สมบัติเชิงกลของผสมระหว่างพอลิโพรพิลีนและอิลาสโตเมอร์

นางสาวพรพรรณ ใจบุญ

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MECHANICAL PROPERTIES OF POLYPROPYLENE/SYNTHETIC ELASTOMER BLENDS

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ศึกษาพอลิเมอร์ผสมระหว่างพอลิโพรพิลีนโคพอลิเมอร์ (PP-cp) อิลาสโตเมอร์ (เอทิลีน-1-ออกทีน โคพอลิเมอร์, EG) และใช้แมลิอิคแอนไฮไดรด์กราฟต์พอลิโพรพิลีน (MAH-g-PP) เป็นสารช่วยในการผสมเพื่อเพิ่มการยึดติดกันของเอทิลีน-1-ออกทีน โคพอลิเมอร์ กับพอลิโพรพิลีนโคพอลิเมอร์ โดยมุ่งเน้นถึงผลของชนิดของเอทิลีน-1-ออกทีน โคพอลิเมอร์ และแมลิอิคแอนไฮไดรด์กราฟต์พอลิโพรพิลีนและสัดส่วนในการผสมที่มีต่อโครงสร้างสัณฐานและสมบัติเชิงกลของผสม โครงสร้างสัณฐานได้ทำการศึกษาโดยใช้เทคนิค SEM ส่วนสมบัติเชิงกลของผสมที่ศึกษาได้แก่ ความทนต่อแรงกระแทก ความทนต่อแรงดึงและความทนต่อการโค้งงอ คุณสมบัติการไหลศึกษาโดยวัดค่าดรรชนีการไหล และ DSC ใช้ศึกษาพฤติกรรมการตกผลึกของพอลิโพรพิลีนโคพอลิเมอร์ในพอลิเมอร์ผสม

ค่าความทนต่อแรงดึง ค่ามอดูลัส ค่าความทนต่อแรงดึงที่จุดครากและค่าความทนต่อการโค้งงอของพอลิเมอร์ผสมลดลงเมื่อปริมาณของเอทิลีน-1-ออกทีนโคพอลิเมอร์เพิ่มขึ้น ในขณะที่การยืดของชิ้นงานที่จุดขาดและค่าความทนต่อแรงกระแทกเพิ่มขึ้น พอลิเมอร์ผสมที่มีปริมาณเอทิลีน-1-ออกทีน โคพอลิเมอร์ ยี่สิบเปอร์เซ็นต์และแมลิอิคแอนไฮไดรด์กราฟต์พอลิโพรพิลีน1.0 phr มีค่าความทนต่อแรงกระแทกสูงกว่าพอลิโพรพิลีนโคพอลิเมอร์ ประมาณ 13.8-15.9 เปอร์เซ็นต์ ศึกษาอิทธิพลของแมลิอิคแอนไฮไดรด์กราฟต์พอลิโพรพิลีนในปริมาณต่างๆกันในขณะที่ปริมาณของเอทิลีน-1-ออกทีนโคพอลิเมอร์คงที่ที่ยี่สิบเปอร์เซ็นต์ สมบัติด้านความทนต่อแรงดึง ความทนต่อการโค้งงอและค่าความทนต่อแรงกระแทกดีกว่าพอลิเมอร์ผสมที่ไม่เติมแมลิอิคแอนไฮไดรด์กราฟต์พอลิโพรพิลีน สมบัติด้านความทนต่อแรงดึง ค่ามอดูลัส ค่าความทนต่อแรงดึงที่จุดครากและค่าความทนต่อแรงกระแทกมีค่าสูงสุดที่ปริมาณเอทิลีน-1-ออกทีนโคพอลิเมอร์ยี่สิบเปอร์เซ็นต์และปริมาณแมลิอิคแอนไฮไดรด์กราฟต์พอลิโพรพิลีน 1.0 phr.

ภาควิชา -
ลายมือชื่อนิสิต
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PORNPUN JAIBOON: MECHANICAL PROPERTIES OF POLYPROPYLENE/SYNTHETIC ELASTOMER BLENDS. (THESIS TITLE) THESIS ADVISOR: ASSOC.PROF. SOPHON ROENGSUMRAN, Ph.D., 107 pp. ISBN 974-346-649-5.

The blends of polypropylene copolymer (PP-cp), elastomer (ethylene-1-octene copolymer, EG) and the maleic anhydride-grafted-polypropylene (MAH-g-PP) compatibilizer which was used to provide better adhesion between the EG and PP-cp. Particular consideration was given to the influence of the type of EG, MAH-g-PP and blends formulation on the morphology and mechanical properties. The morphology of blends were examined utilising SEM. The mechanical properties were determined using Notched Izod impact testing, tensile testing and flexural testing. The rheological properties studied was the melt flow index and DSC was used for determining the crystallization characteristics of PP-cp in the blends.

The tensile strength, Young’s modulus, yield stress and flexural properties of blends decrease with increasing the EG concentration while the elongation at break and impact strength tend to increase. Blends with 20 wt% EG and 1.0 phr MAH-g-PP have a higher impact strength than PP-cp ca. 13.8-15.9%. The effect of MAH-g-PP concentration was studied by vary ratio as 20 wt% EG concentration. The tensile properties, flexural properties and impact strength of the blends at all concentrations are better than blends without MAH-g-PP. The maximum tensile strength, Young’s modulus, yield stress and impact strength were obtained at 20 wt% EG and 1.0 phr MAH-g-PP.

Department - Student's signature
Field of study Petrochemistry and Polymer Science Advisor's signature
Academic year 2000 Co-advisor's signature -

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LIST OF ABBREVIATIONS

Abbreviation	Term
%Wt	Percent Weight
ΔH_f	Heat of Fusion
^0C	Degree Celsius
ASTM	American Society for Testing and Materials
DSC	Differential Scanning Calorimetry
EB	Elongation at Break
EG	Ethylene-1-Octene Copolymer, ENGAGE
FM	Flexural Modulus
FS	Flexural Strength
KJ/m^2	Kilo-Joules per Square Meter
MAH-g-PP	Maleic Anhydride-Grafted-Polypropylene
MFI	Melt Flow Index
MPa	Mega Pascal
N/mm^2	Newton per Square Millimeter
NB	Not Break
NI	Notched Izod Impact Strength
PP-cp	Polypropylene Copolymer
SEM	Scanning Electron Microscopy
T_m	Melting Temperature
TM	Tensile Modulus (Young's Modulus)
TPEs	Thermoplastic Elastomers
TPOs	Thermoplastic Polyolefin Elastomers

TS	Tensile Strength
YS	Yield Stress (Tensile Strength at Yield)

CHAPTER I

INTRODUCTION

1.1 The Purpose of The Investigation

Polypropylene (PP) is the fourth largest tonnage polymer made **[1]**. PP offers a combination of inexpensive price, easy processability, and a wide spectrum of properties. Therefore PP is used to produce a variety of products such as molded parts, films, and textile fibers, among others. This is the only commodity resin that has a heat distortion temperature above 100°C. PP as well as polypropylene copolymer (PP-cp) is used very widely in a number of applications (e.g., in furniture and the automobile industry). The high impact properties of PP-cp make it a better choice over homopolymer PP for such applications. The impact properties of any thermoplastic material can be improved either by chemical modification or by blending with an elastomeric impact modifier such as ethylene propylene diene monomer rubber (EPDM) [**2**], ethylene propylene rubber (EPR) [**3, 4, 5**], natural rubber (NR) [**6**]. Among those, EPR and EPDM have been considered the most effective one **[7]**. These materials exhibit some of the physical properties of conventional elastomers at service temperatures and are processable at elevated temperature.

Recently, polyolefins produced with metallocene catalysts have been used as impact modifiers. Yu used metallocene ethylene-butene copolymers for modifying PP impact resistance **[8]**. He found that the compound had less shrinkage while maintaining good impact to stiffness balance, as well as low temperature ductility. In a study on the composition of the elastomeric modifier, Laughner *et al.* found that as the comonomer is changed from propylene to butene to octene, a substantial increase in Izod impact resistance, Dart impact, and weldline strength were observed **[9]**.

Although sufficient information exists on blend of PP, there are hardly any data on the properties of blends of PP-cp with elastomers. Therefore, in the present work, a study has been performed to investigate PP-cp blends containing ethylene-1-octene copolymer (EG), commercially available polyolefinic elastomer. In addition, maleic anhydride-grafted-polypropylene (MAH-g-PP) will be evaluated in terms of their effect on tensile properties, flexural properties and impact properties of the blends.

1.2 Purpose of Research

This research was studied the mechanical properties of PP-cp/EG blends in order to improve the impact strength of PP-cp and effect of maleic anhydride-grafted-polypropylene (MAH-g-PP) upon the phased morphology and consequently mechanical properties of PP-cp/EG blends. The PP-cp/EG blends are expected to have better mechanical properties comparable to commercial resin.

1.3 Scope of Research

In this research, the effect of increasing octene content and EG concentration including compatibilizing agent or polymer modifiers such as MAH-g-PP on mechanical properties of PP-cp/EG blends were investigated.

All composition was prepared by melt mixing in a single screw extruder. Finally, these mixtures were injection molded to produce the standard ASTM specimens by injection machine. The Differential Scanning Calorimetry (DSC) and Scanning Electron Microscopy (SEM) techniques were used to analyze the blends. The mechanical properties, melt flow index, impact strength, tensile strength, tensile modulus, yield stress, elongation at break, flexural strength and flexural modulus were measured and compared to commercial resin.

CHAPTER II

THEORY AND LITERATURE REVIEW

2.1 Polymer Blends

A polymer blend will be defined as a combination of two or more polymers resulting from common processing steps [**10**]. It has become an increasingly important technique for improving the cost-performance ratio of commercial plastics. For example, blending may be used to reduce the cost of an expensive engineering thermoplastic, to improve the processability of a high-temperature or heat-sensitive thermoplastic or improve impact resistant. Commercial blends may be homogeneous, phase separated [**11**]. In simple mechanical blends the plastic component usually predominates, with the dispersed elastomer having dimensions of the order of several micrometers. The shear action of mechanical blending also generates free radicals through polymer degradation reactions. The free radicals thus induced by mechanochemical action subsequently react to form a small number of true chemical grafted between the two components [**12**].

Some polymer blends are fabricated to improve the melt flow and mechanical properties and/or to reduce shrinkage. For example, polyblends of PVC with ABS or acrylate graft copolymer have impact strength higher than either of the components. Binary blends of PP with LLDPE are commercially attractive for their strength, modulus, and low-temperature impact performance [**13**]. PS blended with PP will improve the thermal stability of

PP during processing [**14**]. The mechanical properties of the blends depend on the state of dispersion: shape, size and orientation of the dispersed phase. For example, at 15% by weight of rubber/polyamide blend, a fourfold drop in Notched Izod Impact Strength was observed in increasing the number average minor size from 0.7 μm to 0.8 μm [**15**]. It has been found that the addition of interfacial agents can improve the properties of immiscible blends.

2.2 Thermoplastic Elastomers (TPEs) [16]

Thermoplastic elastomers first appeared as commercial entities during the late 1950s with the introduction of thermoplastic polyurethane elastomers by both B. F. Goodrich and Mobay Chemical. This was followed by the production of styrene butadiene and styrene isoprene block copolymers by Shell Chemical Company during the middle and late 1960s. A significant innovation in the TPE field was the commercial introduction of copolyester block copolymers by the Du Pont Company during the early 1970s, which was followed by the introduction of a group of rubber-plastic blends (primarily polypropylene and EPDM rubber) by Uniroyal Chemical Company. By the late 1970s, TPEs were beginning to make an impact in the rubber products marketplace. The rapid increase in the use of the thermoplastic elastomers showed by Figure 2.1, which gives the consumption of these materials in the United States between 1970 and the present.

TPEs are a rubbery material with the characteristics of a conventional thermoplastic and the performance properties of a conventional thermoset rubber. TPEs are processed by the extrusion, injection molding, blow molding, and so on and with the same equipment as used for thermoplastics such as polyethylene, polypropylene, or polyvinyl chloride. On the other hand, the properties of TPEs are extremely similar to those of a conventional rubber such as natural rubber, SBR, or EPDM. This rapidly growing field thus brings together the conventional commercial and technical disciplines of rubber and thermoplastics.

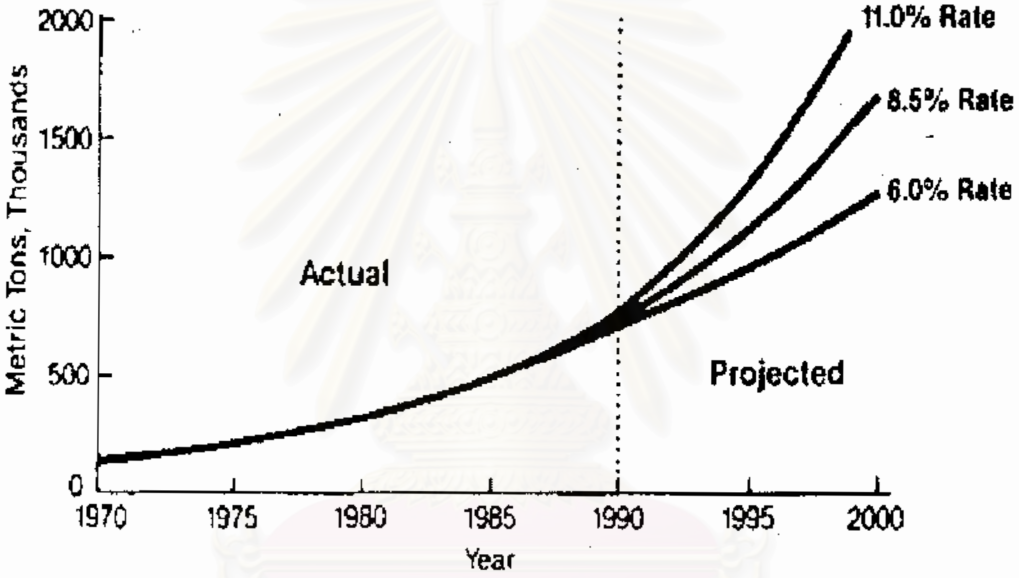


Figure 2.1 Worldwide growth curves for thermoplastic elastomers, actual to 1990: projected for different growth rates 1990-2000.

The desirable performance properties of thermoplastic elastomers are derived from their chemistry and morphology. There are six generic categories of commercial TPEs:

1. Styrenic block copolymers
2. Rubber-polyolefin blends
3. Elastomeric alloys

   a. Thermoplastic vulcanizates (TPVs)
   b. Melt processible rubbers (MPRs)
4. Thermoplastic polyurethanes
5. Thermoplastic copolyesters
6. Thermoplastic polyamides (nylons)

The applications of TPEs are virtually as broad and intensive as those of conventional thermoset rubbers. The major end-use markets for thermoplastic elastomers now are mechanical rubber goods and non-tire automotive product. The major and minor household appliances, building construction, shoes, electrical insulation and jacketing, sheeting, food and beverage contact, and health care **[17]**.

2.3 Thermoplastic Polyolefin Elastomers (TPOs) [18]

TPOs are like all TPE materials. TPO products cover a range of properties, bridging the gap between elastomers and plastics. The processing of these products on standard thermoplastic equipment allows for great production economy. The reuse of regrind from runners, sprues, and so on, almost eliminates scrap. TPO materials are defined as compounds comprising blends of various polyolefin semicrystalline plastics and amorphous elastomers. The most common types of TPOs are composed of polypropylene (PP), ethylene-propylene rubber (EPR) and ethylene-propylene-diene-monomer rubber (EPDM). Other polyolefin polymers commonly used in TPO compounds

include: low-density polyethylene (LDPE), high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), copolymers of ethylene with vinyl acetate (EVA), ethylacrylate (EEA), and methyl acrylate (EMA), semicrystalline copolymers of propylene and ethylene (PP-cp), and polybutene-1. TPO products are blends or mechanical mixtures of polyolefin polymers like most thermoplastic elastomers. They are composed of hard domain (isotactic propylene homopolymer or isotactic propylene copolymer with a minor amount of ethylene as the comonomer) and soft domain (usually a rubber). The exact size and shape of these domains and their properties determine the properties of the resulting formulations. Further, the properties of a TPO can be changed by the method of processing and fabricating finished parts.

TPO products are used in a variety of applications in three major market areas: automotive, wire and cable, and mechanical goods. In each of these markets, TPOs are used because they meet the engineering requirements of the application and can be produced at a cost that is competitive with more traditional materials. They are used extensively in the automotive industry, which is their single largest market. TPO compounds are used for many soft, durable exterior body parts to replace sheet metal including: air dams, body side cladding, body side molding, bumper covers, bumper end caps, fender liners, rub strips, stone deflectors, sight shields, wheel well moldings, and valance panels. TPO products are used in the engine compartment, underhood, carburetor air ducts, conduits, fender liner pads, and firewall pads.

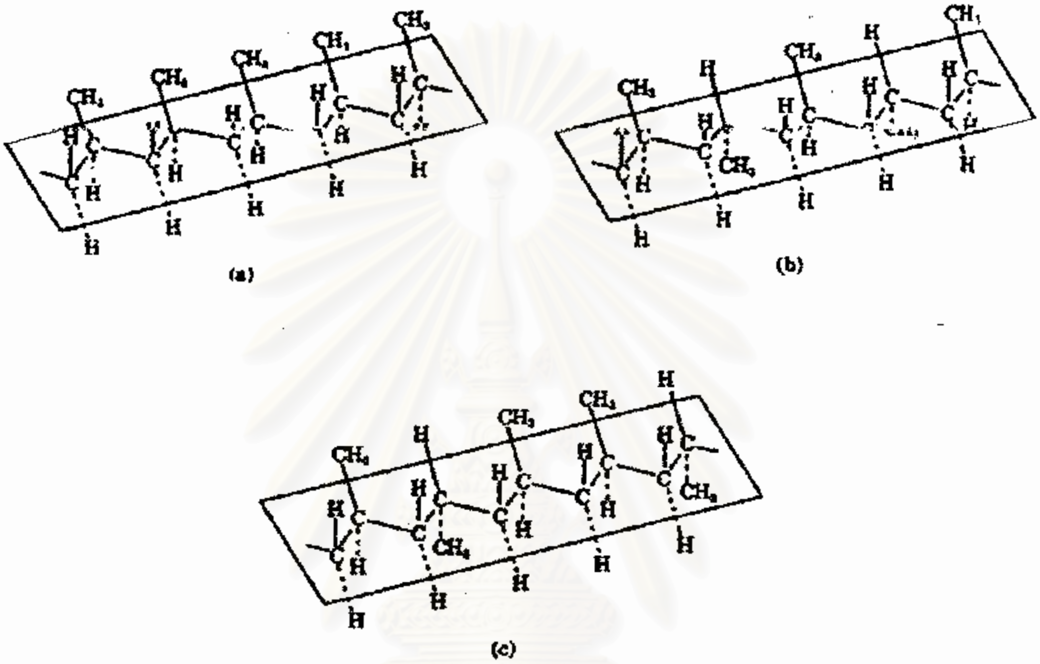
2.4 Polypropylene (PP)

Polypropylene is a thermoplastic polymer with low specific gravity, excellent chemical resistance, high melting point (relative to volume plastics), good stiffness/toughness balance, adaptability to many converting method, great range of special purpose grades, excellent dielectric properties, and low cost (especially per unit volume). It has gained wide acceptance in applications ranging from fibers and films to injection-molded parts for automobiles and food packaging **[17]**. More than 7 billion pounds of polypropylene are produced annually in the United States. About 20 % of this volume consists of copolymers, mostly copolymers containing 2-5 % ethylene into the polymerization reactor. The resulting polymer has increased clarity, toughness and flexibility **[19]**

Although polypropylene has many useful properties, it is not intrinsically tough especially below its glass transition temperature. However, its impact resistance can be improved by adding elastomer usually ethylene/propylene rubber **[20]**. Numerous studies have been carried out that aim at improving PP toughness, stiffness, and strength balance. The addition of mineral fillers and reinforcing agents to the polymeric matrix reduces the cost of the material and enhances some of the mechanical properties.

2.4.1 Polypropylene Homopolymer

Polypropylene is synthesized by placing propylene monomer under controlled conditions of heat and pressure in the presence of organometallic, stereospecific catalysts (Ziegler-Natta tpye). Depending on the catalyst and polymerization process used, the molecular structures of the resulting polymer consist of three different types of stereochemical configurations in varying amounts. These are referred to an isotactic, syndiotactic, and atactic, for which their structures are shown in Figure 2.2 [**21**].



(a) (b) (c)

Figure 2.2 Polypropylene structures

a) isotactic b) syndiotactic c) atactic

2.4.2 Polypropylene Copolymer

Polymerising propylene in the presence of Ziegler-Natta catalyst systems makes isotactic polypropylene homopolymer. The ethylene/propylene rubber fraction is either synthesized in the presence of homopolymer in a second, gas phase reactor or is purchased beforehand and then blended with the homopolymer in the extruder. The resulting impact polypropylene copolymer is pelletized and sold as such.

Impact polypropylene copolymer has a density less than 1, and is less expensive per pound than PET, PBT, HIPS, and ABS. Based on specific volume; the cost per cubic unit of impact polypropylene is less than these resins and PVC. Only HDPE is competitive by this measure. The effect of the elastomer is that amorphous rubber particles distributed throughout the semicrystalline homopolymeric matrix provide stress concentration point at the interface, which initiated local deformation instead of allowing cracks to propagate. So, impact polypropylene copolymer has excellent notched impact energy: Izod impact strength range from 1.5 to 15 ft-lb/inch, and also excellent in Gardner impact properties at low temperatures. Furthermore, it is highly resistant to chemicals and environmental stress cracking. [**17**]

The chief commercial application of impact polypropylene is injection molding of articles used in automotive applications, housewears, and appliances. The impact resistance, low density, colorability, and processability of impact polypropylene make it ideal for such applications. More application for extruded sheeting made from impact polypropylene copolymers, extruded sheets can be thermoformed into large, thick parts. Good samples are fender and trunk liners in the automotive industry [**22**].

Table 2.1 Typical properties of polypropylene copolymer

Property	**ASTM**	**Unit**	**Block copolymer**	**Random copolymer**
Melt Flow Index	D-1238	g/10min	1-43.8	8.3-23.2
Tensile Strength at Yield	D-638	Kgf/cm^2	147-263	221-300
Flexural Strength	D-790	Kgf/cm^2	191-267	237-267
Flexural Modulus	D-790	Kgf/cm^2	4000-9000	5000-6000
Hardness	Rockwell	R-scale	65-92	85-92
Izod Impact Strength	D-256	Kgf-cm/cm	8.4-68.5	2.7-4.6

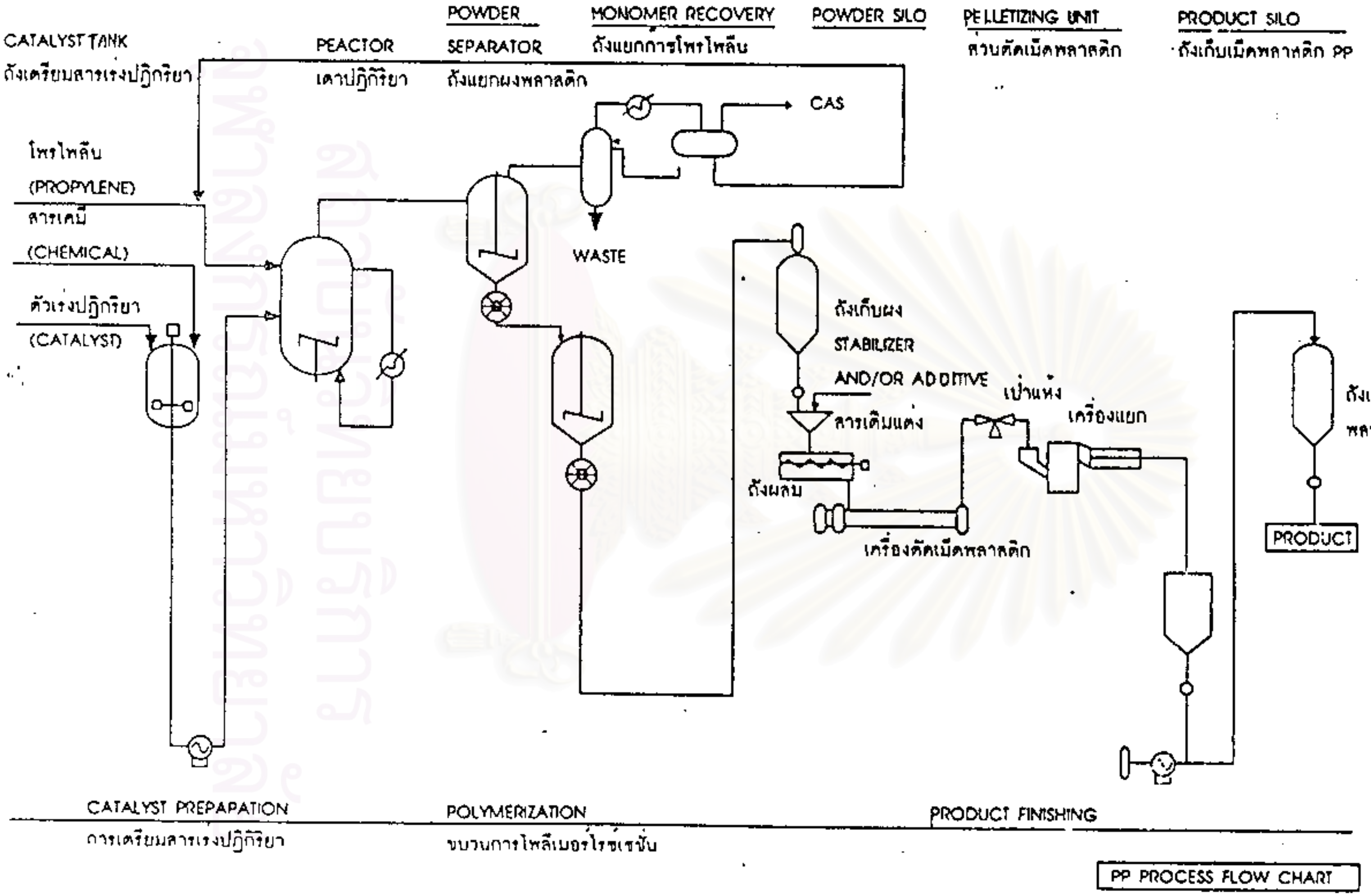


Figure 2.3 Manufacturing of polypropylene

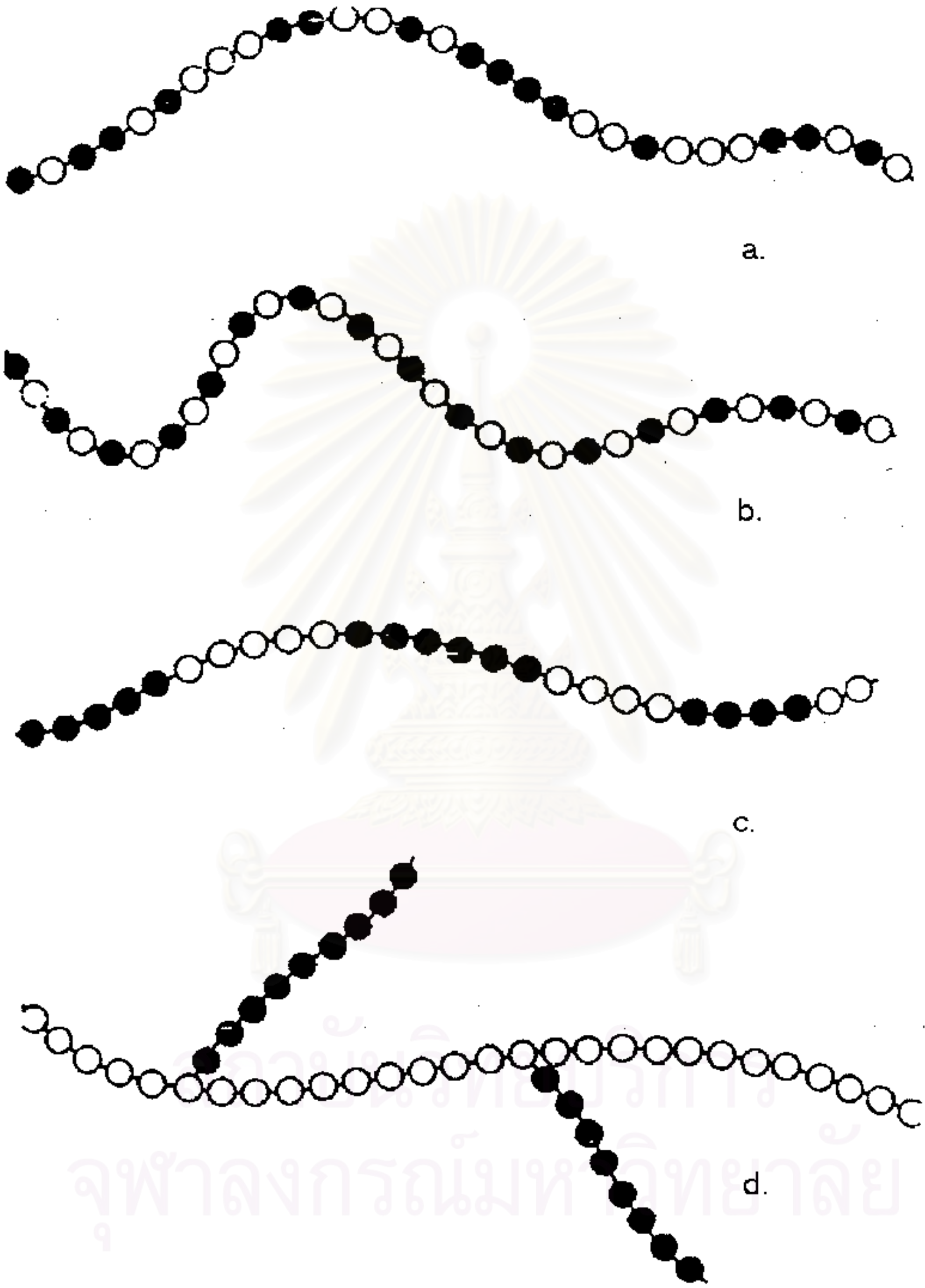


Figure 2.4 Structures of copolymer molecules

a) Random copolymer b) Alternating copolymer

c) Block copolymer d) Graft copolymer

2.5 Ethylene-1-Octene Copolymer (ENGAGE)

Engage polyolefin elastomers are ethylene copolymer produced using "INSITE^{TM}", a catalyst and process technology that allows extraordinary control over polymer structure, properties and rheology, by controlling molecular architecture, "INSITE^{TM}", designed to process like thermoplastics and perform like elastomer. The unique characteristics of "INSITE^{TM}" are flexibility, hardness, elasticity, clarity, and other key properties. These properties can be further improved through compounding and the use of filler. When crosslinked, it also offers excellent compression set and heat resistance. Engage is the enabling polymer in a broad range of thermoplastic elastomer (TPE) compounds. It is a highly versatile material for thermoplastic compounding and imparts a unique combination of processability and toughness when used to modify today's premier rigid TPO blends for exterior bumpers and fascias.

Table 2.2 Typical properties of ethylene-1-octene copolymer

Typical Properties	Range of Values
Density, g/cc. ASTM D-792	0.864-0.913
Flexural Modulus, 2% Secant, MPa, ASTM D-790	7-19
Elongation, %, ASTM D-638	700
Melting Point, ^{0}C	50-100
Hardness, Shore A, ASTM D-2240	65-95
Melt Index, I2, ASTM D-1238, dg/min	0.5-30

2.5.1 Impact of Ethylene-1-Octene Copolymer onThermoplastic Olefins

2.5.1.1 Stiffness and Ductility

Ethylene-1-octene copolymer strikes the ideal balance between stiffness and ductility at equivalent loading of elastomer. Even at –30 ^{0}C, TPOs made with ethylene-1-octene copolymer maintain their integrity in high-impact applications. Combine this with good flowability and part fill. It cans downgauge to thinner parts to help reduce material and part costs.

2.5.1.2 Better Flow

While polypropylene's high-flow characteristics make it difficult to impact modify with high viscosity material such as EPDM. New polymer that brings high-impact capability to high-flow PP allowing better, more efficient processing and improved knit line strength is ethylene-1-octene copolymer because its properties is low molecular weight, good flowability and good part fill etc.

2.5.1.3 Superior Dispersibility

Ethylene-1-octene copolymer offers superior dispersibility into polypropylene when compared with EPDM. Using it in TPOs blends can help:

- Better impact efficiency
- Faster and more uniform mixing
- Lower overall processing and part costs

Table 2.3 Improved impact performance vs. EPDM in TPOs

Feature	Benefit
Superior stiffness/ductility balance	- Better value as an impact modifier. - Higher modulus TPOs with equivalent impact strength - Allows use of thinner parts, reducing costs
Better and faster dispersibility	- Improves impact performance of TPOs blends
Easier handling than bales and crumbs	- Reduces labor costs

2.5.2 New Advantage to a Variety of Application

Ethylene-1-octene copolymer is used in insulation and jacketing for utility and industrial power applications. Appliance and medical industry specifiers choose it to meet requirements for flexibility in a variety of molded and extrudered components.

Two of the many industries that look to ethylene-1-octene copolymer both today and for future application are the footwear and automotive markets.

Table 2.4 Examples of application-footwear and automotive

Footwear	Automotive
- Unit soles	- Brake seals, diaphragms
- Water shoes	- Air ducts
- Compounds	- Flooring, mats, liners
- Outsoles	- Hosing, tubing, covers
- Direct injection molding	- Bumpers, rub strips
- Foams	

2.6 Compatibilization

Generally, melt mixing of polymers produces a material that is weak and brittle. The low deformation modulus may follow approximately an linear mixing rule, but the ultimate properties certainly will not follow this rule because of the presence of stress concentrators and wear interfaces between the disperse phase and a matrix [**23**]. The process of bridging to enhance the mechanical properties by the addition of a third component, or by *in situ* chemical reaction is termed compatibilization. In most cases, the compatibilizer has many possible effects to the final blend, for example:

i) To reduce the interfacial tension in the melt, leading to a finer dispersed phase

ii) To increase the adhesion at phase boundaries, giving improved stress transfer and strengthen the interface in the solid state

iii) To stabilize the dispersed phase by reducing the rate of domain coalescence during melt processing and annealing

2.6.1 Addition of Block and Graft Copolymer

Most compatibilizing agents contain blocks chemically identical to the blend component polymers. When the melt blend cools, the two ends of the copolymer will be physically held in the relevant phase, by a chemical link of the copolymer chain. This action mode is illustrated in Figure 2.5. Better dispersion and adhesion result in improved mechanical properties of the compatibilized blend. However, the finest dispersion is not necessarily giving the best physical properties to the blend. The optimum size of dispersion must be related to the required end-use properties of the blend.

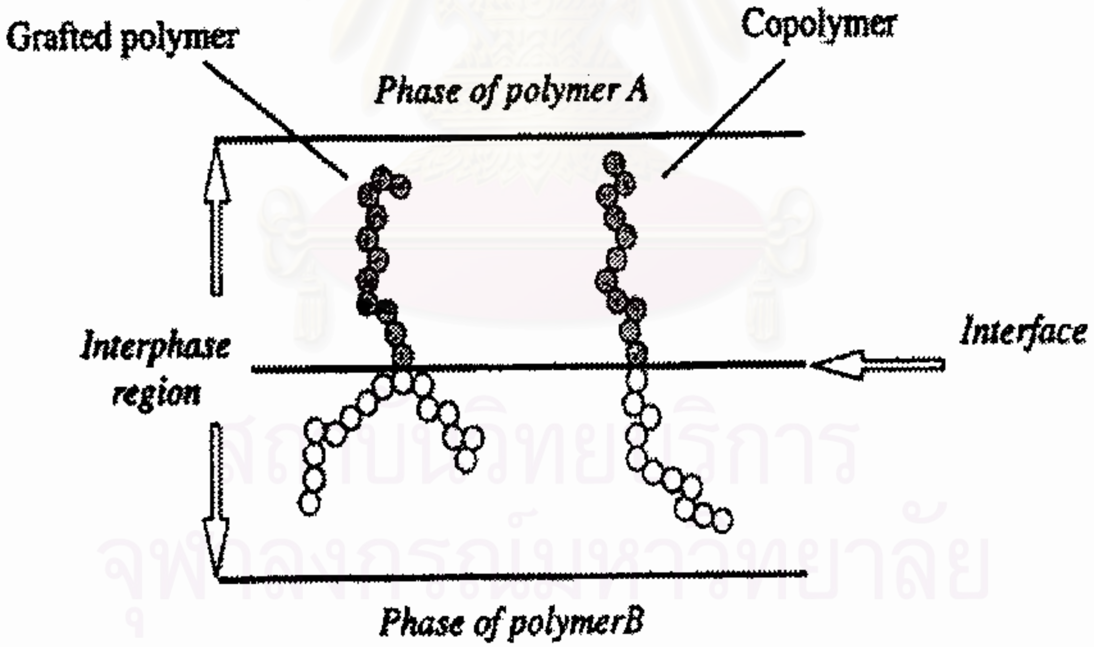


Figure 2.5 Schematic diagram showing location of block and graft copolymers at phase interfaces.

2.7 Maleic Anhydride-Grafted-Polypropylene

Effective application of polymer composites is determined by the interfacial interactions between polymer and filler. The role of interaction is more critical because of the non-polar hydrophobic nature of the polymer phase and the hydrophilic character of inorganic filler. The polarity of the polymer matrix can be increased by several methods. One of the most common processes is to use a functional monomer with a pendant reactive polar group. The most widely used reactive functionalities are unsaturated acids and their derivatives. The maleic anhydride-grafted-polypropylene or polyethylene is at the present time a classical example of the reactive functionality.

Considerable effort has been devoted to developing methods for grafting maleic anhydride (MAH) to the backbones of variety of saturated and unsaturated polymeric materials. In general, MAH grafting has been continuously explored as a technique to improve properties of polymer by providing polarity to promote hydrophilic and adhesion, to give functionality for crosslinking and other chemical modification, and promote compatibility with other materials. A polymer containing grafted MAH has anhydride and carboxyl groups that interact with functional groups on another polymer, which are capable of forming covalent or hydrogen bonds therewith. Thus, laminates or coatings based on MAH-grafted polymers have good adhesion to other polymers in the form of fabricated shapes or films.

Blending PP-g-MAH with nylon 6 in the melt at 230 ^{0}C results in the formation of a compatlbilizing agents containing segment of PP and nylon 6. An oil-resistant thermoplastic elastomer, Geolast ^{TM} is prepared by melt blending PP containing about 10% PP-g-MAH and nitrile rubber (NBR) containing 0.2-3% amine terminated liquid NBR [**24**].

2.8 Literature Reviews

Improving mechanical properties such as toughness is usually the main reason for the development of novel thermoplastic alloy and blends. Other reasons for blending two or more polymers together include: (1) to improve the polymer's processability (2) to enhance the physical and chemical properties of the blend making them more desirable than those of the individual polymer and (3) to meet the market force.

Thermoplastic elastomers are materials that combine the excellent processing characteristics of thermoplastics at higher temperatures, and the wide range of physical properties of elastomers at service temperature.

Willis and Favis (1988) [**25**] investigated the processing-morphology relationships of compatibilized polyolefin/polyamide blends. They reported that the morphology of compatibilized polyolefin/polyamide blends was found to be significantly dependent on the concentration of an ionomer compatibilizer (polyethylene-methacrylic acid-isobutyl acrylate terpolymer) in the blend. For a dispersed phase content of 10% by weight, a maximum reduction in phase size was observed when only 0.5% by weight of ionomer was added to the blend. A more significant reduction of the dispersed phase size was observed when the minor phase was nylon. These interactions were confirmed by Fourier transform infrared spectroscopy. The results observed were explained in term of a speculative model of the interaction occurring across the nylon polyolefin interface.

Armat and Moet (1993) [**26**] investigated the effect of compatibilizing polyethylene and nylon 6 on the morphology and mechanical properties of their blends. A maleic anhydride functionalized styrene (styrene-co-butylene)-styrene block copolymer (MA/SEAB) was added to the blends as a compatibilizer. They reported that the compatibilizer was found to play a dual interfacial function. On one hand, it reduced the interfacial tension of the system, resulting in reduction of the particle size of the dispersed polyethylene phase and it enhanced the interfacial adhesion through the formation of micro-bridges.

Rijsdijk, Contant and Peijs (1993) [**27**] investigated the influence of maleic anhydride-modified polypropylene (M-PP) on mechanical properties of continuous-glass-fiber-reinforced polypropylene (PP) composites. M-PP was added to the PP homopolymer to improve the adhesion between the matrix and the glass fiber. These tests showed an increase in both longitudinal and transverse flexural strength up to 10 wt % M-PP, whereas at higher weight fractions of M-PP a decrease in flexural strength was observed. No significant influence of M-PP on composite stiffness was observed. Additional mechanical tests on unidirectional glass/PP composites with 0 wt% and 10 wt% M-PP showed only a small increase in fiber-dominate properties such as longitudinal tensile strength and strain, whereas composite properties that are governed by the interphase, such as transverse, shear and compressive strength, showed significant increases as a result of matrix modification and an enhanced interaction between the glass fibers and the PP matrix.

George *et al* (1997) [**28**] studied the effect of blend ratio and compatibilization on dynamic mechanical properties of PP/NBR was investigated at different temperatures. The storage modulus of the blend decreased with increase in rubber content and showed two T-g's indicating the incompatibility of the system. Various composite models have been used to predict the experimental viscoelastic data. The addition of phenolic modified polypropylene (Ph-PP) and maleic modified polypropylene (MA-PP) improved the storage modulus of the blend at lower temperatures. The enhancement in storage modulus was correlated with the change in domain size of dispersed NBR particles.

DaSilva *et al* (1997) **[29]** studied about the effectiveness of the polyethylene elastomer (PEE) as an impact modifier for polypropylene in relation to the traditional modifier EPDM. The flow properties of the PEE/PP and EPDM/PP blends were also evaluated and analyzed by solid-state C-13 Nuclear Magnetic Resonance (C-13-NMR) Spectroscopy, Scanning Electron Microscopy (SEM), and Differential Scanning Calorimetry (DSC). The results showed that PEE/PP and EPDM/PP blends present a similar crystalline behavior, which resulted in a similar mechanical performance of the blends, on the composition analyzed. It was also verified that the PEE/PP blend has lower torque than the EPDM/PP blend, which indicates a better processability.

Carriere and Silvis (1997) **[30]** studied the effect of short-chain branching and comonomer type on the interfacial tension of polypropylene-polyolefin elastomer blends. They found the effect of increasing octene content and comonomer type on the compatibility of polypropylene-polyolefin elastomer (PP-POE) blends via direct measure of the interfacial tension. The interfacial tension was found decreased with increasing octene content from a starting value of 1.5+/-0.16 dyn cm at an initial octene level of

9% down to 0.56+/-0.07 dyn cm at an octene content of 24%. These can be interpreted in terms of the effective decrease in the molecular weight between chain ends for the branched POE materials. The experimental data were found to be described well by a modification of the empirical relationship used to describe the effect of molecular weight on the interfacial tension for linear materials. The measured interfacial tension was also found to be dependent on the type of comonomer used in the PP-POE systems. The interfacial tension ranges from 1.07+/-0.09 dyn cm for a PP-POE system made using ethylene-propylene down to 0.56+/-0.07 dyn cm for a PP-POE made using ethylene-octene (24%octene).

Michel *et al.* (1999) [**31**] studied the effect of compounding conditions and composition on the properties of talc/ethylene-octene copolymer/PP compounds. The use of 30% talc provided a twofold increase in tensile modulus compared with pure PP. Impact resistances of filled and unfilled compounds were found to increase rapidly once the copolymer concentration reached around 20 wt% based on the polymer phase. Modulus and tensile strength decreased linearly with copolymer concentration. They used four different commercial maleic anhydride-grafted PP with interfacial modifiers and found that a slight tensile strength increases when using between 2 and 10 wt% maleic anhydride-grafted PP.

Premphet and Horanont (1999) [**32**] investigated ternary–phase polypropylene (PP) composites containing an ethylene-octene copolymer (EOR) and calcium carbonate ($CaCO_3$). Particular consideration was given to the influence of stearic acid treatment of the filler on the phase morphology and mechanical properties of the composites. The use of filler treated with stearic acid had no effect either on the dispersion or the interaction of the filler and the polymer components. However, the surface-treated filler was found to promote the beta-hexagonal crystallization of PP and gave a composite with lower T_c onset and T_c values. As a consequence, differences in mechanical properties, impact strength were exhibited in which calcium carbonate with stearic acid treatment was apparently more effective in increasing the impact strength of the composites in comparison with the composites containing the uncoated filler.

Dietmar *et al.* (1999) [**33**] studied the influence of comonomer incorporation on morphology and thermal and mechanical properties of blends based upon isotactic metallocene-polypropylene and random ethylene/1-butene copolymers. Blends of isotactic polypropylene (i-PP) with random ethylene/1-butene (EB) copolymers containing 10, 24, 48, 58, 62 82, and 90 wt% 1-butene were prepared in order to examine the influence of the EB molecular architecture on the morphology development as well as on the thermal and mechanical properties. Compatibility between i-PP and EB increased with increasing 1-butene content in EB to afford single-phase blends at a 1-butene content exceeding 82 wt%. The morphology was investigated using AFM and TEM. Improved compatibility accounted for enhanced EB dispersion and interfacial adhesion and highly flexible as well as stiff blends with improved toughness were obtained.

Steven and Robert (1999) [**34**] studied the blends of polypropylene and polyamide-6,6 compatibilized with polypropylene that was carboxylated through a reactive extrusion process with asymmetric functional peroxide. The compatibilized blends demonstrated a finely dispersed minor phase as shown by SEM. Because of the enhanced dispersion, addition of the carboxylated polypropylene to the blends resulted in a change in the crystallization nucleation mechanism of the PA-6,6 minor phase from heterogeneous to homogeneous in nature. A linear increase in the impact strength and significant enhancement in the tensile properties of the blends was observed with incorporations of the compatibilizer up to 30% of the matrix phase. When compared on an equivalent basis (total concentration of carboxylate or anhydride functionality added to the blend), the carboxylated polypropylene demonstrated a slightly better compatibilizing efficiency than that of the carboxylated polypropylene, which was attributed to a higher grafting efficiency of the carboxylation procedure as compared to the anhydride functionalization procedure.

CHAPTER III

EXPERIMENTAL

3.1 Materials

3.1.1 Polypropylene Resin (PP)

The polypropylene copolymer (PP-cp), used in this study was an injection grade (grade 2500H). It was manufactured by Thai Petrochemical Industry (Public) Company Limited.

Typical data of polypropylene copolymer grade 2500H are shown in **Appendix I (Table 1).**

3.1.2 Ethylene-1-Octene Copolymer (ENGAGE, EG)

The impact modifier was ethylene-1-octene copolymer; prepared by Dow's INSITE ^{TM} constrained geometry catalyst and process technology (INSITE ^{TM}), which is a trademark of the Dow Chemical Company, commercial grade of ethylene-1-octene copolymer (EG8100, EG8150).

Product specifications of ethylene-1-octene copolymer grade EG8100, EG8150 are shown in **Appendix I (Table 2, 3).**

3.1.3 Maleic Anhydride-Grafted-Polypropylene (MAH-g- PP)

In this study, MAH-g-PP, under the trade name of Polybond 3150 (PB3150) was evaluated as compatibilizing agent or polymer modifier. Uniroyal Chemical Company Limited manufactured it.

Product specifications of MAH-g-PP (PB3150) are shown in **Appendix I (Table 4).**

3.2 Instruments and Apparatus

1. Mixing Machine : Bosco Engineering Model Mixer 50
2. Single Screw Extruder : Axon Ab Plastmaskiner
3. Plastic Injection Molding Machine: Cosmo Model TTI-220/80 PC
4. Tensile Tester : Universal Testing Machine; LLOYD Instruments LR 30K
5. Flexural Tester : Universal Testing Machine; LLOYD Instruments LR 30K
6. Universal Impact Tester : Yasuda Seiki Seisakusho Ltd.
7. Melt Indexer : Davenport
8. Differential Scanning Calorimeter : Perkin-Elmer DSC-7
9. Scanning Electron Microscope : JEOL Model JSM-5300

3.3 Polymer Processing

3.3.1 Mixing and Extrusion

A dry blending of PP-cp, EG, and MAH-g-PP was performed according to the formulation show in Table 3.1 using the mixing machine. This mixture was then melt blending and extrudated by single screw extruder was set at 100 rpm and temperature profile in the extruder from the feed to the metering zone was set 230^0C as shown in Figure 3.1 The extruder was passed through a water-cooling, dried, and subsequently pelletized.

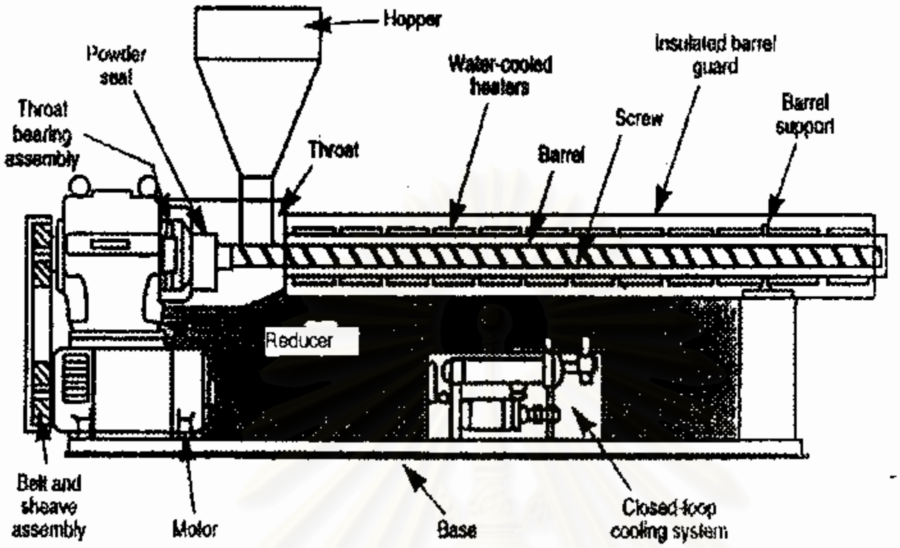


Figure 3.1 A single screw extruder

3.3.2 Injection Molding

The pellets of PP-cp/EG/MAH-g-PP were injection molded by using injection machine as shown in Figure 3.2. The testing specimens were prepared according to ASTM using a mold that is generally used for the commercial samples.

Different levels of EG loading from 5, 10, 20, 30, 40, 50, and 60% (by weight of blends) and different levels of MAH-g-PP from 0.5, 1, 2, 3 phr. were prepared. For each level of EG loading, five to eight specimens were tested in each case. (See Appendix II)

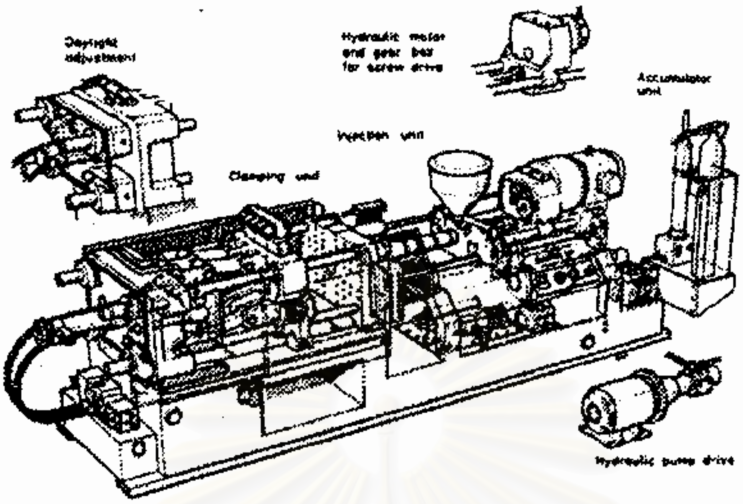


Figure 3.2 A plastic injection molding machine (*Courtesy Mannesmann-Demag Kunststofftechnik*)

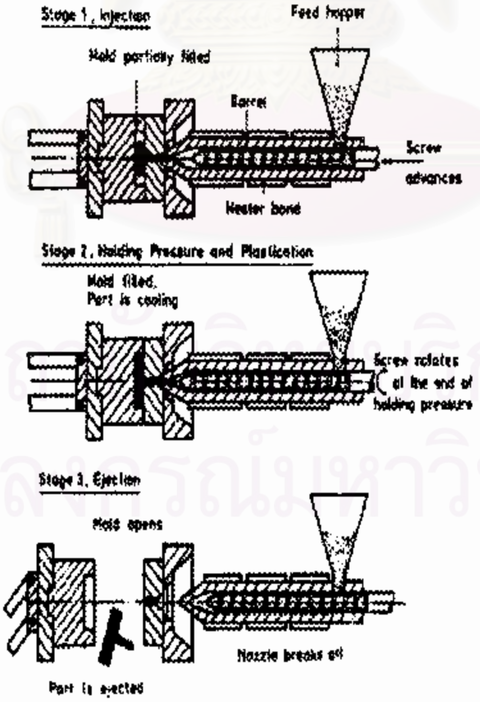


Figure 3.3 The three stages of injection molding: injection, plastication (feeding), ejection

Table 3.1 Formulation of PP-cp/EG/MAH-g-PP blends

Sample No.	PP-cp (wt%)	EG 8150 (wt%)	EG 8100 (wt%)	MAH-g-PP (phr)
1	100	0	-	-
2	95	5	-	-
3	90	10	-	-
4	80	20	-	-
5	70	30	-	-
6	60	40	-	-
7	50	50	-	-
8	40	60	-	-
9	95	-	5	-
10	90	-	10	-
11	80	-	20	-
12	70	-	30	-
13	60	-	40	-
14	50	-	50	-
15	40	-	60	-
16	80	20	-	0.5
17	80	20	-	1.0
18	80	20	-	2.0
19	80	20	-	3.0
20	80	-	20	0.5
21	80	-	20	1.0
22	80	-	20	2.0
23	80	-	20	3.0

3.4 Characterization of Polypropylene, Elastomers and Blends

3.4.1. ASTM D1238: Standard test method for melts flow index.

The melt flow index of PP-cp, EG and polypropylene blends were determined using a Melt Flow Indexer according to ASTM D1238. The temperature of cylinder with piston and die in place has been at the test temperature 190°C and 230°C for at least 4 min before a test is begun. PP-cp and blends were melting at 230°C while EG was melting at 190°C. The polymer melt was driven through the capillary die using a 2.16 kg piston. The sample obtained is then weighed and the melt flow property expressed in grams per 10 minutes of the operation.

3.4.2 Differential Scanning Calorimeter (DSC)

A Perkin-Elmer DSC-7 apparatus was used to determine the thermal transition behavior of PP-cp, EG, and their blends. About 5-7 mg of samples were placed in an aluminum pan, which was sealed by using a sample pan crimper. The sample was heated up to 180°C at a rate of 10°C /min then cooled down at a scan rate of 10°C /min. The results are shown in Tables 4.2-4.3.

3.4.3 Microstructure of The Fracture Surface of The Polymer Blends

The fracture surfaces from impact testing specimens were observed by a JEOL Scanning Electron Microscope (SEM), Model JSM-5300 and operated at 20kv, 2000x. The samples were coated with gold before scanning observations.

3.5 Mechanical Testing of Sample

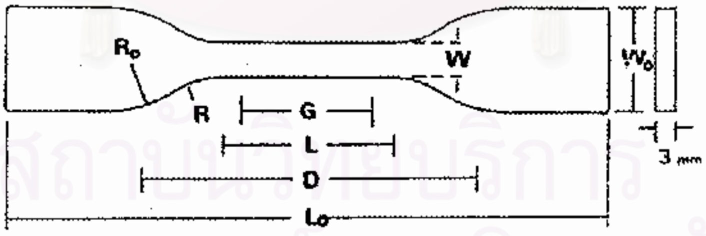
Mechanical properties of the blends were measured by the following ASTM test methods.

3.5.1. ASTM D638: Standard test method for tensile properties.

The tensile properties were measured according to ASTM D638 using Universal Testing Machine Model LR 30K. The dumbell specimen of type IV was used. Figures 3.4 and 3.5 shown the dimensions of dumbell specimen of type IV and schematic of tensile test set-up.

The tensile testing conditions were as follows:

Temperature	23^{0}C
Relative humidity	54 %
Speed of testing	50.00 mm/min
Gauge length	25.00 mm/min



W : 6 mm W_O: 19 mm G : 25 mm R : 14 mm
L : 33 mm L_O: 115 mm D : 65 mm R_O: 25 mm

Figure 3.4 Dimension of tensile test specimen (Type IV)

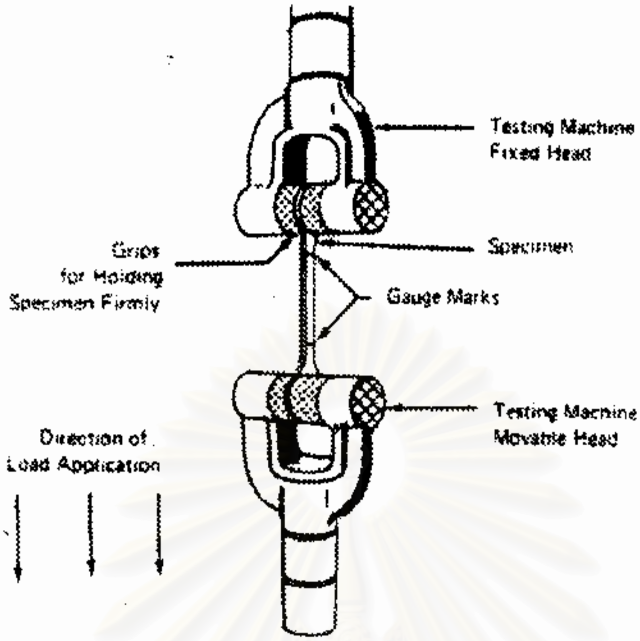


Figure 3.5 Schematic of tensile test set-up

3.5.2. ASTM D790M: Standard test method for flexural properties.

Flexural properties were measured using an Universal Testing Machine Model LR 30K. Specimen having 10 mm in width and 4 mm in depth and 80 mm in length were used for testing flexural strength and flexural modulus of the sample. Figures 3.6 and 3.7 shown schematic of flexural test set-up and schematic of stress in flexed sample.

For a 3-point bending flexural testing, the length of the support span depends upon the thickness. In this case, 64.0 mm span length was used in order to have support span to thickness ratio 16:1. A test specimen was loaded via at a 10.05 mm diameter of crosshead loading nose by using the rate of crosshead motion at 1.7 mm/min.

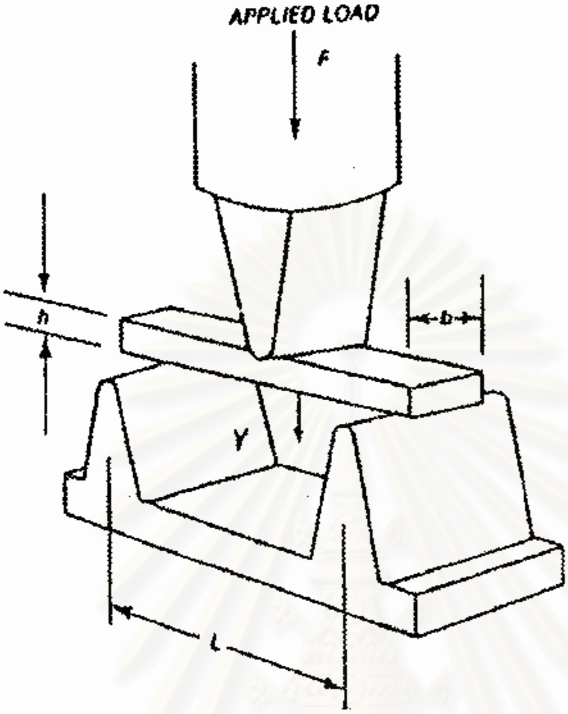


Figure 3.6 Schematic of flexural test set-up

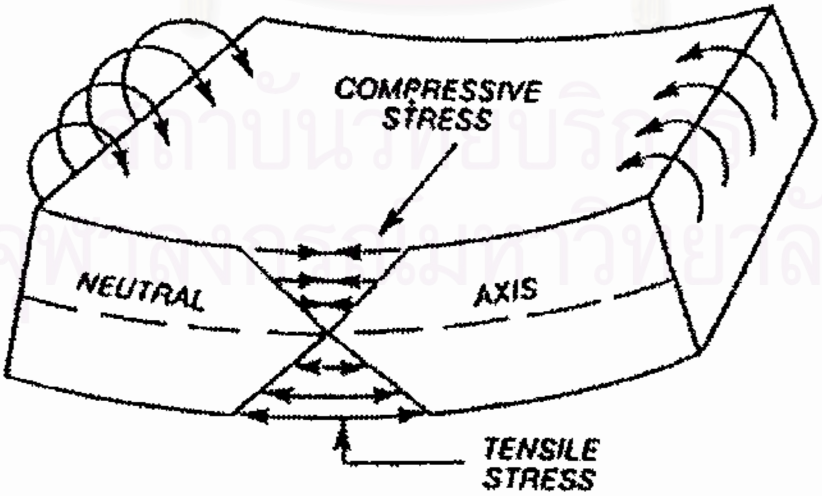


Figure 3.7 Schematic of stress in flexed sample

3.5.3. ASTM D256: Standard test method for impact resistance.

Impact strength was measured according to ASTM D256 on an Universal Impact Tester. The test specimen dimension for Izod type test and schematic of Izod test are shown in Figures 3.8 and 3.9.

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

Temperature	23°C
Relative humidity	54 %
Pendulum capacity	5.5 J

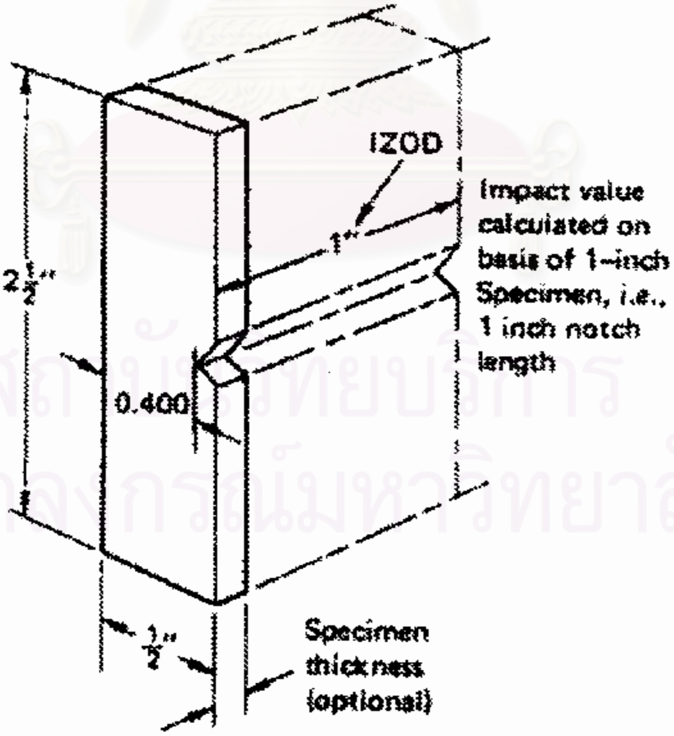


Figure 3.8 Dimensions of Izod type test specimen

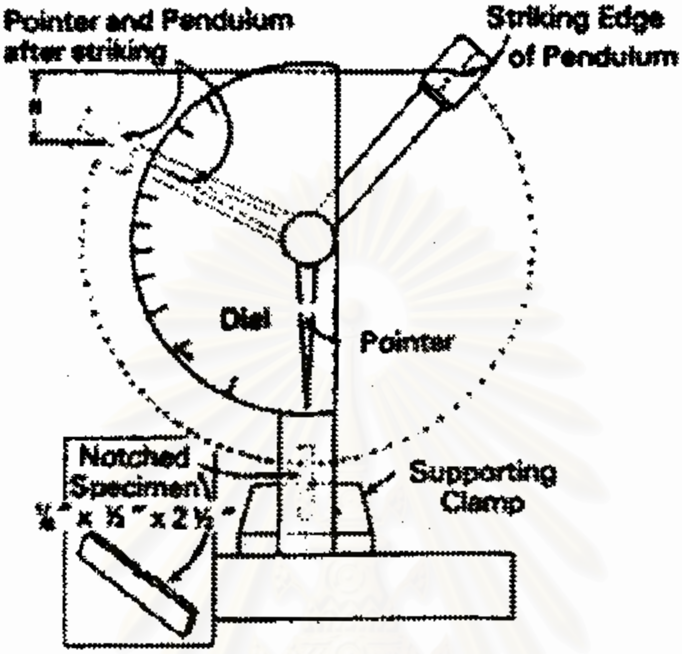


Figure 3.9 Schematic of Izod test

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this research is to improve mechanical properties of polypropylene copolymer with ethylene-1-octene copolymer. The focus of this research is on the application for the automobile part, car bumpers. At present, commercial resin has been used for manufacturing the car bumpers according to their quality. Thus, their mechanical properties have been measured and used as the benchmarks to compare with those of the blends of this study. They are as follow:

Melt Flow Index, g/10 min	11
Tensile Strength at Yield, MPa	>16
Flexural Modulus, MPa	750
Elongation at break, %	>300
Notched Izod impact strength, MPa	not break

4.1 Effect of EG Concentration on Melt Flow Index of PP-cp/EG Blends

From Figure 4.1, Table 4.1 when the percentage of elastomer, EG concentration increased the melt flow index value decreased, therefore the viscosity of the blends increased. Choudhary *et al*. [**35**] showed that addition of EPDM rubber results in an increase in viscosity of PP/HDPE blend. It is possible that the EG could be obstructing the flow and reducing the fluidity of

PP-cp so that the melt flow index value reduced which agreed the results of Liao *et al*. [**36**] that the increased rubber content caused a decrease in the melt flow index value of a PC/PET blend system.

Table 4.1 Melt flow index of PP-cp/EG blends

EG (wt%)	**MFI (g/10min) EG 8150**	**MFI (g/10min) EG 8100**
0	2.10	2.10
5	2.04	2.07
10	1.96	2.00
20	1.80	1.85
30	1.75	1.79
40	1.52	1.68
50	1.35	1.57
60	1.30	1.42

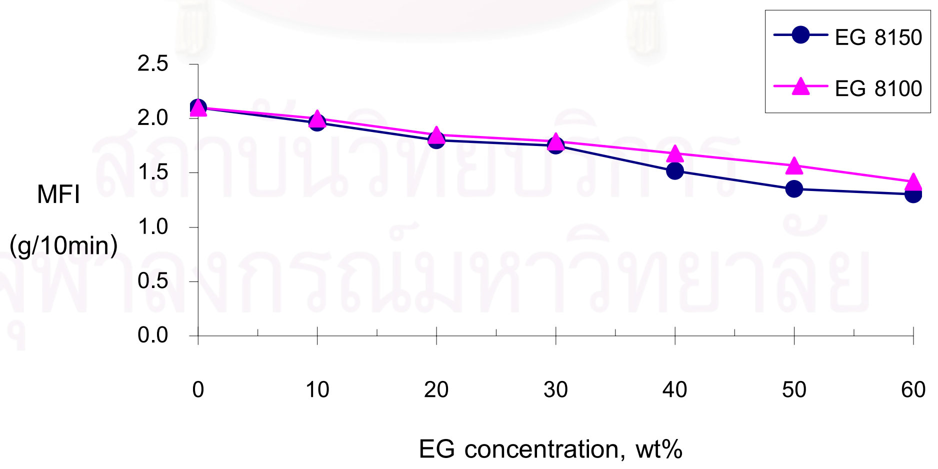


Figure 4.1 Melt flow index (MFI) of PP-cp/EG blends.

4.2 Effect of EG and MAH-g-PP Concentration on Thermal Behavior

4.2.1 Study by Differential Scanning Calorimeter

The mechanical properties of PP-cp are determined by its crystalline structure. Any changes in that structure will result in a change of properties. So it is essential to determine the effect of elastomer blending on the crystalline structure as well as on the melting and crystallization behavior of PP. DSC curves illustrating melting behavior of the pure polymer and PP-cp blends are showed in Figures 1-12 in Appendix III. The PP-cp/EG and PP-cp/EG/MAH-g-PP blends had only one melting peak, which situated between the peaks of PP-cp and EG. Thermal properties of PP-cp, PP-cp blends are summarized in Tables 4.2-4.3. It can be seen that there is change in the crystallization behavior of the PP-cp matrix when EG and MAH-g-PP contents are added. The melting temperature (T_m) and heat of fusion (ΔH_f) were determined from the heating cycle of a DSC scan. The percentage crystallinity was also calculated by using the relationship

$$\% \text{ Crystallinity} \quad = \quad [\Delta H_f^{obs} / \Delta H_f^{0} (100\%)] \times 100$$

A value of ΔH_f^{0} (100%) is heat of fusion of 100 % crystallinity PP = 209.0 J/g. In this work PP-cp containing 10% ethylene comonomer, so heat of fusion of 100 % crystallinity PP-cp = [209-(209x10)/100] = 188.1 J/g and ΔH_f^{obs} is heat of fusion from experiment [**37**].

The blends show a broad melting endotherm, which is probably related to changes in the distribution of PP-cp crystal morphology when elastomers are added. The melt temperatures of pure PP-cp and PP-cp blends occur at about 153.7-157.2 ^{0}C. As should be expected, the results show that as the EG and MAH-g-PP concentrations increase, the percentage crystallinity and the heat of fusion decrease in relation to pure PP-cp. In the composition analyzed, the percentage crystallinity of the PP-cp/EG8150, PP-cp/EG8100 and PP-cp/EG/MAH-g-PP blends are similar.

Table 4.2 Effect of EG 8150 and MAH-g-PP concentration on the thermal behavior by DSC measurement

Sample No.	**EG 8150 (wt%)**	**MAH-g-PP (phr)**	**T_m (^{0}C)**	**ΔH (J/g)**	**Crystallinity (%)**
1	0	-	157.3	75.9	40.4
3	10	-	155.4	63.5	33.7
4	20	-	154.3	53.2	28.6
7	50	-	153.8	30.0	16.0
17	20	1.0	157.2	53.2	28.3
18	20	2.0	154.2	55.9	29.7

Table 4.3 Effect of EG 8100 and MAH-g-PP concentration on the thermal behavior by DSC measurement

Sample No.	**EG 8100 (wt%)**	**MAH-g-PP (phr)**	**T_m (^{0}C)**	**ΔH (J/g)**	**Crystallinity (%)**
1	0	-	153.7	75.0	40.4
10	10	-	155.3	62.8	33.4
11	20	-	154.1	56.6	30.1
14	50	-	155.3	33.5	17.8
21	20	1.0	154.6	55.7	29.6
22	20	2.0	155.0	54.6	29.0

4.3 Effect of EG Concentration on Mechanical Properties of PP-cp/EG Blend.

4.3.1 Tensile Properties and Flexural Properties

Figures 4.2-4.9, Tables 4.4-4.5 and Appendix II show the effect of EG concentration on tensile properties and flexural properties. It can be seen that the tensile strength, Young's modulus, yield stress and flexural properties of PP-cp/EG blends decrease while the elongation at break and impact strength increase with increasing the EG concentration. It can be described due to the crystallinity and orientation. Side chain branching of EG disrupts chain of molecular order and chain regularity of PP-cp, thereby reducing both crystallinity and the melting point. Orientation has a very large effect on both crystallinity morphology and rate of crystallization [**38**]. It induces nucleation growth along the flow lines by shear, and then growth occurs from these nuclei.

Table 4.4 Tensile and flexural properties of PP-cp/EG 8150 blends.

Sample No.	**EG 8150 (wt%)**	**TS (MPa)**	**TM (MPa)**	**YS (MPa)**	**EB (%)**	**FS (MPa)**	**FM (MPa)**
1	0	25.55	232.52	24.85	334.31	25.44	878.01
2	5	21.41	184.64	20.95	350.23	25.19	834.83
3	10	21.03	160.46	19.72	370.77	22.25	782.51
4	**20**	**20.10**	**154.28**	**13.38**	**410.12**	**14.72**	**501.33**
5	30	19.14	130.48	11.38	470.20	12.36	450.26
6	40	16.33	117.65	6.73	526.00	7.05	225.47
7	50	15.26	104.25	5.41	580.72	4.39	187.38
8	60	14.04	94.28	4.35	593.20	3.15	160.25

Table 4.5 Tensile and flexural properties of PP-cp/EG 8100 blends.

Sample No.	EG 8100 (wt%)	TS (MPa)	TM (MPa)	YS (MPa)	EB (%)	FS (MPa)	FM (MPa)
1	0	25.55	232.52	24.85	334.31	25.44	878.01
9	5	22.06	195.80	21.18	345.20	25.29	854.37
10	10	21.75	180.99	20.35	357.71	23.85	838.34
11	**20**	**20.59**	**170.70**	**15.54**	**368.72**	**16.01**	**534.20**
12	30	19.92	147.66	12.89	424.51	13.24	492.36
13	40	18.45	128.53	7.53	450.81	7.74	266.40
14	50	15.76	115.72	6.28	510.25	5.02	210.35
15	60	14.95	107.13	5.52	552.11	3.93	182.76

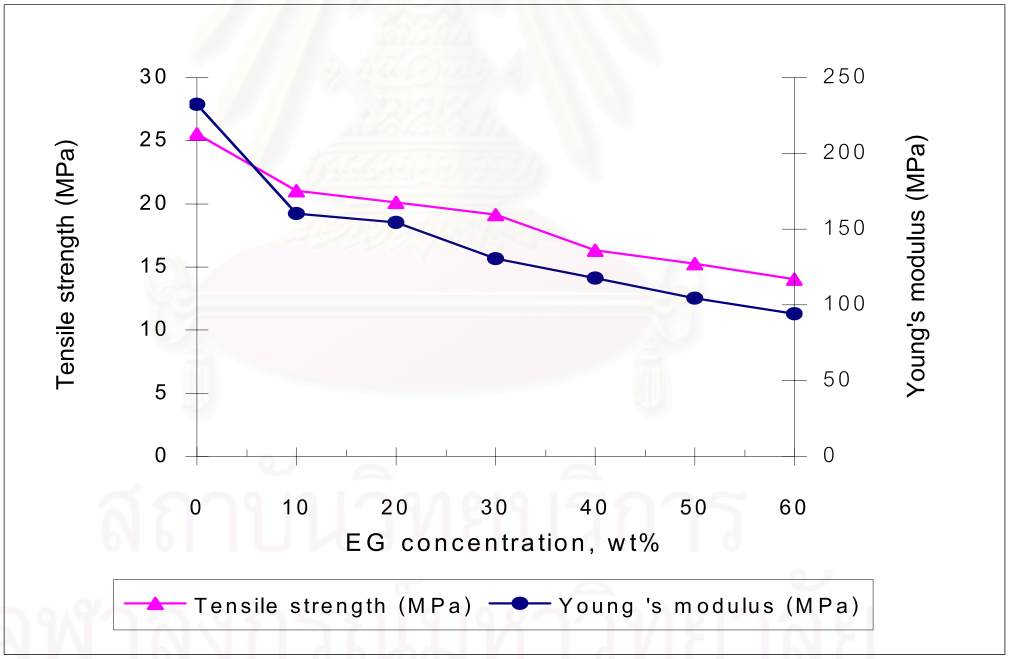


Figure 4.2 Tensile strength and Young’s modulus against the concentration of EG of PP-cp/EG 8150 blends.

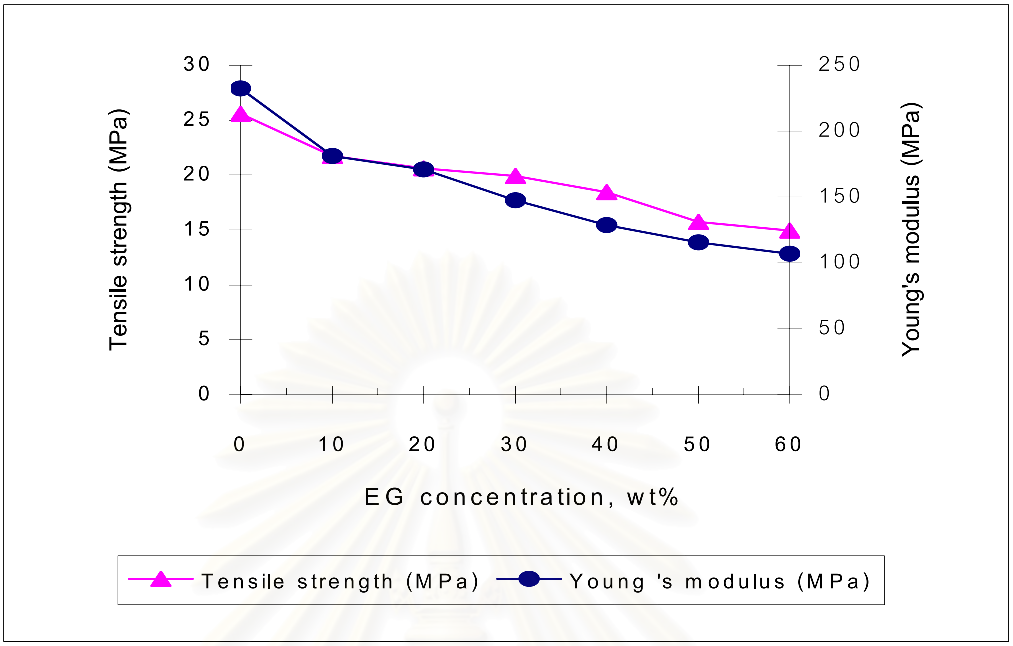


Figure 4.3 Tensile strength and Young's modulus against the concentration of EG of PP-cp/EG 8100 blends.

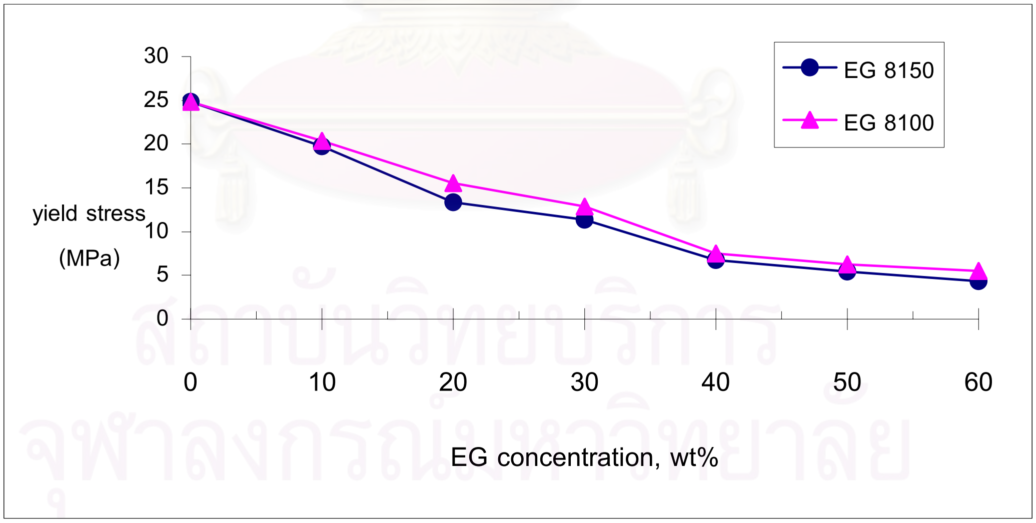


Figure 4.4 Yield stress against the concentration of EG of PP-cp/EG 8150 blends and PP-cp/EG 8100 blends.

The properties of PP-cp/EG blends were examined as a function of the 1-octene content in EG. Figures 4.4-4.8 indicate that yield stress, the tensile strength, Young's modulus and flexural properties decrease with increasing amount of 1-octene content in the blends. It was noted that the tensile strength, Young's modulus and yield stress of the system containing EG with high 1-octene content (EG 8150, 25 wt% 1-octene) showed the low value, as a result of branching or 1-octene content which it strongly influences the crystallization, melting behavior and the degree of crystallinity of the fractions. The lamellae become decreasing with increasing branch content and eventually the crystallinity has fewer tendencies to be occurred [**39**].

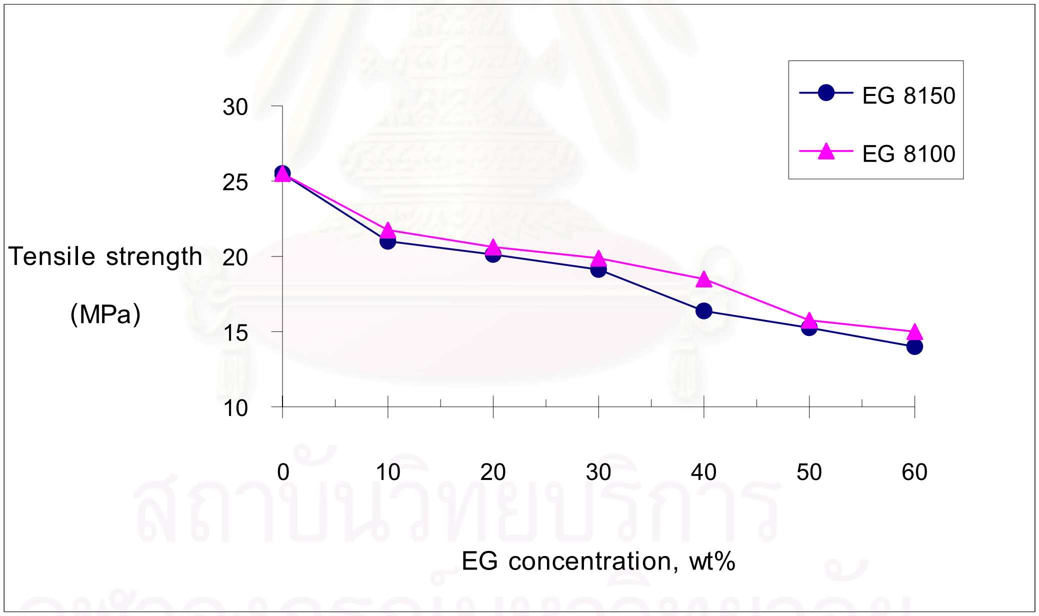


Figure 4.5 Tensile strength against the concentration of EG of PP-cp/EG 8150 blends and PP-cp/EG 8100 blends.

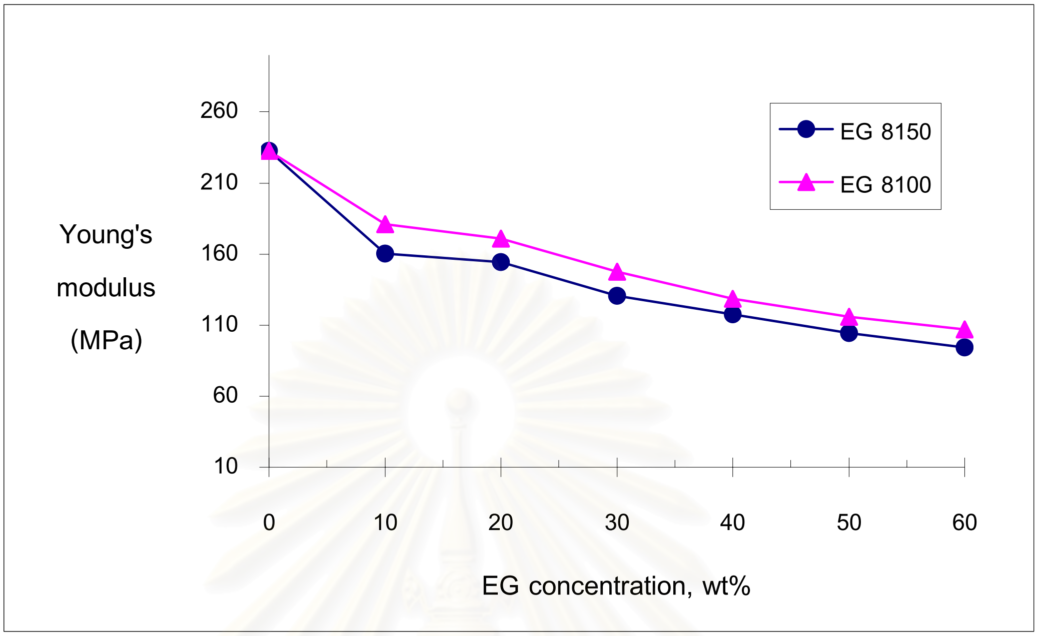


Figure 4.6 Young's modulus against the concentration of EG of PP-cp/EG 8150 blends and PP-cp/EG 8100 blends

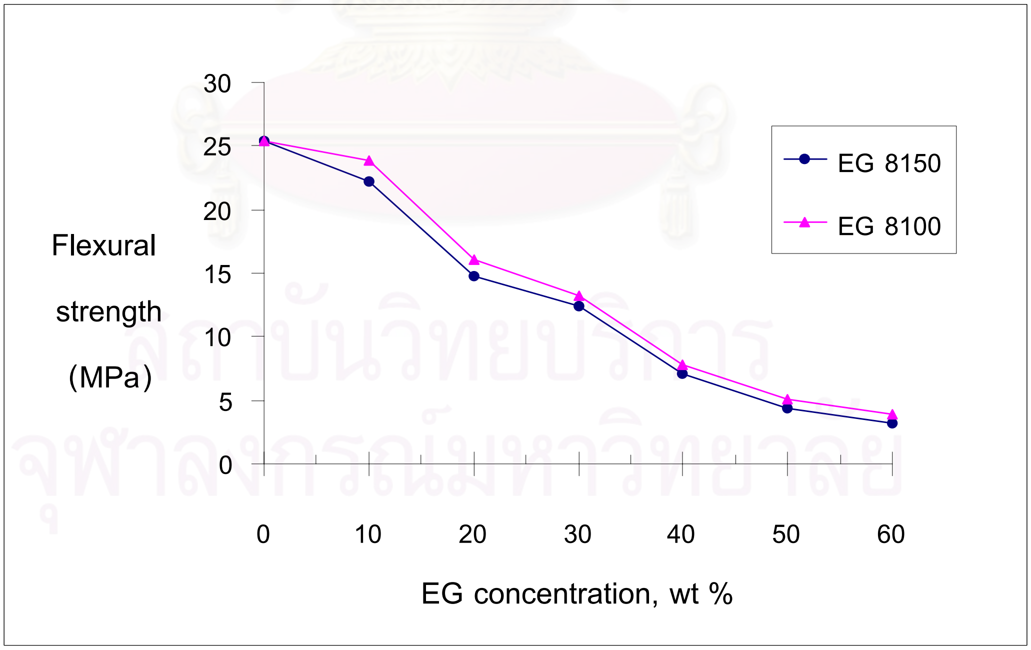


Figure 4.7 Flexural strength against the concentration of EG of PP-cp/EG 8150 blends and PP-cp/EG 8100 blends.

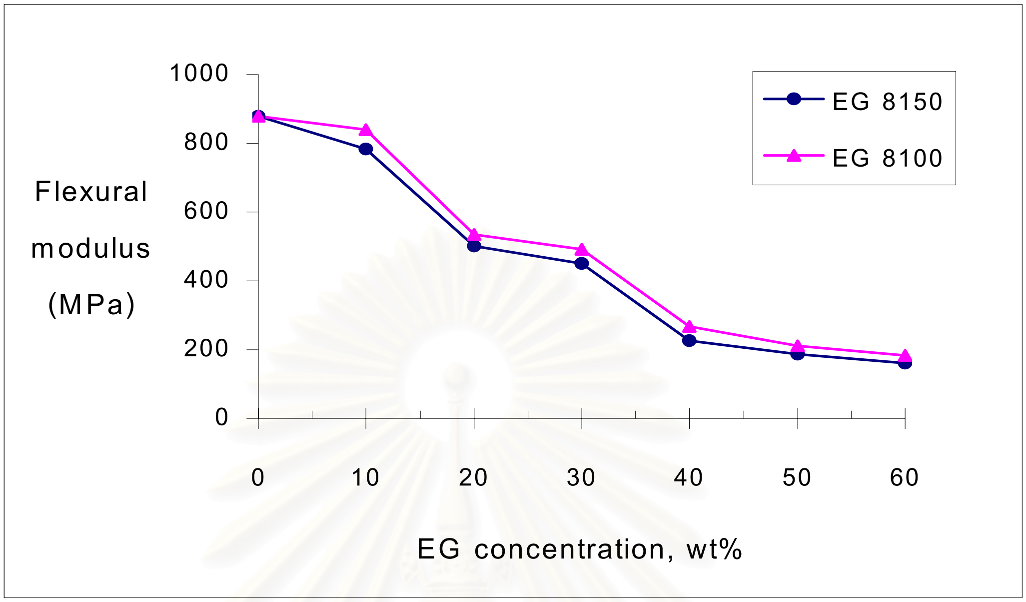


Figure 4.8 Flexural modulus against the concentration of EG of PP-cp/EG 8150 blends and PP-cp/EG 8100 blends.

Similar observation was also reported by Mehrabzadeh and Hossein [**40**]. They found that rubber content and ethylene content are important factors in controlling the blend properties.

Figure 4.9 illustrates the increase of elongation at break with increasing concentration of EG. It can be seen that elongation at break of the blends with high content of 1-octene (PP-cp/EG 8150) shows high values. Because the comonomer unit in EG acts to increase high elasticity so the flexibility or extensibility is increased. The elongation depends on the amorphous part of the molecule, which contains the segment of free mobile chain [**41**]. EG has more amorphous phase than PP-cp, higher EG concentration in blends will increase in amorphous phase, which will lead to higher free volume. The free volume could allow the chain to move easy when the stress is applied.

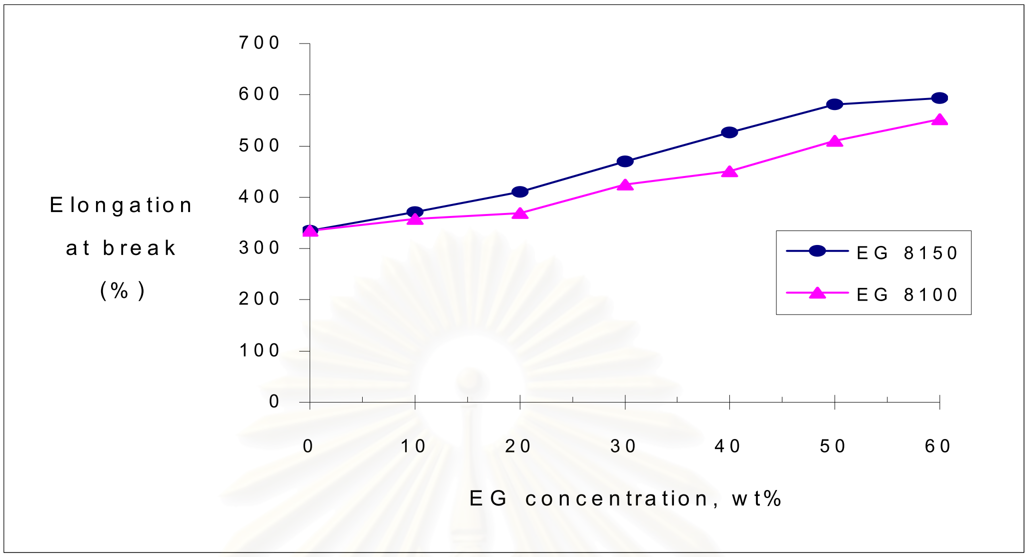


Figure 4.9 Elongation at break against the concentration of EG of PP-cp/EG 8150 blends and PP-cp/EG 8100 blends.

4.3.2 Notch Izod Impact Strength

A tough material is one that can absorb a large amount of energy before failure. This means that there needs to be available to the polymer one or more deformation mechanism, which absorbs energy before crack propagation, occurs. It is recognized that elastomer particles in the PP matrix play an important role in improving the impact strength by functioning as stress concentrators under deformation.

From Figure 4.10 and Table 4.6, it can be seen that the Notched Izod impact strengths of PP-cp/EG 8150 and PP-cp/EG 8100 blends were not much different. Compounds containing EG 8150 had slightly higher impact strength than the one containing EG 8100. This may be due to the difference in amount of 1-octene content in EG. The maximum value of impact strength appears when EG concentration was 20 wt% and sample did not break on the further addition of EG concentration up to 30 wt%. A similar behavior was found for high flow polypropylene/ethylene-propylene elastomers blends by Dharmarajan and Kaufman [**42**]. They found that long chain branched ethylene-propylene elastomers provide enhanced impact resistance with a ductile failure mode in high flow polypropylene.

Table 4.6 Notched Izod impact strength of PP-cp/EG blends

EG (wt%)	**NI (KJ/m^2)** **EG 8150**	**NI (KJ/m^2)** **EG 8100**
0	57.60	57.60
5	58.92	58.44
10	62.97	62.12
20	**64.80**	**63.55**
30	NB	NB
40	NB	NB
50	NB	NB
60	NB	NB

NB: sample did not break

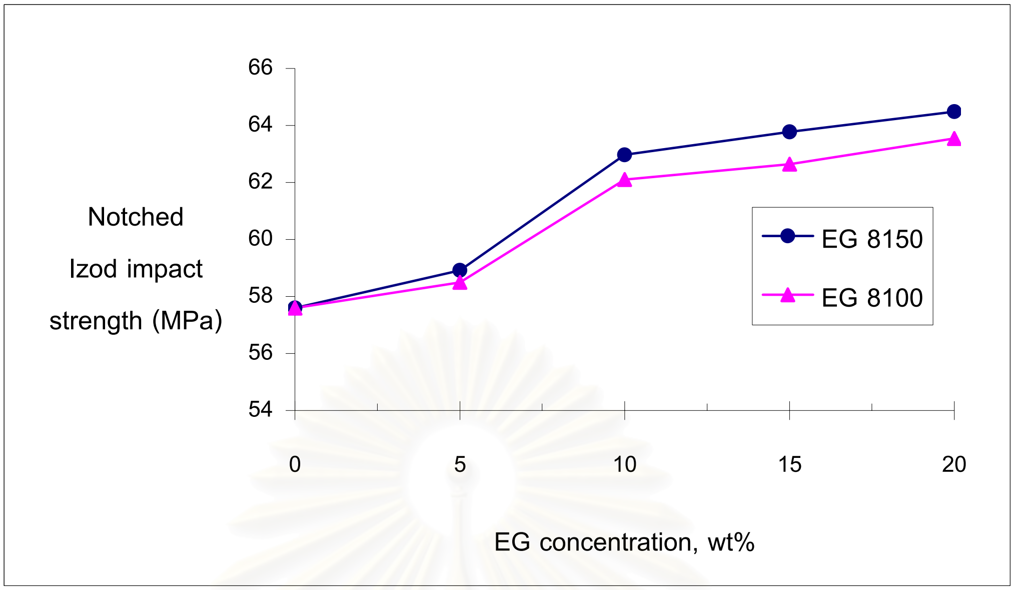


Figure 4.10 Notched Izod impact strength against the concentration of EG of PP-cp/EG 8150 and PP-cp/EG 8100 blends.

4.4 State of Dispersion of PP-cp/EG Blends.

The Notched Izod impact fracture surface of the blends was studied by using SEM. Figures 13-17 in Appendix III shows the effect of concentration of EG. The SEM micrographs show that EG particles are uniformly distributed in the PP-cp matrix and the size of the elastomer domains increases as the EG concentration increases. Perhaps some agglomeration may have taken place. No phase separation seems to be evident for any concentration. The disperse phase seems to be in elongated form for blends containing more than 20 wt% EG blends.

Table 4.7 Properties of commercial resin, PP-cp and PP-cp/EG blends

Properties	Commercial resin	PP-cp (100%)	PP-cp/EG (80/20)
Melt Flow Index, g/10 min	**11**	**2.1**	**1.8-1.9**
Tensile Strength at Yield, MPa	**>16**	**24.85**	**13.4-15.5**
Flexural Modulus, MPa	**750**	**878.01**	**501.3-534.2**
Elongation at break, %	**>300**	**334.31**	**368.7-410.1**
Notch Izod impact strength, MPa	**Not break**	**57.60**	**63.5-64.8**

PP-cp/EG (80/20) has lower yield stress or tensile strength at yield, flexural modulus and impact strength than commercial resin. MAH-g-PP is added 0.5-3.0 phr in PP-cp/EG (80/20) blends in order to improve those properties.

4.5 Effect of MAH-g-PP Concentration on Melt Flow Index of PP-cp/EG/MAH-g-PP Blends at 20 wt% EG

Figure 4.11, Table 4. show that the influences of the addition of MAH-g-PP on melt flow index of PP-cp melts. The addition 1.0 phr MAH-g-PP gave the system a further decrease melt flow index or increase in viscosity, though the viscosity of MAH-g-PP was lower than that of PP-cp. This phenomenon implied that MAH-g-PP might have improved the interfacial adhesion of PP-cp and EG. Other studies showed that functionalized thermoplastics such as maleated polypropylene could be used to improve the compatibility of waste paper and thermoplastic [**44**].

Table 4.8 Melt flow index of PP-cp/EG/MAH-g-PP blends at 20 wt% EG

Grade	MAH-g-PP (phr)	MFI (g/10min)
EG 8150	0	1.80
	0.5	1.87
	1.0	1.84
	2.0	1.78
	3.0	1.76
EG 8100	0	1.85
	0.5	1.93
	1.0	1.91
	2.0	1.90
	3.0	1.89

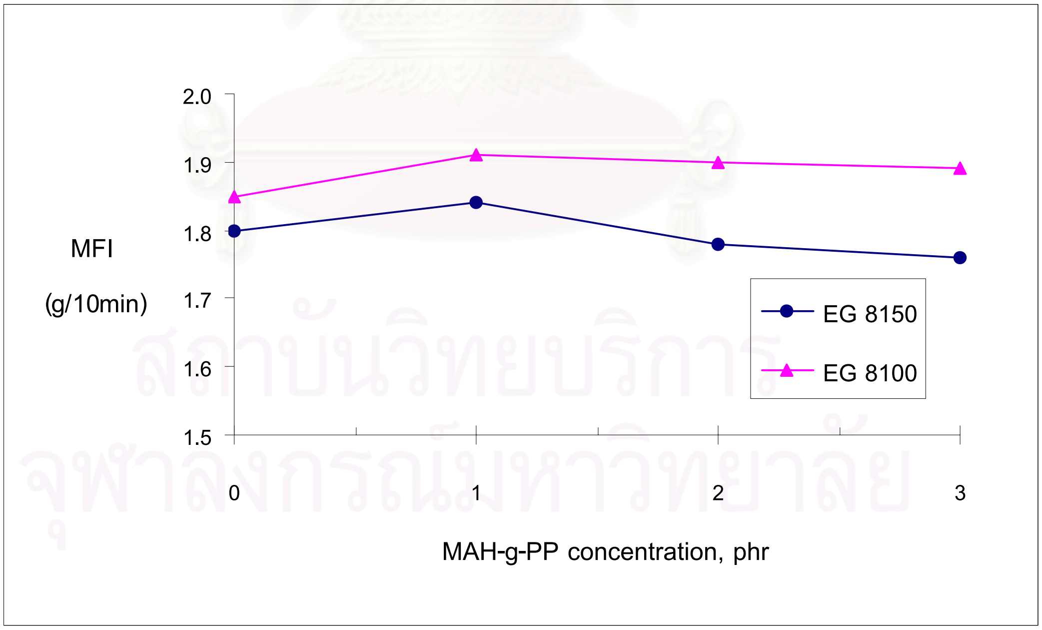


Figure 4.11 Melt flow index of PP-cp/EG/MAH-g-PP blends at 20 wt% EG.

4.6 Effect of MAH-g-PP Concentration on Mechanical Properties of PP-cp/EG/MAH-g-PP Blends at 20 wt% EG

MAH-g-PP had two part structures, polar and non-polar parts. In this case maleic anhydride is the polar part and PP is the non-polar part. Therefore, it can be expected that each part of the compatibilizer can be miscible with each phase of compound that similar in polarity. MAH-g-PP was added to improve the adhesion between the phases and enhance the mechanical properties of the blends. The effect of increasing concentration of MAH-g-PP on the tensile properties, flexural properties and impact strength of the PP-cp/EG blends with a fix EG concentration at 20 wt% was investigated.

The results of this work are shown in the Figures 4.12-4.18 and Tables 4.8-4.9, the concentration of MAH-g-PP within the blend rises to 3.0 phr. There is a large improvement of the Young's modulus, yield stress, impact strength and a moderate change of tensile strength and flexural properties at the amount of MAH-g-PP 1.0 phr. At the same figure, it can be seen that 0.5 phr MAH-g-PP was enough to improve the tensile properties, flexural properties and impact strength. A highest tensile strength, Young's modulus, yield stress, flexural strength and flexural modulus properties of PP-cp/EG 8150 blends are obtained using 1.0 phr MAH-g-PP with 17.91%, three times, 59.19%, 23.23% and 25.76% increases, respectively. The tensile properties, flexural properties and impact strength of the blends with different amounts of MAH-g-PP in this experiment are better than those of the blends without compatibilizer at the same percentage of EG, while impact strength increases slightly and sample did not break as MAH-g-PP concentration up to 1.0 phr and the elongation at break shows 69.36% decrease i.e. from 368.7 to 112.95%.

EG8150 has the more 1-octene content than EG8100. Consequently, the tensile properties, flexural properties and impact strength of PP-cp/EG8150/MAH-g-PP blends should be less than PP-cp/EG8100/MAH-g-PP blends, as a result of branching or comonomer (1-octene) content which it strongly influences the crystallization and melting behavior. The lamellae first become decreasing with increasing branch content and eventually the crystallinity has fewer tendencies to be occurred **[39]**.

Table 4.9 Mechanical properties of PP-cp/EG/MAH-g-PP blends at 20 wt% EG 8150

Sample No.	**MAH-g-PP (phr)**	**TS**	**TM**	**YS**	**EB**	**FS**	**FM**	**NI**
4	0	20.10	154.28	13.38	410.12	14.72	501.33	64.80
16	0.5	22.06	244.06	17.68	182.51	15.78	522.05	66.79
17	**1.0**	**23.70**	**456.30**	**21.30**	**133.20**	**17.05**	**550.30**	**NB**
18	2.0	23.19	365.29	18.72	150.10	18.14	630.46	NB
19	3.0	22.61	326.25	16.94	165.40	17.97	610.48	NB

Table 4.10 Mechanical properties of PP-cp/EG/MAH-g-PP blends at 20 wt% EG 8100

Sample No.	**MAH-g-PP (phr)**	**TS**	**TM**	**YS**	**EB**	**FS**	**FM**	**NI**
11	0	20.59	170.70	15.54	368.72	16.01	534.20	63.55
20	0.5	22.21	258.43	19.08	159.97	16.52	540.43	65.54
21	**1.0**	**24.09**	**541.21**	**21.80**	**112.95**	**18.12**	**610.40**	**NB**
22	2.0	23.47	380.18	20.45	129.70	19.47	665.15	NB
23	3.0	22.94	351.55	18.18	137.75	18.42	630.70	NB

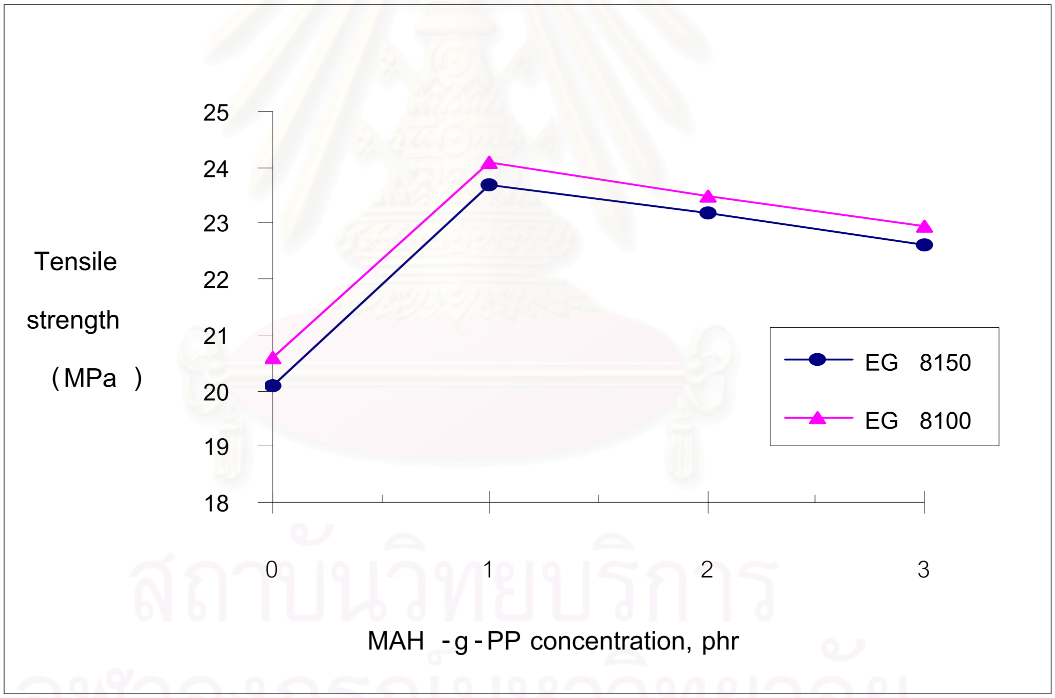


Figure 4.12 Tensile strength against the concentration of MAH-g-PP of PP-cp/20 wt% EG/MAH-g-PP blends.

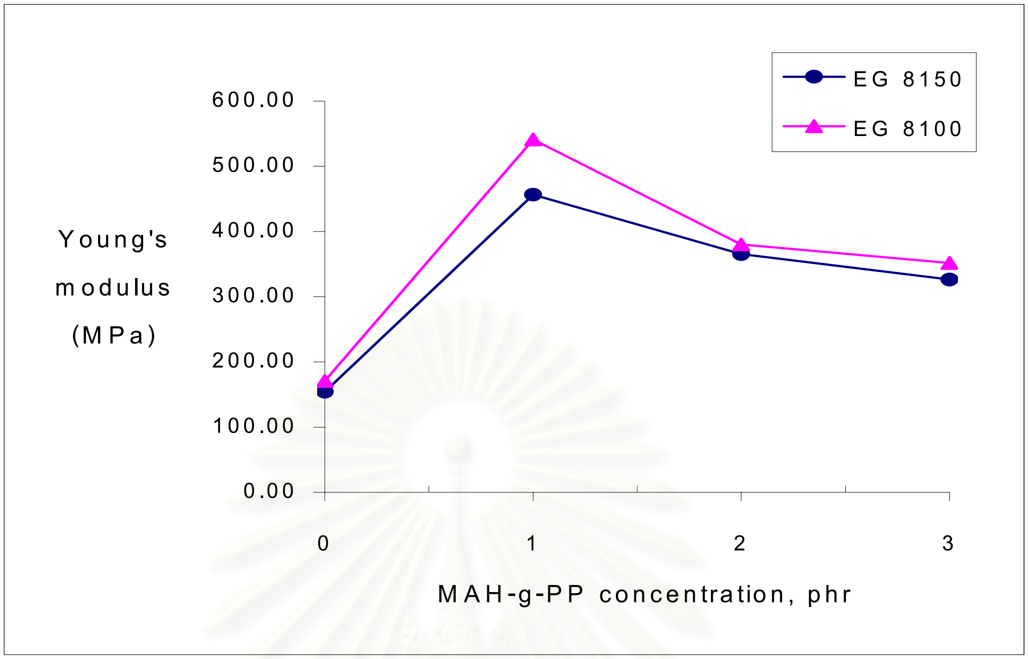


Figure 4.13 Young’s modulus against the concentration of MAH-g-PP of PP-cp/20 wt% EG/MAH-g-PP blends.

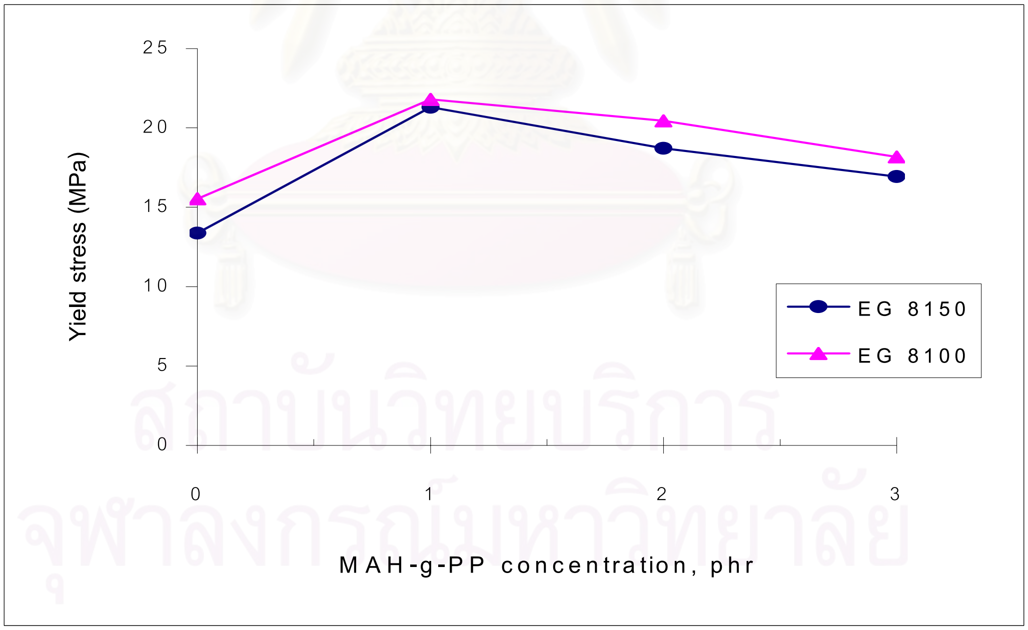


Figure 4.14 Yield stress against the concentration of MAH-g-PP of PP-cp/20 wt% EG/MAH-g-PP blends.

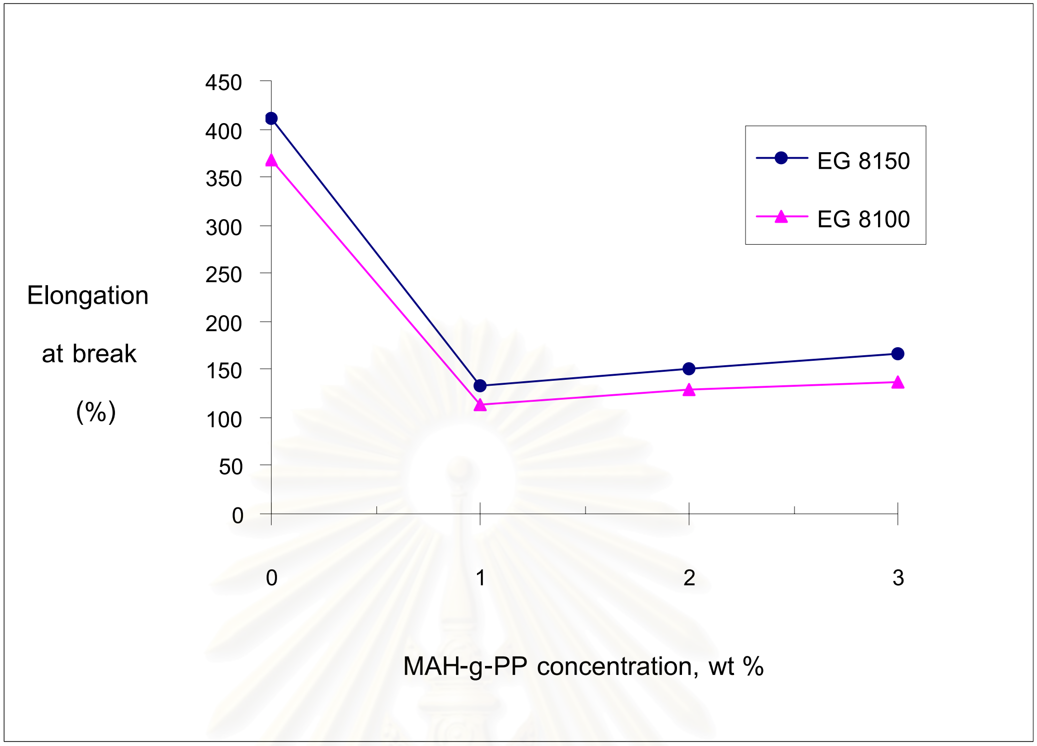


Figure 4.15 Elongation at break against the concentration of MAH-g-PP of PP-cp/20 wt% EG/MAH-g-PP blends.

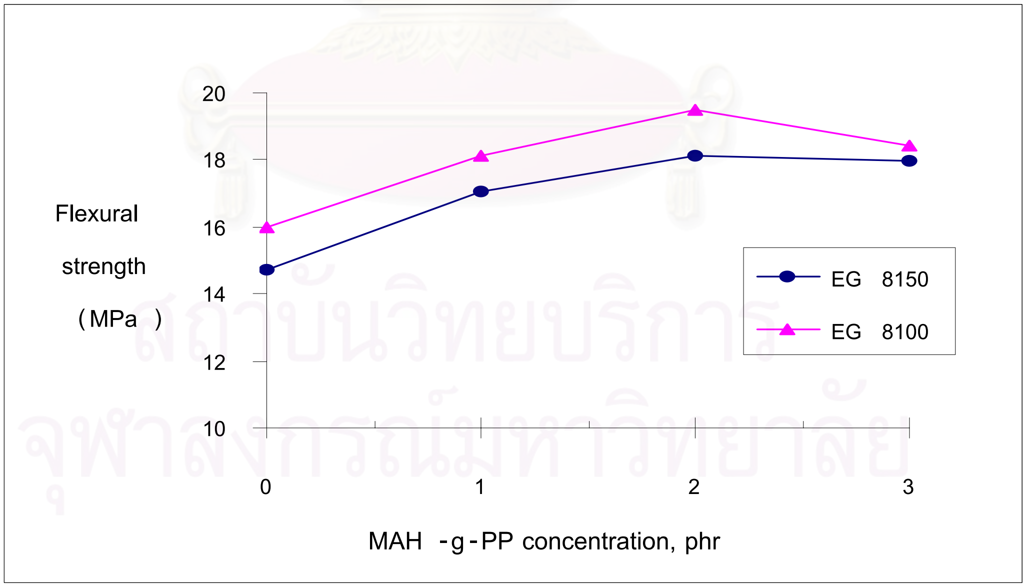


Figure 4.16 Flexural strength against the concentration of MAH-g-PP of PP-cp/20 wt% EG/MAH-g-PP blends.

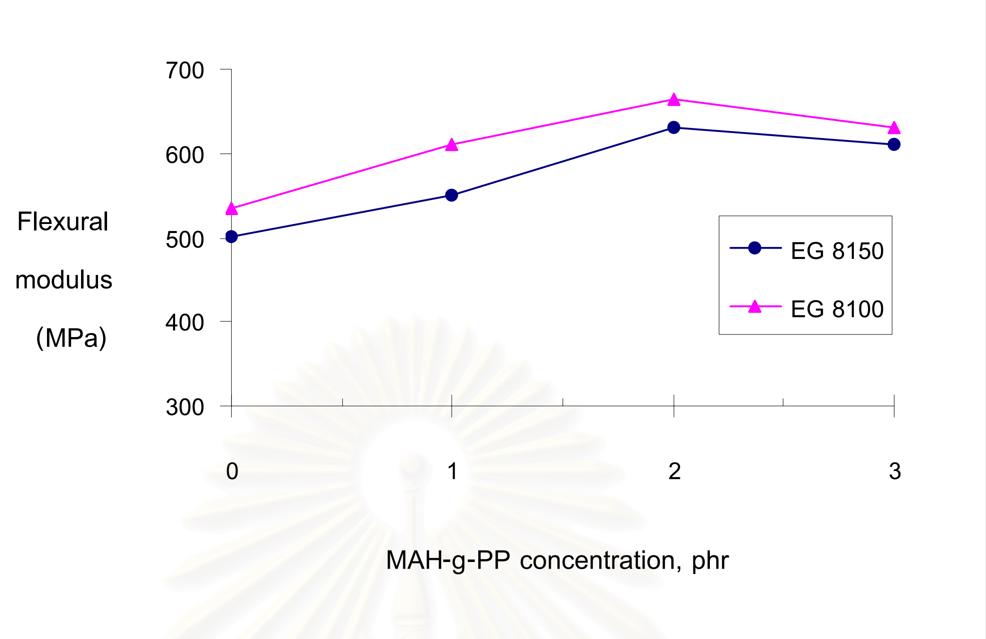


Figure 4.17 Flexural modulus against the concentration of MAH-g-PP of PP-cp/20 wt% EG/MAH-g-PP blends

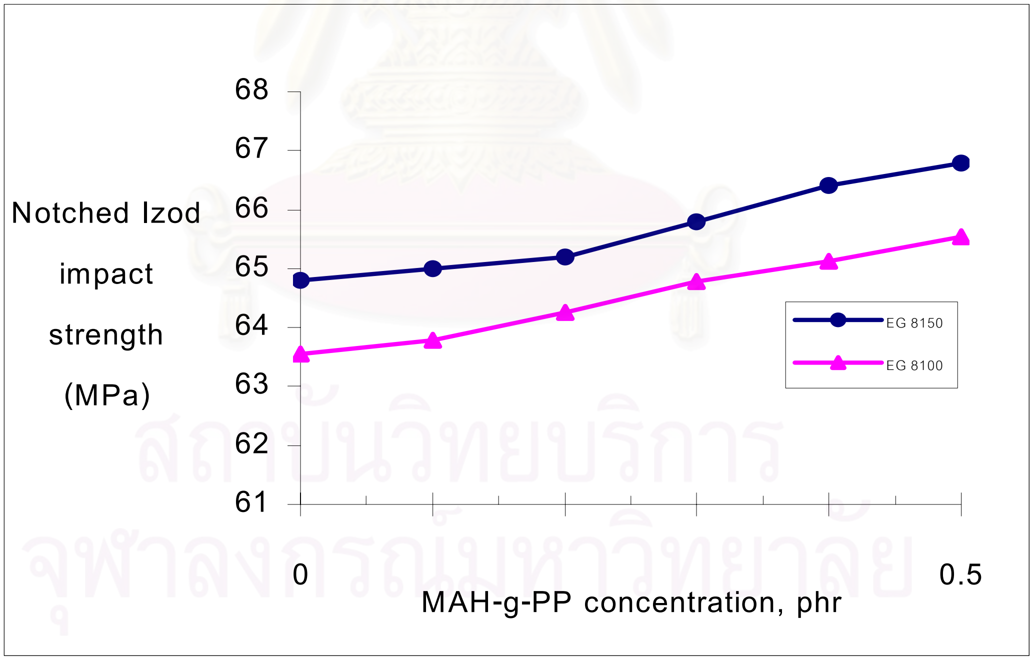


Figure 4.18 Notched Izod impact strength against the concentration of MAH-g-PP of PP-cp/20 wt% EG/MAH-g-PP blends

4.7 State of Dispersion of PP-cp/EG/MAH-g-PP Blends at 20 wt% EG

Scanning electron microscope (SEM) was used to study the surface of blends containing 20 wt% EG. SEM micrographs are shown in Figures 18-20 in Appendix III. As described in Section 2.6, compatibilization reduces the interfacial tension, which contributes interfacial adhesion, a finer dispersion and a more uniform distribution of the dispersed phase. MAH-g-PP compatibilized blends exhibit more finely dispersed phase than blends without compatibilizer.

From SEM micrographs, the size reduction and increased dispersion occur in proportion to MAH-g-PP concentration. At 1.0 phr MAH-g-PP the EG domains have a finer dispersion related to other MAH-g-PP concentrations. This explains maximum tensile properties, flexural properties and impact strength found at 1.0 phr MAH-g-PP. When the amount of MAH-g-PP higher than 1.0 phr, the tensile properties and flexural properties drop from the maximum values. The optimum amount of compatibilizer gives highest mechanical properties.

4.8 Economic Consideration

From the result of this research, the best composition is PP-cp/EG/MAH-g-PP at 80/20/1, which its mechanical properties approach to commercial resin. The cost of this blend is based on the cost of PP-cp, EG, MAH-g-PP. The costs of PP-cp, EG, MAH-g-PP in August 2000 are approximately 30, 110, and 225 Baht/kg, respectively. Table 4.11 indicated the cost analysis of the blends. It can be seen that the cost of the blends per kilogram is relatively low.

Using blends of EG and PP-cp would reduce the cost versus a 100% EG compound. Conversely, addition of small amounts of EG to PP-cp would only increase price slightly. The use of a chemically modified polyolefin (MAH-g-PP) as a compatibilizer in PP-cp/EG blends will be explored as a way to achieve cost-effective blends with desirable mechanical properties.

Table 4.11 Cost analysis of PP-cp/EG/MAH-g-PP blends.

	Materials Cost (Baht/kg)			
PP-cp/EG/MAH-g-PP	**PP-cp**	**EG**	**MAH-g-PP**	**Cost of blends (Baht/kg)**
80/20/1	**30**	**110**	**225**	**48.2**

** Cost of commercial resin = 100 Baht/kg.

CHAPTER V

CONCLUSIONS AND SUGGESTIONS

5.1 Conclusions

The polypropylene copolymer, PP-cp has been blended with two different types of ethylene-1-octene copolymer, EG and 20 wt% EG were added with maleic anhydride-grafted-polypropylene, MAH-g-PP. The effects of increasing octene content, EG concentrations and MAH-g-PP concentrations on mechanical properties, thermal properties and morphology of PP-cp/EG/MAH-g-PP blends were investigated. The following results should to be noted:

1. The values of PP-cp/EG blend melt flow index are between the values of the pure component melt flow index, and these values decrease as the EG concentration and 1-octene content increase. The melt flow index of PP-cp/EG 8150 is higher than PP-cp/EG 8100 blend. This behavior can be related to the effect of the presence of EG long chain branches that become more significant and thus entanglement between branching and chain segments of EG and PP-cp can occur. The addition of 1.0 phr MAH-g-PP gave system a further decrease melt flow index. This behavior implied that MAH-g-PP might have improved the interfacial adhesion of PP-cp and EG.

2. Thermal analysis shows that there is no change in the crystallization behavior of the matrix when different elastomer and compatibilizer content are added. It is also verified that as the EG, 1-octene and MAH-g-PP content

increases, the crystallinity degree and the heat of fusion decrease in the relation to PP-cp.

3. The main factor affecting the mechanical properties of the investigated ethylene-1-octene copolymer is the degree of crystallinity. In general, the higher the crystallinity, the higher the tensile strength, Young's modulus, yield stress and the resistance to strain of copolymers. Since the degree of crystallinity is directly related to the concentration of EG and octene content, it decreases as the concentration of EG and 1-octene content increase.

4. The present study shows that incorporating EG and MAH-g-PP can enhance the impact properties of PP-cp in the PP-cp matrix. At 20 wt% EG and 1.0 phr concentration, PP-cp/EG blends showed a significant increase in impact strength and sample did not break at up to 30 wt% EG and up to 1.0 phr MAH-g-PP.

5. The elasticity of the blends increase with increasing the EG and 1-octene content. This behavior is a result of the presence of the entanglements between branching and chain segment of EG and PP-cp.

6. MAH-g-PP is a compatibilizer for PP-cp/EG blends. It can be expected that the PP segments of MAH-g-PP formed misicible blends with the bulk PP through cocrystallization and the polar of MAH-g-PP (maleic anhydride) formed a chemical bond with the EG. Thus it can improve the compatibility of PP-cp and EG and hence increase the mechanical properties of the blends.

7. The SEM micrographs show that the presence of 0.5-1.0 phr MAH-g-PP enhanced the adhesion of EG and PP-cp, improved the compatibility of two phases and therefore led to better mechanical properties.

In this research, the formulations of PP-cp blends that provide good balance of mechanical properties comparable to commercial resin, composed of 80 wt% PP-cp, 20 wt% EG and 1.0 phr MAH-g-PP. This formulation shows MFI ca. 1.84-1.91 g/10 min, tensile strength ca. 23.70-24.09 MPa, tensile modulus ca. 456.30-541.21 MPa, yield stress ca. 21.30-21.80 MPa, elongation at break 112.95-133.20 %, flexural strength ca. 17.05-18.12 MPa, flexural modulus ca. 550.30-610.40 MPa and sample from Izod impact test did not break. Consequently, this formulation is a potential material replacing commercial resin due to good mechanical properties and cost advantage.

Table 5.1 Properties of commercial reain, PP-cp, PP-cp/EG (80/20) blend, PP-cp/EG/MAH-g-PP (80/20/1) blend

Properties	**Commercial resin**	**PP-cp (100%)**	**PP-cp/EG (80/20)**	**PP-cp/EG/MAH-g-PP (80/20/1)**
Melt Flow Index, g/10 min	11	2.1	1.80-1.85	1.84-1.91
Tensile Strength at Yield, MPa	>16	24.85	13.38-15.54	21.30-21.80
Flexural Modulus, MPa	750	878.01	501.33-534.20	550.30-610.40
Elongation at Break, %	>300	334.31	368.72-410.12	112.95-133.20
Notch Izod Impact Strength, MPa	not break	57.60	63.55-64.80	not break

5.2 Suggestion for Further Study

According to this research, the mechanical properties and physical properties such as elongation at break and melt flow index of PP-cp blends cannot be achieved compared with the commercial resin. In order to improve the properties close to that of commercial resin, the following study are suggested.

1. The effect of high MFI of PP-cp and EG on MFI of the polymer blends.
2. The effect of type of polyolefin elastomer, type and content of comonomer on the properties.
3. The effect of temperature on Notched Izod impact strength.
4. In order to improve mixing efficiency, the varying rotation speed of twin screw extruder should be investigated.

Moreover, it is important to consider the cost performance, environmental impact of the polymer blends as well.

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APPENDICES

APPENDIX I

Table 1. Typical Data of Polypropylene Copolymer (grade 2500H).

Item	Test method	Typical data
Melt Flow Index, g/10min	ASTM D1238	2.1
Charpy Notched Impact Strength at -20^0C, mJ/mm^2	DIN 53453	10
Tensile Strength at Yield, N/mm^2	ASTM D638	23
Shear Modulus, N/mm^2	DIN 53457	465

Table 2. Product Specification of Ethylene-1-Octene Copolymer (EG8150)

Item	Test method	Specification
Percent Comonomer, Octene Content		25.0
Melt Flow Index, g/10 min	ASTM D1238	0.5
Mooney Viscosity, ML 1+4 at 121^{0}C	ASTM D1646	35.0
Ultimate Tensile Strength, N/mm^2	ASTM D638-90	15.4

Table 3. Product Specification of Ethylene-1-Octene Copolymer (EG8100)

Item	Test method	Specification
Percent Comonomer, Octene Content		24.0
Melt Flow Index, g/10 min	ASTM D1238	1.0
Mooney Viscosity, ML 1+4 at 121^{0}C	ASTM D1646	23.0
Ultimate Tensile Strength, N/mm^2	ASTM D638-90	16.3

Table 4. Product Specification of Maleic Anhydride-Grafted-Polypropylene (MAH-g-PP)

Item	**Specification**
Composition : Maleic Anhydride Modified Homopolymer Polypropylene	
Physical Form : Pellets	
Melt Flow Index, g/10min	50
Density at 23 ^{0}C, g/cc	0.91
Melting Point, ^{0}C	157

APPENDIX II

Table 5. Physical Analysis Data Sheet of PP-cp/EG Blends.

Sample No.	Analysis No.	MFI	TS	TM	YS	EB	FS	FM	NI
1	1	2.08	25.61	232.45	24.89	334.27	25.45	878.05	57.50
	2	2.10	25.50	232.60	24.80	334.31	25.46	878.01	57.72
	3	2.11	25.55	232.52	24.85	334.35	25.42	877.98	57.58
	Average	2.10	25.55	232.52	24.85	334.31	25.44	878.01	57.60
2	1	2.03	21.38	184.59	20.93	350.21	25.23	834.81	58.93
	2	2.04	21.40	184.62	20.95	350.23	25.20	834.86	58.90
	3	2.04	21.44	184.70	20.97	350.25	25.15	834.83	58.94
	Average	2.04	21.41	184.64	20.95	350.23	25.19	834.83	58.92
3	1	1.97	21.05	160.50	19.73	370.80	22.29	782.54	62.93
	2	1.96	21.01	160.42	19.71	370.77	22.25	782.50	63.00
	3	1.95	21.03	160.46	19.72	370.75	22.21	782.48	62.97
	Average	1.96	21.03	160.46	19.72	370.77	22.25	782.51	62.97
4	1	1.80	20.12	154.32	13.39	410.07	14.74	501.31	64.76
	2	1.80	20.09	154.25	13.36	410.10	14.68	501.33	64.80
	3	1.81	20.10	154.27	13.39	410.18	14.75	501.36	64.83
	Average	1.80	20.10	154.28	13.38	410.12	14.72	501.33	64.80
5	1	1.76	19.14	130.46	11.37	470.17	12.38	450.34	NB
	2	1.74	19.15	130.50	11.38	470.20	12.34	450.24	NB
	3	1.75	19.14	130.47	11.38	470.24	12.36	450.20	NB
	Average	1.75	19.14	130.48	11.38	470.20	12.36	450.26	NB
6	1	1.52	16.31	117.63	6.69	525.97	7.07	225.50	NB
	2	1.50	16.35	117.67	6.75	526.00	7.03	225.44	NB
	3	1.53	16.34	117.64	6.74	526.04	7.06	225.46	NB
	Average	1.52	16.33	117.65	6.73	526.00	7.05	225.47	NB

Table 5. (continued)

Sample No.	Analysis No.	MFI	TS	TM	YS	EB	FS	FM	NI
7	1	1.36	15.28	104.28	5.43	580.69	4.40	187.46	NB
	2	1.33	15.26	104.24	5.41	580.71	4.42	187.35	NB
	3	1.35	15.25	104.22	5.40	580.75	4.36	187.32	NB
	Average	1.35	15.26	104.25	5.41	580.72	4.39	187.38	NB
8	1	1.30	14.07	94.35	4.38	593.18	3.15	160.19	NB
	2	1.32	14.01	94.25	4.32	593.20	3.18	160.25	NB
	3	1.28	14.03	94.27	4.34	593.21	3.11	160.31	NB
	Average	1.30	14.04	94.28	4.35	593.20	3.15	160.25	NB
9	1	2.06	22.05	195.90	21.17	345.15	25.32	854.32	58.50
	2	2.07	22.07	195.70	21.17	345.20	25.25	854.42	58.38
	3	2.07	22.06	195.80	21.20	345.25	25.29	854.36	58.43
	Average	2.07	22.06	195.80	21.18	345.20	25.29	854.37	58.44
10	1	1.99	21.78	181.02	20.38	357.73	23.82	838.34	62.11
	2	2.02	21.74	180.97	20.35	357.68	23.88	838.30	62.15
	3	2.00	21.73	180.99	20.33	357.71	23.85	838.38	62.09
	Average	2.00	21.75	180.99	20.35	357.71	23.85	838.34	62.12
11	1	1.85	20.56	170.72	15.52	368.70	16.05	534.24	63.56
	2	1.84	20.59	170.69	15.54	368.67	16.01	534.16	63.53
	3	1.85	20.61	170.70	15.57	368.80	15.97	534.20	63.57
	Average	1.85	20.59	170.70	15.54	368.72	16.01	534.20	63.55
12	1	1.80	19.94	147.64	12.87	424.49	13.27	492.36	NB
	2	1.78	19.90	147.65	12.89	424.51	13.24	492.38	NB
	3	1.79	19.93	147.68	12.92	424.53	13.21	492.34	NB
	Average	1.79	19.92	147.66	12.89	424.51	13.24	492.36	NB

Table 5. (continued)

Sample No.	Analysis No.	MFI	TS	TM	YS	EB	FS	FM	NI
13	1	1.68	18.43	128.53	7.52	450.84	7.78	266.45	NB
	2	1.66	18.45	128.56	7.54	450.80	7.74	266.41	NB
	3	1.70	18.46	128.51	7.54	450.80	7.70	266.35	NB
	Average	1.68	18.45	128.53	7.53	450.81	7.74	266.40	NB
14	1	1.57	15.75	115.71	6.27	510.29	5.06	210.40	NB
	2	1.59	15.75	115.72	6.28	510.25	4.99	210.35	NB
	3	1.56	15.77	115.74	6.29	510.21	5.02	210.30	NB
	Average	1.57	15.76	115.72	6.28	510.25	5.02	210.35	NB
15	1	1.42	14.97	107.14	5.52	552.14	3.96	182.80	NB
	2	1.41	14.94	107.11	5.50	552.09	9.90	182.75	NB
	3	1.44	14.95	107.14	5.53	552.10	3.94	182.72	NB
	Average	1.42	14.95	107.13	5.52	552.11	5.93	182.76	NB
16	1	1.87	22.07	244.08	17.72	182.51	15.79	522.10	66.82
	2	1.86	22.08	244.07	17.69	182.55	15.82	522.05	66.79
	3	1.88	22.04	244.04	17.64	182.48	15.72	521.99	66.77
	Average	1.87	22.06	244.06	17.68	182.51	15.78	522.05	66.79
17	1	1.84	23.72	456.30	21.32	133.24	17.06	550.33	NB
	2	1.83	23.69	456.28	21.27	133.20	17.01	550.27	NB
	3	1.84	23.70	456.31	21.30	133.17	17.08	550.30	NB
	Average	1.84	23.70	456.30	21.30	133.20	17.05	550.30	NB
18	1	1.77	23.23	365.33	18.75	150.12	18.17	630.42	NB
	2	1.80	23.16	365.25	18.69	150.11	18.11	630.45	NB
	3	1.78	23.19	365.30	18.72	150.07	18.14	630.50	NB
	Average	1.78	23.19	365.29	18.72	150.10	18.14	630.46	NB

Table 5. (continued)

Sample No.	Analysis No.	MFI	TS	TM	YS	EB	FS	FM	NI
19	1	1.78	22.64	326.29	16.98	165.43	17.97	610.52	NB
	2	1.76	22.61	326.25	16.94	165.38	18.04	610.42	NB
	3	1.76	22.59	326.22	16.90	165.40	17.91	610.49	NB
	Average	1.76	22.61	326.25	16.94	165.40	17.97	610.48	NB
20	1	1.94	22.24	258.46	19.12	160.07	16.53	540.47	65.52
	2	1.93	22.21	258.43	19.08	159.95	16.46	540.42	65.57
	3	1.92	22.19	258.41	19.04	159.90	16.58	540.40	65.54
	Average	1.93	22.21	258.43	19.08	159.97	16.52	540.43	65.54
21	1	1.91	24.10	541.24	21.83	112.90	18.14	610.35	NB
	2	1.92	24.08	541.22	21.81	112.95	18.13	610.43	NB
	3	1.89	24.10	541.18	21.77	112.99	18.10	610.41	NB
	Average	1.91	24.09	541.21	21.80	112.95	18.12	610.40	NB
22	1	1.90	23.47	380.20	20.49	129.74	19.44	665.20	NB
	2	1.91	23.44	380.17	20.40	129.67	19.47	665.16	NB
	3	1.90	23.50	380.18	20.45	129.70	19.51	665.08	NB
	Average	1.90	23.47	380.18	20.45	129.70	19.47	665.15	NB
23	1	1.90	22.95	351.58	18.21	137.74	18.43	630.77	NB
	2	1.89	22.92	351.52	18.15	137.79	18.45	630.64	NB
	3	1.88	22.94	351.54	18.19	137.71	18.38	630.70	NB
	Average	1.89	22.94	351.55	18.18	137.75	18.42	630.70	NB

Remarks : MFI = Melt Flow Index, g/10min
TS = Tensile Strength, MPa
TM = Tensile Modulus, MPa
YS = Yield Stress, MPa
EB = Elongation at break, %
FS = Flexural Strength, MPa
FM = Flexural Modulus, MPa
NI = Notched Izod Impact Strength, MPa
NB = Not break

Table 6. Average Physical Analysis Data Sheet of PP-cp/EG Blends

Properties	PP-cp	EG 8150							EG 8100						
		Sample No.							Sample No.						
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
MFI	**2.1**	2.04	1.96	**1.80**	1.75	1.52	1.35	1.30	2.07	2.00	**1.85**	1.79	1.68	1.57	1.42
TS	**25.55**	21.41	21.03	**20.1**	19.14	16.33	15.26	14.04	22.06	21.75	**20.59**	19.92	18.45	15.76	14.95
TM	**232.52**	184.46	160.46	**154.28**	130.48	117.65	104.25	94.28	195.80	180.99	**170.70**	147.66	128.53	115.72	107.13
YS	**24.85**	20.95	19.72	**13.38**	11.38	6.73	5.41	4.35	21.18	20.35	**15.54**	12.89	7.53	6.28	5.52
EB	**334.31**	350.23	370.77	**410.12**	470.20	526.00	580.72	593.20	345.20	357.71	**368.72**	424.51	450.81	510.25	552.11
FS	**25.44**	25.19	22.25	**14.72**	12.36	7.05	4.39	3.15	25.29	23.85	**16.01**	13.24	7.74	5.02	3.93
FM	**878.01**	834.83	782.51	**501.33**	450.26	225.47	187.38	160.25	854.37	838.34	**534.20**	492.36	266.40	210.35	182.76
NI	**57.6**	58.92	62.97	**64.80**	NB	NB	NB	NB	58.44	62.12	**63.55**	NB	NB	NB	NB

NB : Sample did not break

Table 7. **Average Physical Analysis Data Sheet of PP-cp/EG/MAH-g-PP Blends at 20 wt% EG**

Sample No.	MAH-g-PP (phr)	MFI	TS	TM	YS	EB	FS	FM	NI
4	0	1.80	20.10	154.28	13.38	410.12	14.72	501.33	64.80
16	0.5	1.87	22.06	244.06	17.68	182.51	15.78	522.05	66.79
17	1.0	1.84	23.70	456.30	21.30	133.20	17.05	550.30	NB
18	2.0	1.78	23.19	365.29	18.72	150.10	18.14	630.46	NB
19	3.0	1.76	22.61	326.25	16.94	165.40	17.97	610.48	NB
11	0.0	1.85	20.59	170.7	15.54	368.72	16.01	534.2	63.55
20	0.5	1.93	22.21	258.43	19.08	159.97	16.52	540.43	65.54
21	1.0	1.91	24.09	541.21	21.80	112.95	18.12	610.40	NB
22	2.0	1.90	23.47	380.18	20.45	129.70	19.47	665.15	NB
23	3.0	1.89	22.94	351.55	18.18	137.75	18.42	630.70	NB

APPENDIX III

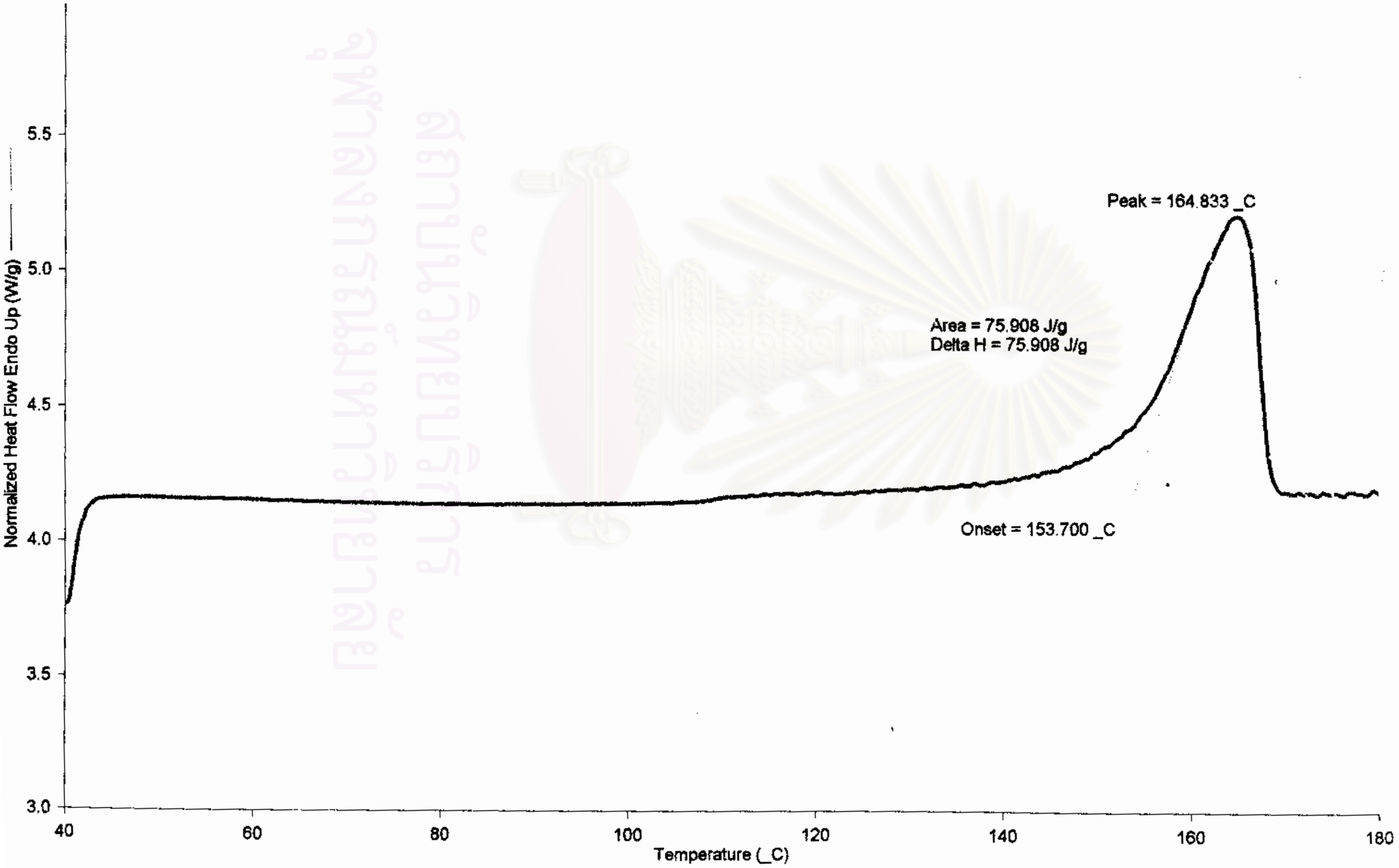

Figure 1. DSC curve of PP-cp

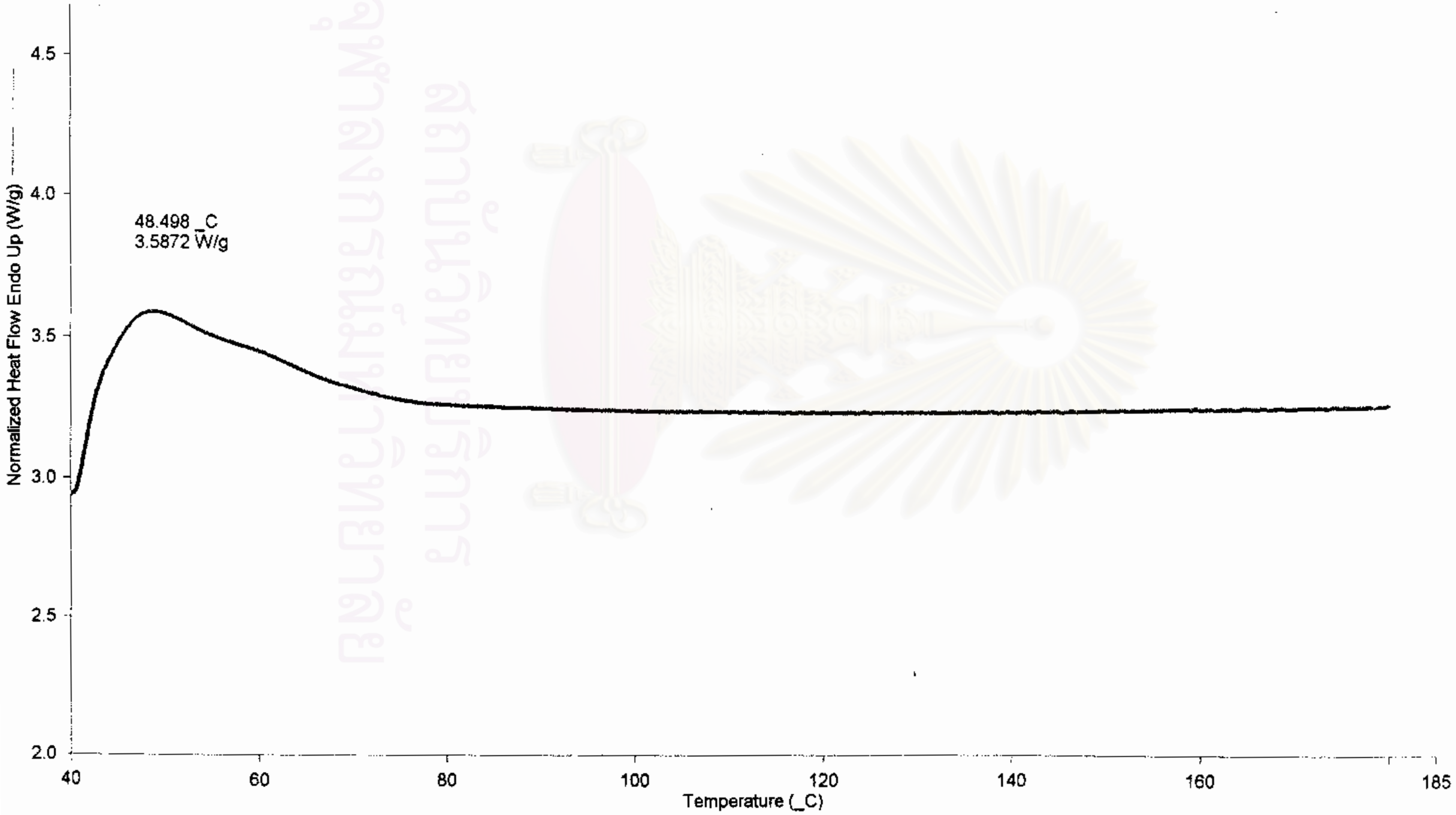

Figure 2. DSC curve of elastomer

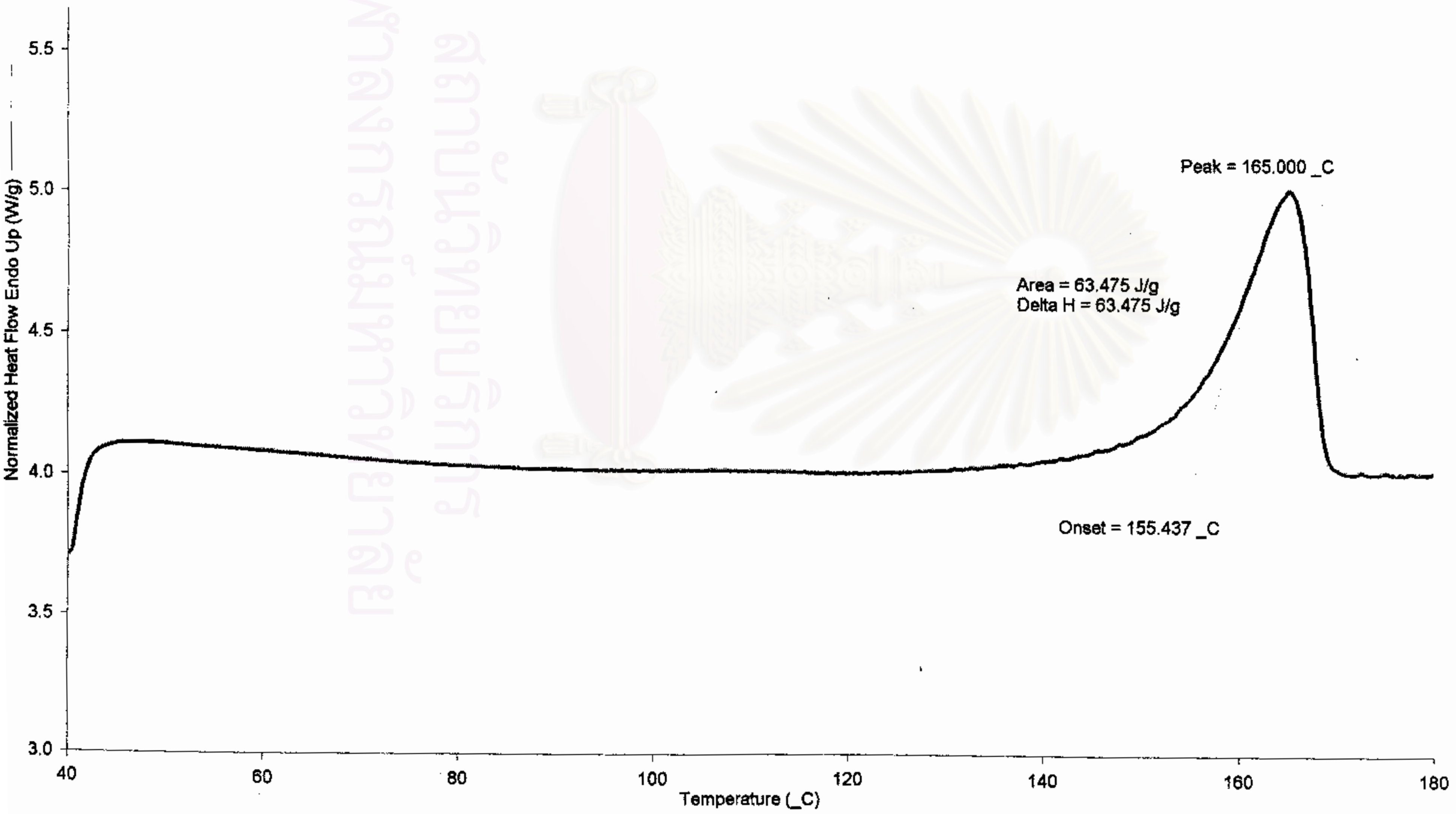

Figure 3. DSC curve of PP-cp/10 wt% EG 8150 blends

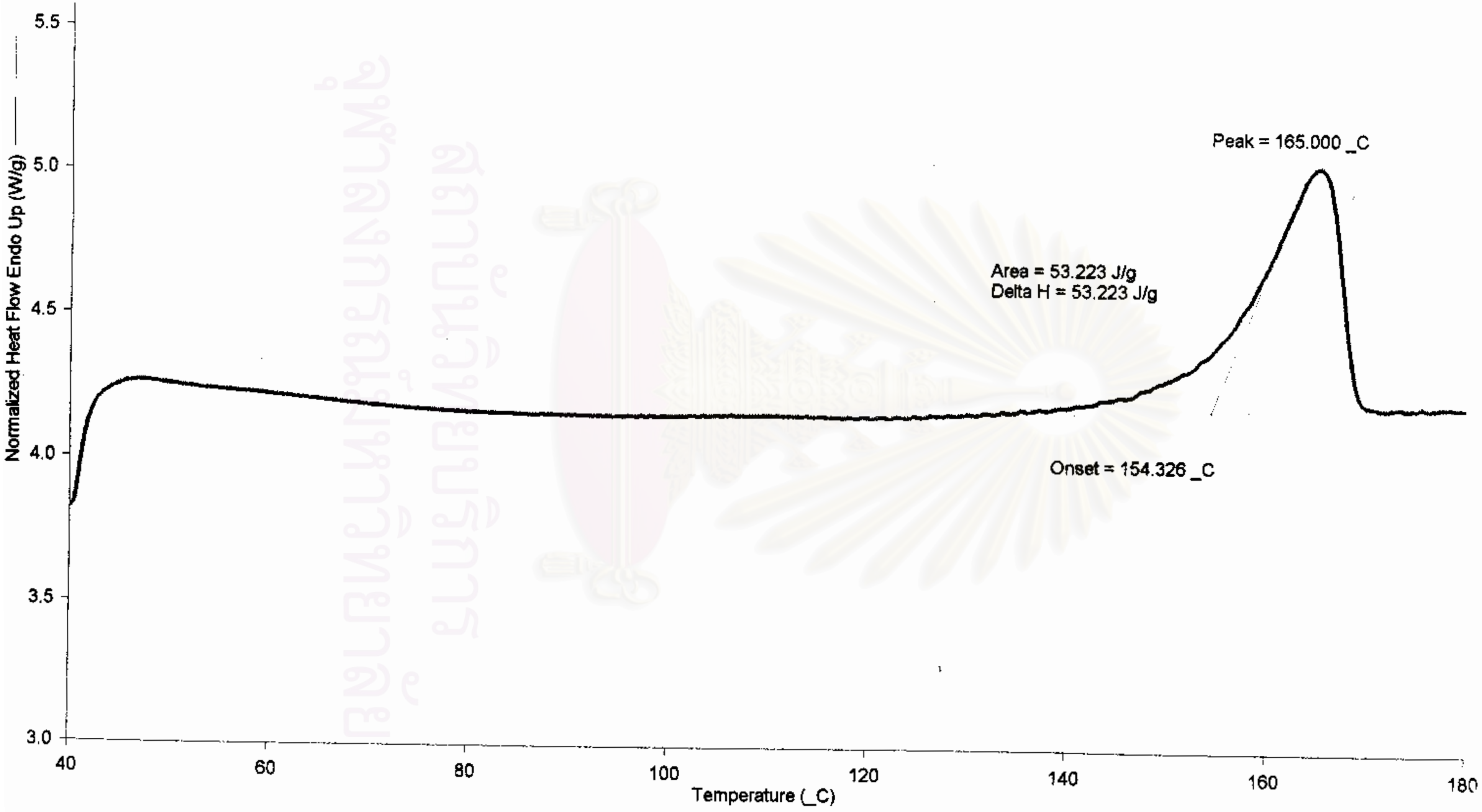

Figure 4. DSC curve of PP-cp/20 wt% EG 8150 blends

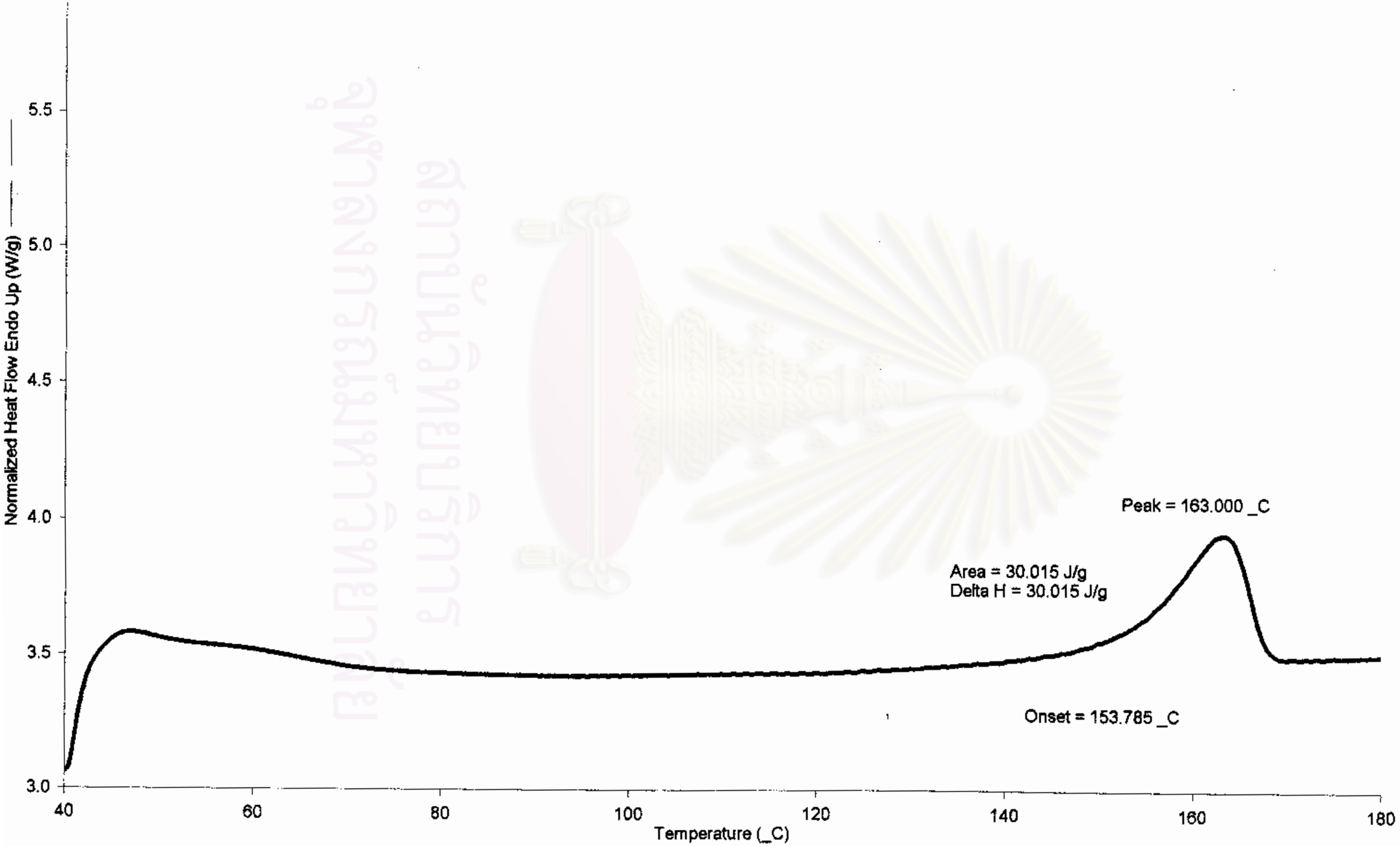

Figure 5. DSC curve of PP-cp/50 wt% EG 8150 blends

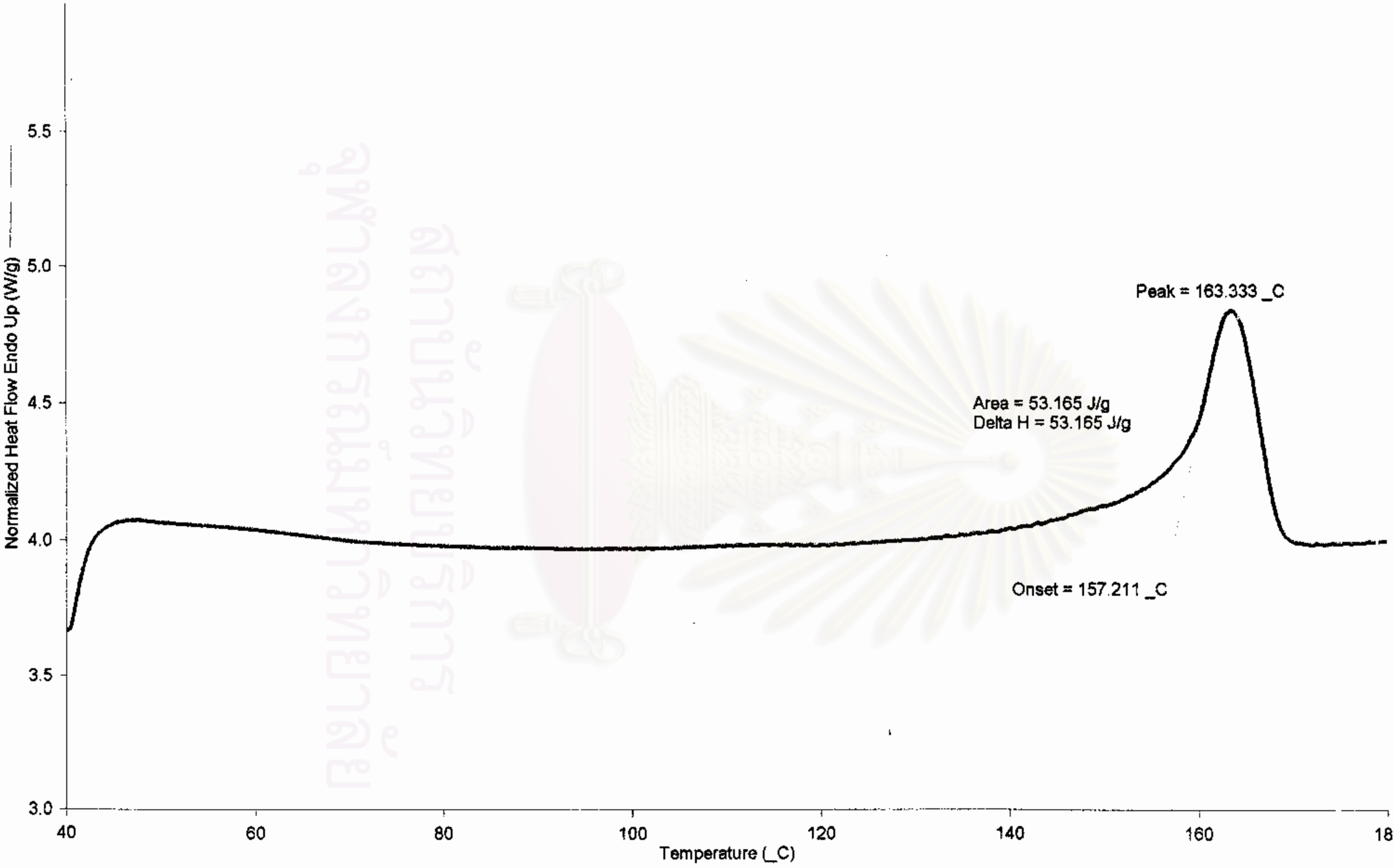

Figure 6. DSC curve of PP-cp/20 wt% EG 8150 /1.0 phr MAH-g-PP blends

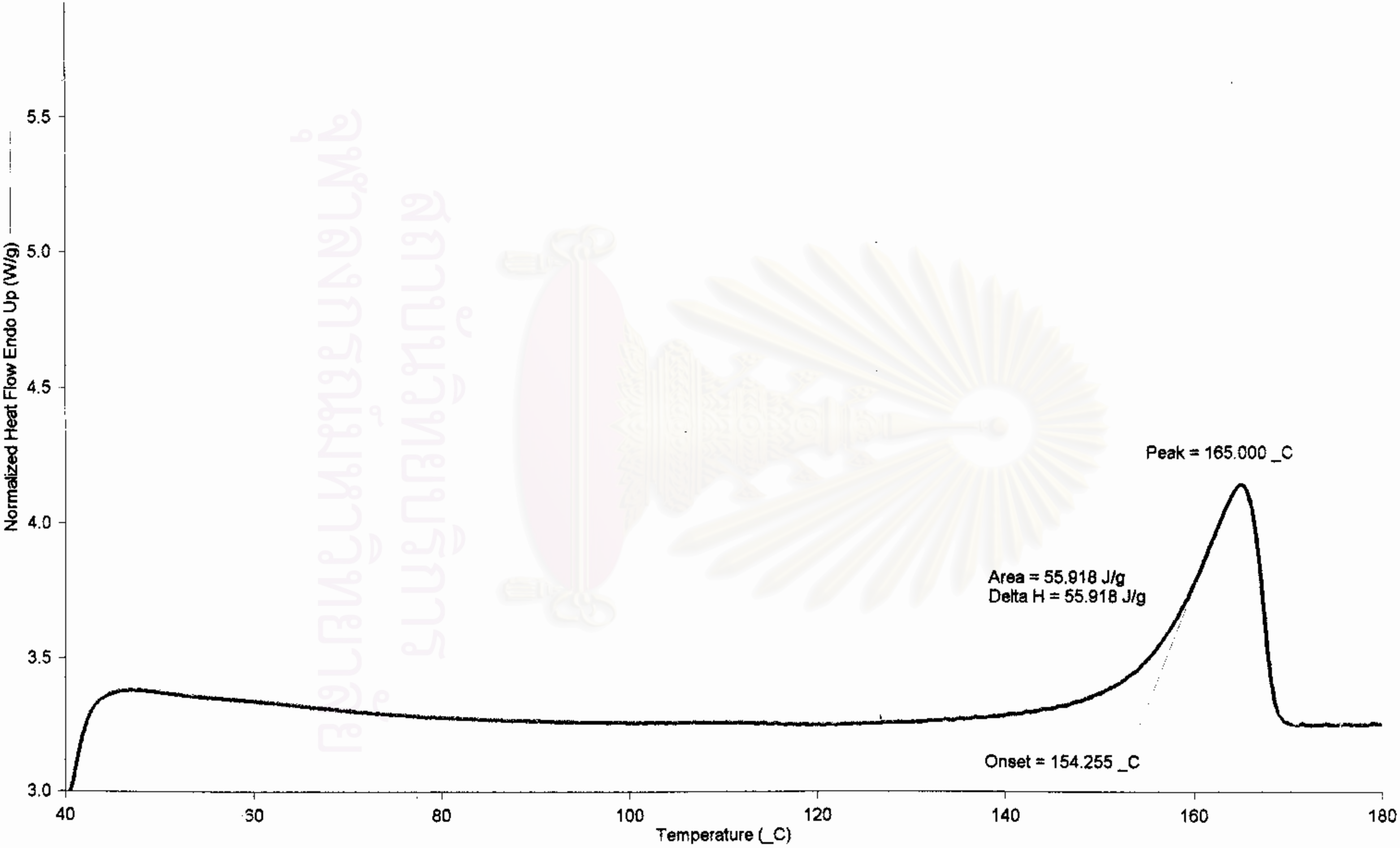

Figure 7. DSC curve of PP-cp/20 wt% EG 8150 /2.0 phr MAH-g-PP blends

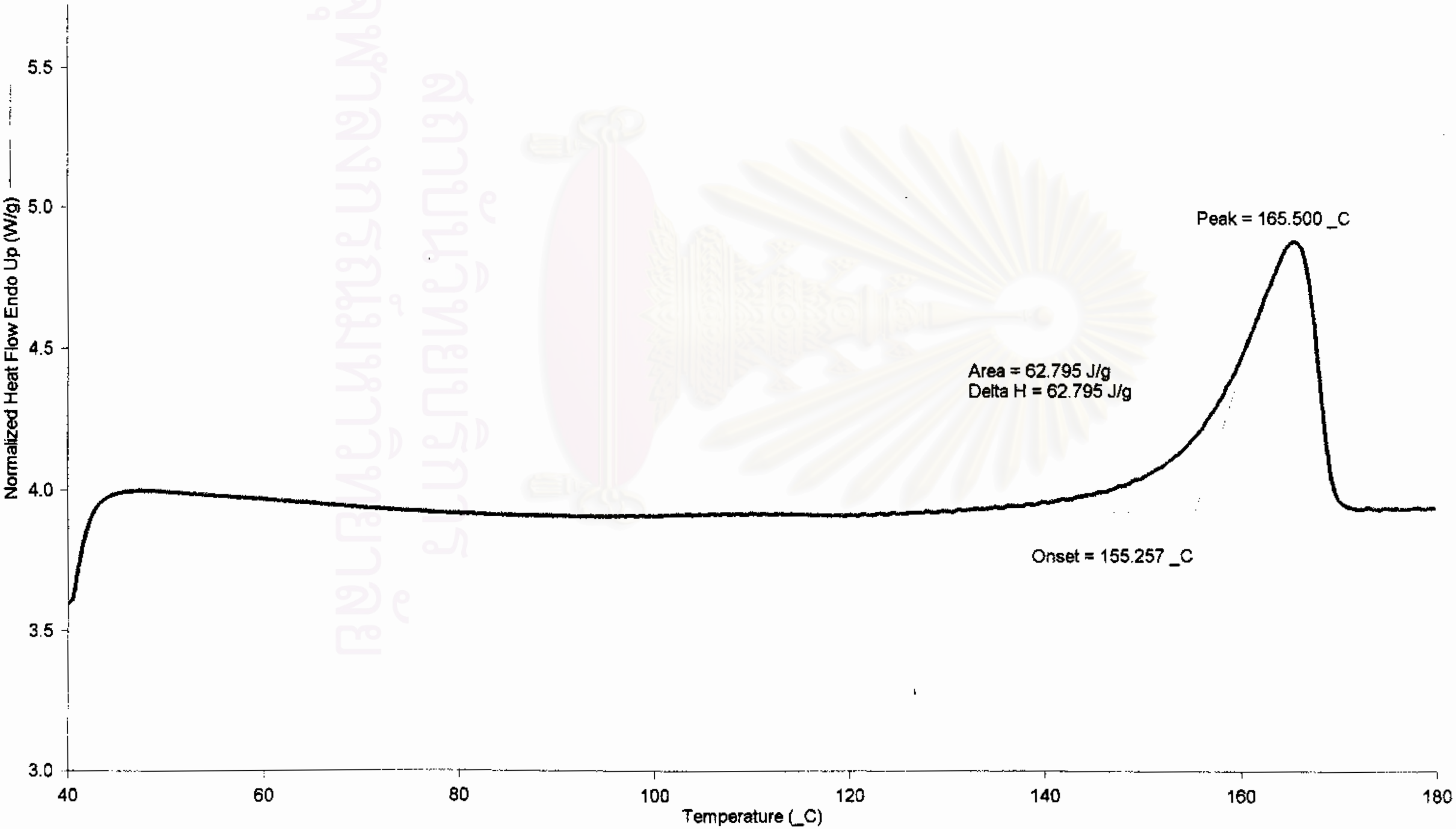

Figure 8. DSC curve of PP-cp/10 wt% EG 8100 blends

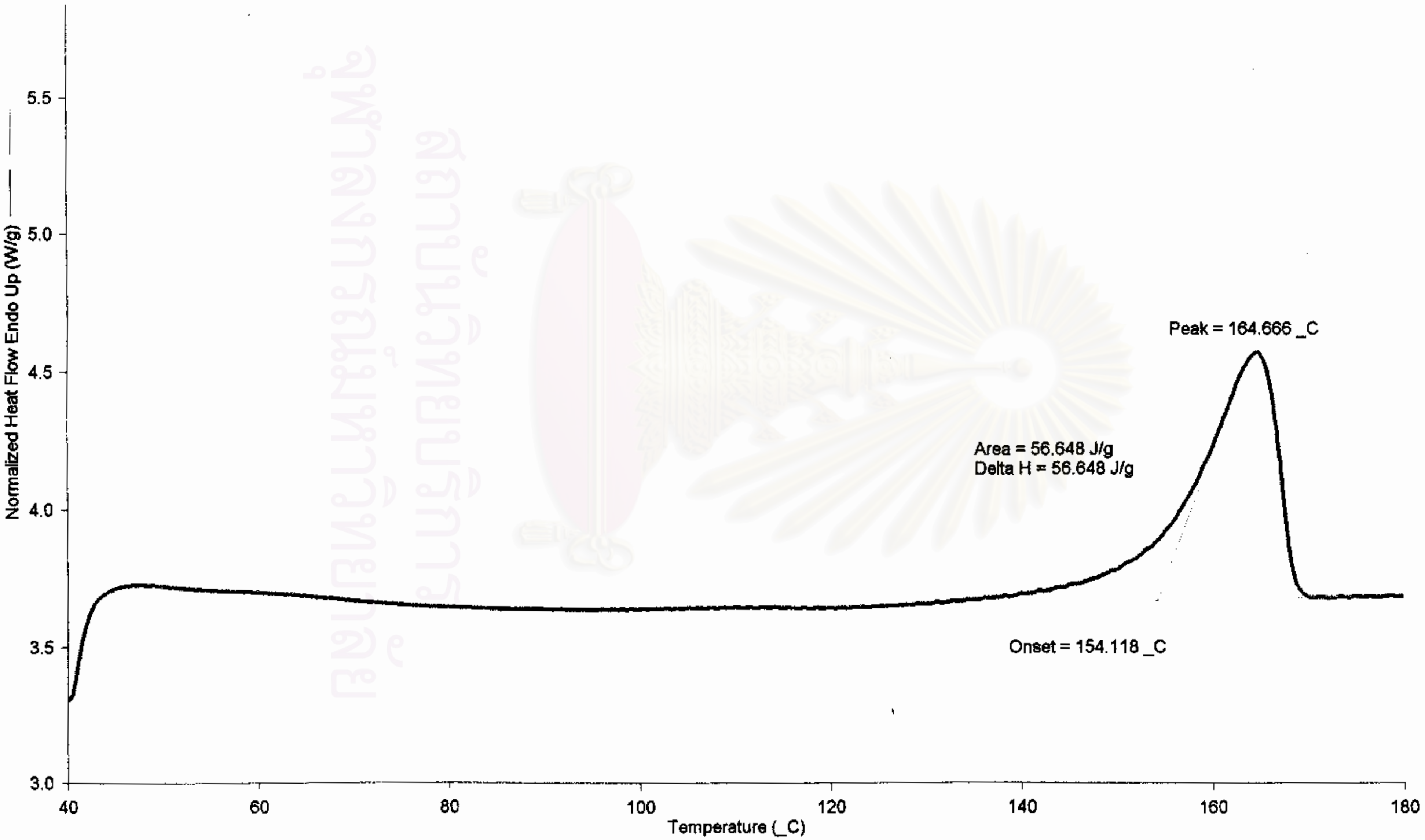

Figure 9. DSC curve of PP-cp/20 wt% EG 8100 blends

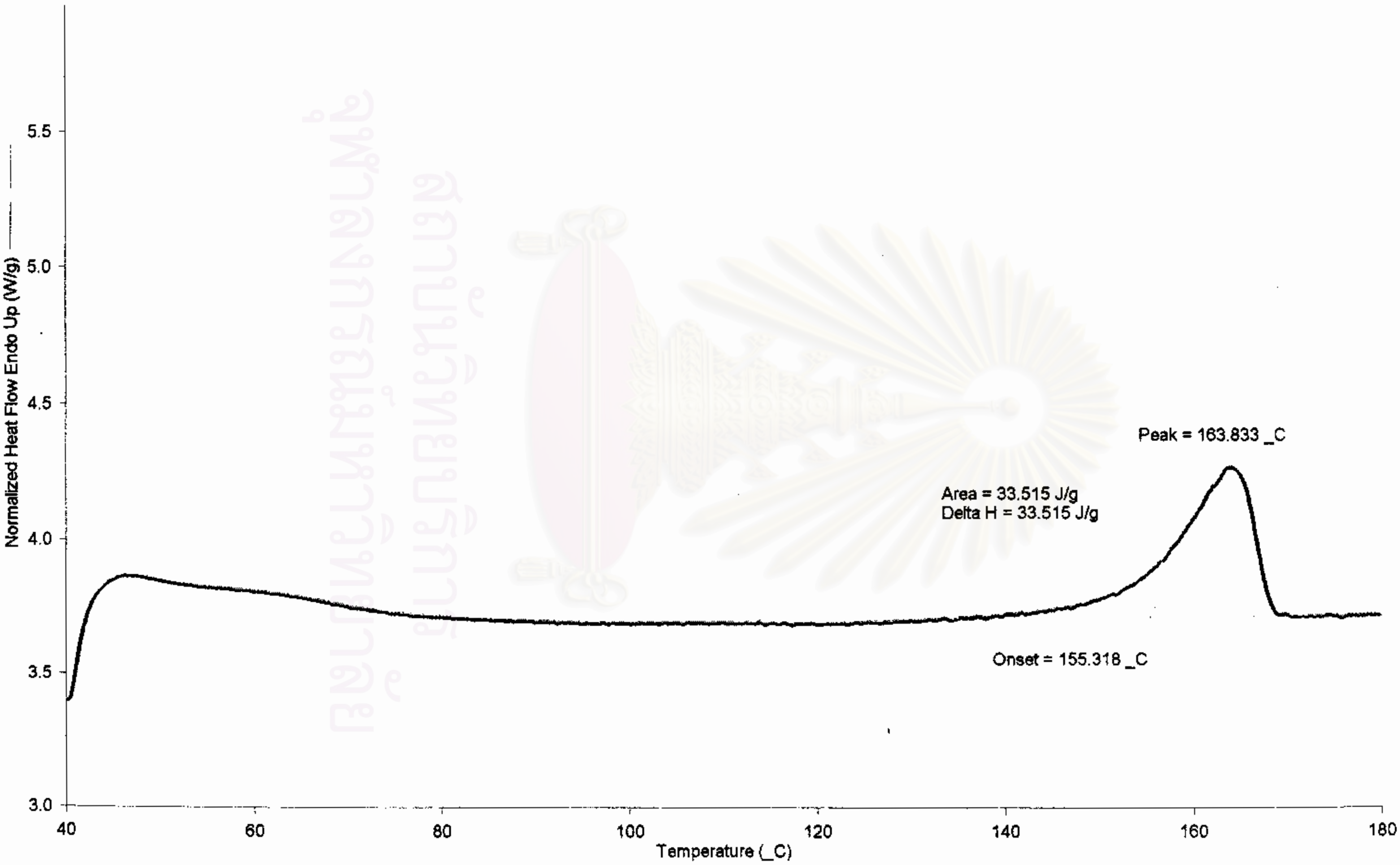

Figure 10. DSC curve of PP-cp/50 wt% EG 8100 blends

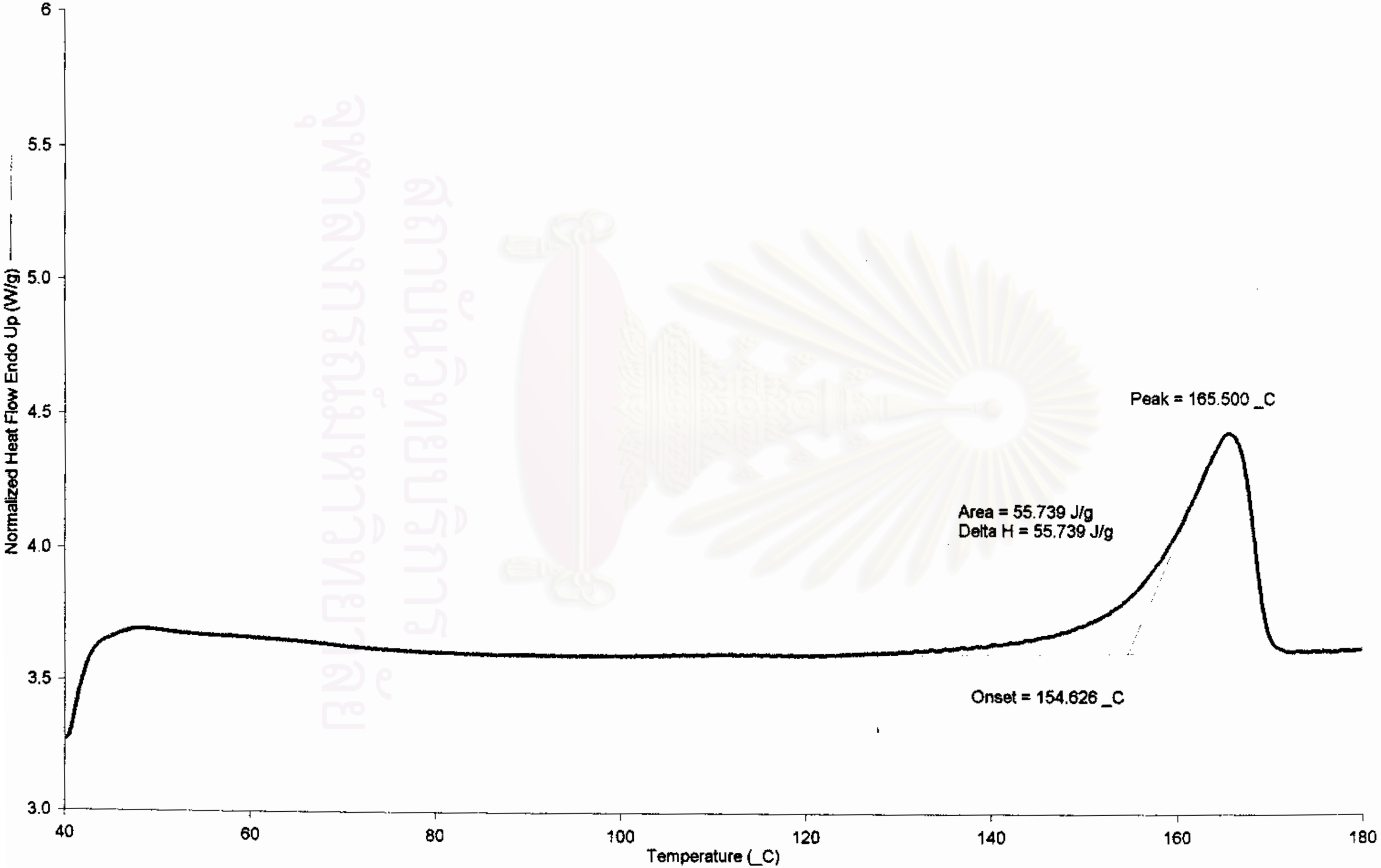

Figure 11. DSC curve of PP-cp/20 wt% EG 8100 /1.0 phr MAH-g-PP blends

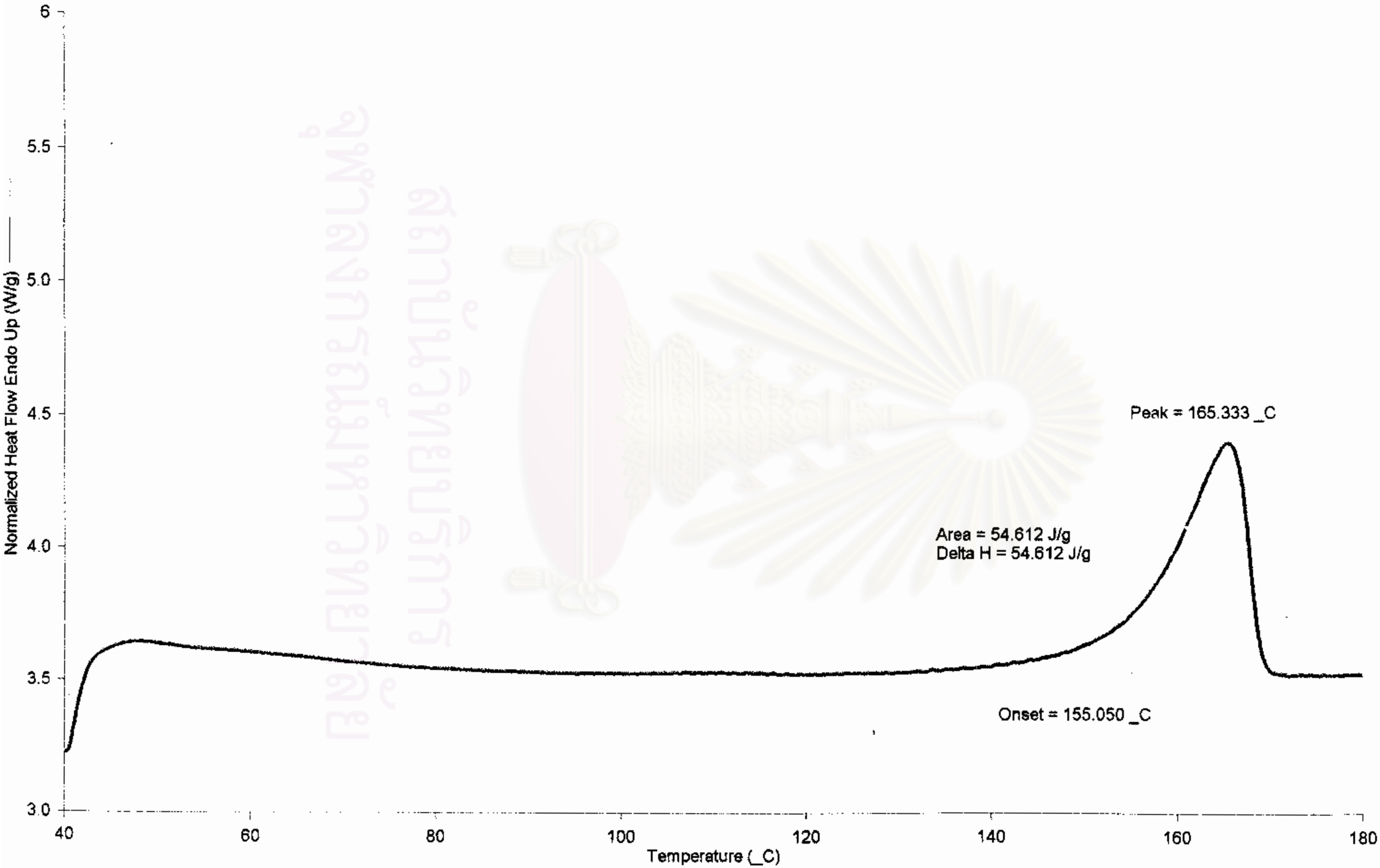

Figure 12. DSC curve of PP-cp/20 wt% EG 8100 /2.0 phr MAH-g-PP blends

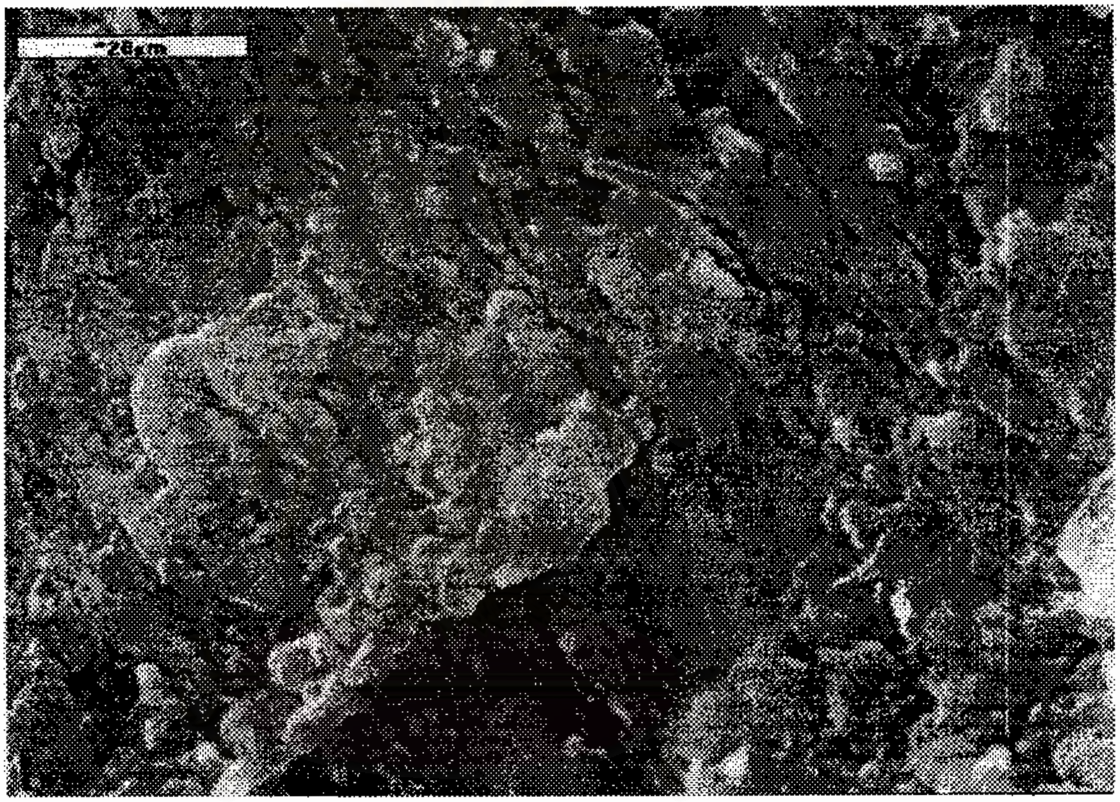

Figure 13. SEM micrograph of PP-cp

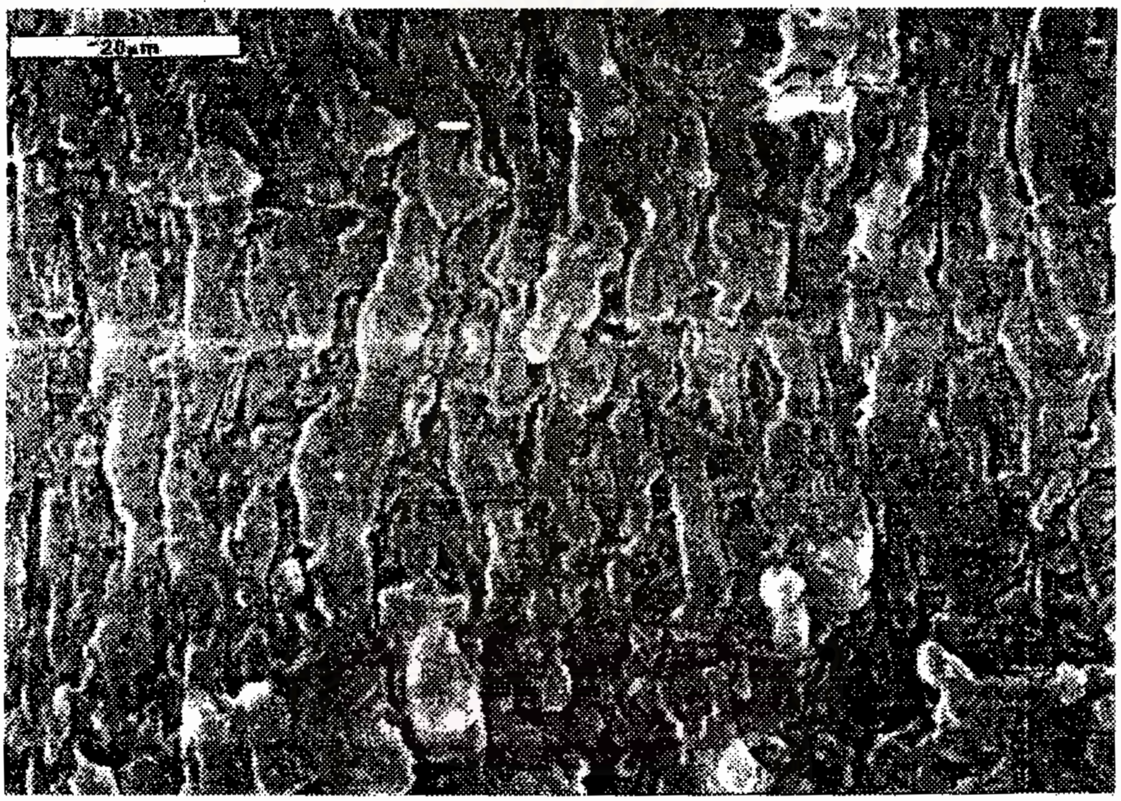

Figure 14. SEM micrograph of PP-cp/10 wt% EG blends

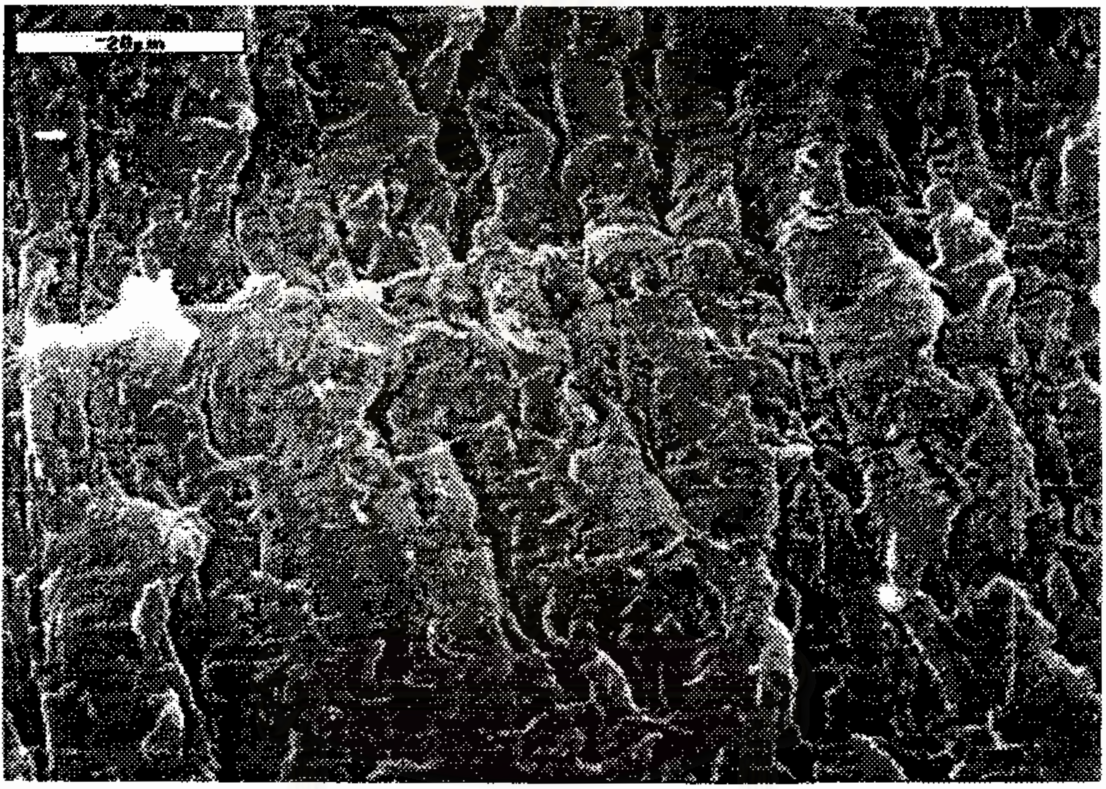

Figure 15. SEM micrograph of PP-cp/20 wt% EG blends

Figure 16. SEM micrograph of PP-cp/30 wt% EG blends

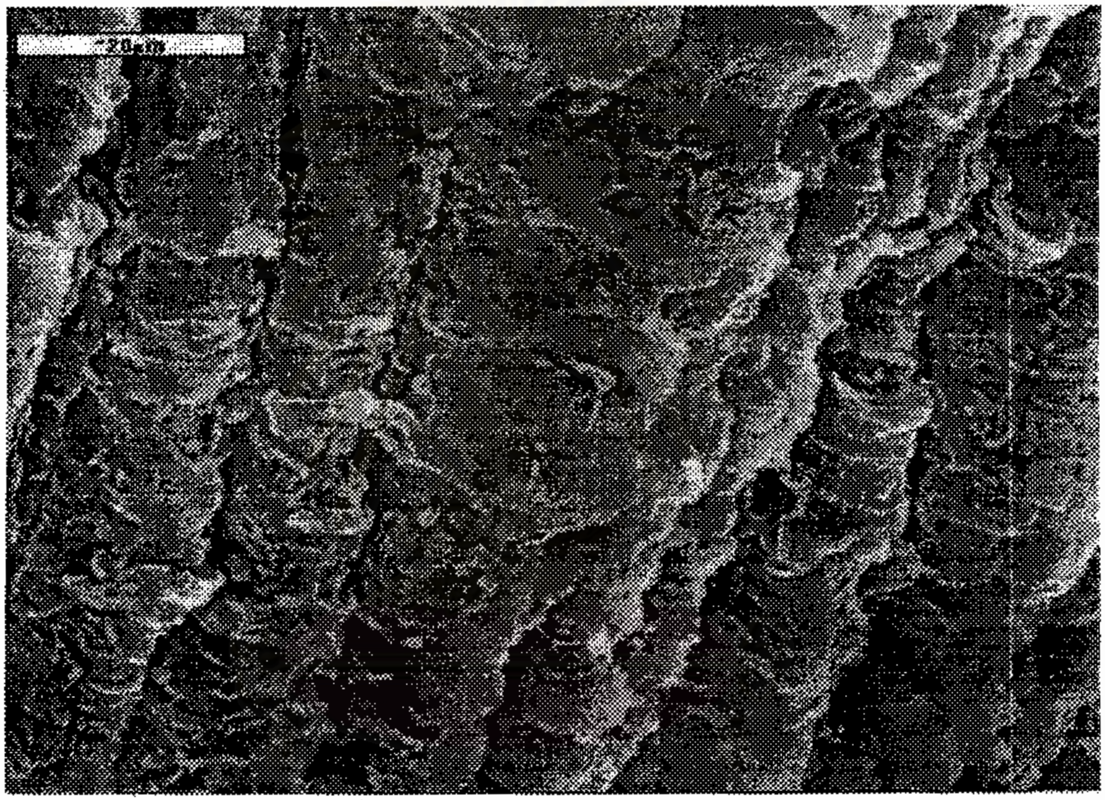

Figure 17. SEM micrograph of PP-cp/50 wt% EG blends

Figure 18. SEM micrograph of PP-cp/20 wt% EG/1.0 phr MAH-g-PP blends

Figure 19. SEM micrograph of PP-cp/20 wt% EG/2.0 phr MAH-g-PP blends

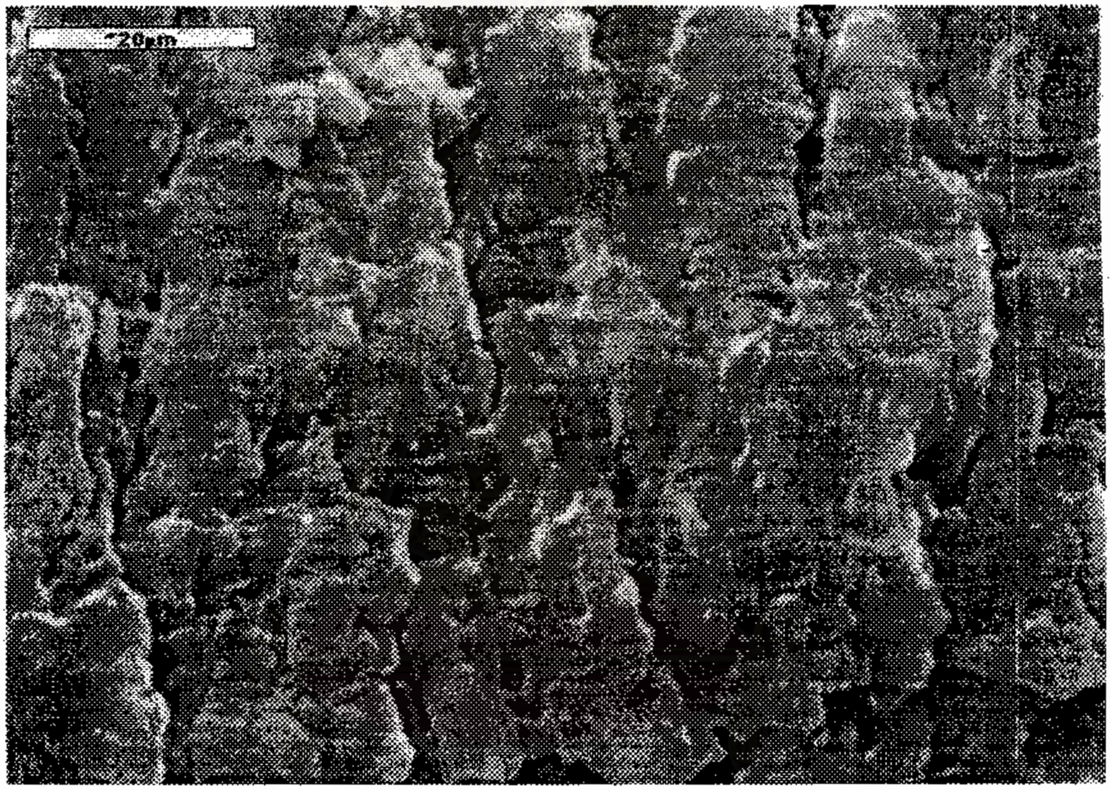

Figure 20. SEM micrograph of PP-cp/20 wt% EG/3.0 phr MAH-g-PP blends

APPENDIX IV

Table 8. Polypropylene Demand by End Use for Thailand for the Period 1985-2000 (Thousand Metric Tons)

	1985	1989	1990	1991	1992	1993	1994	1995	2000	Average Annual Growth Rate (%) 1985/1989	1989/2000
Film	21	50	60	65	70	75	80	85	115	24.2	7.9
Fiber	-	-	-	-	-	-	-	-	-	-	-
Blowing Molding	-	-	-	-	-	-	-	-	-	-	-
Injection Molding	20	40	55	60	65	70	75	80	130	18.9	11.3
Extrusion	28	43	65	75	83	91	95	99	135	11.3	11.0
Rotomolding	-	-	-	-	-	-	-	-	-	-	-
Extrusion Coating	-	-	-	-	-	-	-	-	-	-	-
Others	5	7	10	10	12	14	15	16	20	8.8	10.0
Total Demand	74	140	190	210	230	250	265	280	400	17.3	10.0

Source : Chem Systems.

Table 9. Production of Polypropylene in Thailand (Metric Tons/Year)

	1992	1993	1994	1995	1996	1997	1998	1999	2000
HMC	100	100	100	100	100	240	240	240	240
TPI	100	100	170	220	220	220	470	470	470
TPP	-	100	100	100	100	240	240	240	240
TOTAL	200	300	370	420	420	700	950	950	950

VITA

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