	136	111
	138	136	135	112
	141	137	137	106
Mean	**140**	**138**	**135**	**109**
SD	**3.42**	**2.17**	**1.58**	**2.41**
80/20	138	134	129	107
	138	133	128	108
	140	132	131	108
	136	133	134	109
	141	136	129	106
Mean	**139**	**134**	**130**	**108**
SD	**1.95**	**1.52**	**2.39**	**1.14**
75/25	134	132	141	111
	134	129	140	108
	136	133	140	106
	132	128	138	108
	131	130	137	110
Mean	**133**	**130**	**139**	**109**
SD	**1.95**	**2.07**	**1.64**	**1.95**

Table D-2 Elongation at break of ABS/UHMWPE blends

Polymer blends	Elongation at break (%) in each exposed time in hour			
ABS/UHMWPE (5phr SEBS)	**100**	**250**	**500**	**1000**
ABS	64	57	51	47
	65	59	52	43
	61	60	51	45
	66	61	52	45
	61	58	50	44
Mean	**63**	**59**	**51**	**45**
SD	**2.30**	**1.58**	**0.84**	**1.48**
95/5	64	62	60	53
	63	63	60	51
	64	62	57	50
	66	64	57	55
	67	64	61	55
Mean	**65**	**63**	**59**	**53**
SD	**1.64**	**1.00**	**1.87**	**2.28**
90/10	56	54	50	47
	58	54	50	46
	55	55	52	44
	54	57	48	48
	56	55	49	48
Mean	**56**	**55**	**50**	**47**
SD	**1.48**	**1.22**	**1.48**	**1.67**
85/15	46	40	40	35
	45	42	40	36
	46	43	39	36
	47	42	38	33
	45	42	42	32
Mean	**46**	**42**	**40**	**34**
SD	**0.84**	**1.10**	**1.48**	**1.82**
80/20	41	43	38	34
	42	48	37	33
	44	41	39	35
	46	42	43	33
	47	42	42	31
Mean	**44**	**43**	**40**	**33**
SD	**2.55**	**2.77**	**2.59**	**1.48**
75/25	41	40	39	33
	42	43	40	35
	43	41	40	34
	45	41	37	36
	41	44	36	33
Mean	**42**	**42**	**38**	**34**
SD	**1.67**	**1.64**	**1.82**	**1.30**

Table D-3 Izod impact strength of ABS/UHMWPE blends

Polymer blends	Izod impact strength (kg-cm/cm^2) in each exposed time in hour			
ABS/UHMWPE (5phr SEBS)	**100**	**250**	**500**	**1000**
ABS	9.5	8.9	8.1	7.4
	8.6	8.4	8.1	7.3
	8.9	9.0	8	7.2
	9.4	9.0	8.8	7.5
	8.8	8.9	8.8	7.3
Mean	**9.0**	**8.8**	**8.4**	**7.3**
SD	**0.39**	**0.25**	**0.40**	**0.11**
95/5	17.3	16.8	16.5	15.4
	17.3	16.7	15.8	15.2
	17.6	16.9	15.9	15.3
	17.5	16.9	16.1	15.6
	17.4	16.9	16.2	15.2
Mean	**17.4**	**16.8**	**16.1**	**15.3**
SD	**0.13**	**0.09**	**0.27**	**0.17**
90/10	16.4	15.4	14.3	13.5
	16.1	15.4	14.9	12.9
	15.7	15.9	14.7	13.8
	15.8	15.7	14.6	13.7
	15.9	15.5	14.8	13.7
Mean	**16.0**	**15.6**	**14.7**	**13.5**
SD	**0.28**	**0.22**	**0.23**	**0.36**
85/15	15.6	14.8	14.4	13.5
	15.4	14.9	14.8	13.6
	15.3	14.6	15.2	13.4
	15.8	15.4	15.2	13.7
	15.8	15.2	15	13.7
Mean	**15.6**	**15.0**	**14.9**	**13.6**
SD	**0.23**	**0.32**	**0.33**	**0.13**
80/20	15.3	14.9	13.1	12.8
	15.6	14.8	13.5	12.8
	15.0	14.5	13.6	12.9
	15.1	14.9	13.2	12.5
	15.1	14.7	13.6	12.5
Mean	**15.2**	**14.8**	**13.4**	**12.7**
SD	**0.24**	**0.17**	**0.23**	**0.19**
75/25	14.0	13.9	12.9	12.8
	14.3	13.8	13.3	12.8
	15.0	13.9	13.2	13.0
	14.8	14.2	13.2	13.0
	14.1	13.7	13.1	13.1
Mean	**14.4**	**13.9**	**13.1**	**12.9**
SD	**0.44**	**0.19**	**0.15**	**0.13**

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