ผลของสารเพิ่มความเข้ากันได้ต่อสมบัติเชิงกลของพอลิเมอร์ผสมของ
พีพี/ไนลอน 6/อีวีเอ

นางสาววรุณศิริ จักรบุตร

EFFECT OF COMPATIBILIZER ON MECHANICAL PROPERTIES OF

PP/NYLON 6/EVA BLENDS

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Thesis Title   Effect of compatibilizer on mechanical properties of PP/nylon 6/EVA blends

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Field of study   Petrochemistry and Polymer Science

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งานวิจัยนี้มุ่งเน้นการปรับปรุงความเข้ากันได้ของพอลิเมอร์ผสมระหว่าง พีพี/ไนลอน 6/อีวี
เอ (PP/nylon 6/EVA) ด้วยสารช่วยเพิ่มความเข้ากันได้อันได้แก่ พีพีที่กราฟท์ด้วยมาเลอิกแอนด์ไฮ
ไดรด์ (PP-g-MA) โดยศึกษาถึงปริมาณของสารเพิ่มความเข้ากันได้ และอัตราส่วนของพอลิเมอร์
ผสม การเตรียมพอลิเมอร์เบลนด์กับ PP-g-MA ซึ่งเป็นสารเพิ่มความเข้ากันได้ทำโดยใช้เครื่องอัดรีด
พลาสติกชนิดสกรูเดี่ยวที่อุณหภูมิ 220 °C ความเร็วรอบสกรูเท่ากับ 40 รอบต่อนาที และมี PP-g-
MA อยู่ตั้งแต่ 0 - 20 phr การศึกษาสมบัติเชิงกลกระทำโดยการวิเคราะห์จากค่าการทนต่อแรงดึง
เปอร์เซ็นต์การยืดตัว การทนต่อแรงกระแทกกระทันหัน และการทนต่อการโก่งงอ เมื่อมี PP-g-
MA ผสมอยู่ในพอลิเมอร์เบลนด์พบว่าสมบัติการทนต่อแรงกระแทกและเปอร์เซ็นต์การยืดตัวดีขึ้น
แต่การทนต่อแรงดึง และการทนต่อการโก่งงอไม่เปลี่ยนแปลงอย่างมีนัยสำคัญ เมื่อวิเคราะห์ภาพ
จากกล้องจุลทรรศน์อิเล็กตรอน พบว่าขนาดโดเมนของเฟสกระจายซึ่งก็คือ ไนลอน 6 นั้นมีขนาด
เล็กลงเมื่อเติม PP-g-MA ในพอลิเมอร์เบลนด์นี้ ที่เป็นเช่นนี้เนื่องจากมาลิอิกแอนด์ไฮไดรด์อาจเกิด
พันธะไฮโดรเจน และ/หรือการเชื่อมยึดทางเคมีกับหมู่อะมิโนของไนลอนได้ ส่งผลให้พอลิเมอร์
ผสมนี้มีสมบัติเชิงกลดีขึ้นได้

สาขาวิชาปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์   ลายมือชื่อนิสิต…………….................……
หลักสูตรปิโตรเคมีและวิทยาศาสตร์พอลิเมอร์   ลายมือชื่ออาจารย์ที่ปรึกษา ....
ปีการศึกษา 2545   ลายมือชื่ออาจารย์ที่ปรึกษาร่วม…................

WAROONSIRI JAKARBUTR : EFFECT OF COMPATIBILIZER ON MECHANICAL PROPERTIES OF PP/NYLON 6/EVA BLENDS. THESIS ADVISOR: Dr. VARAWUT TANGPASUTHADOL, THESIS COADVISOR :ASSISTANT PROFESSOR Dr. MONGKOL SUKWATTANASINITT, 71 pp ISBN 974-17-1246-4.

The goal of this research is to improve compatibility of PP/Nylon 6/EVA blends by a compatibilizer, PP grafted with maleic anhydride (PP-g-MA). This study focuses on the effect of composition of blends and compatibilizer content on the blends. The polymer blends with PP-g-MA used as a compatibilizer were prepared by melt blending with a single screw extruder at 220 $^\circ$C and a screw speed of 40 rpm with varying PP-g-MA contents from 0-20 phr. The tensile strength, elongation at break, flexural strength and impact strength were determined. The blend containing of PP-g-MA showed a positive effect on the impact strength and elongation at break. The tensile strength and flexural strength were not, however, significantly affected by the presence of PP-g-MA. SEM micrographs revealed that the sizes of domains of dispersed nylon 6 phase decreased upon the addition of the compatibilizer. The maleic anhydride functionalities in the compatibilizer may involve in the formation of hydrogen bond and/or reacted with the amino groups of nylon 6.

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Field of study Petrochemistry and Polymer Science   Student's signature ………………………

Program Petrochemistry and Polymer Science.   Advisor's signature.....................................

Academic year 2002   Co-Advisor' s signature....................................

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CHAPTER I

INTRODUCTION

1.1 Introduction

For over 20 years, blending has been one of the most promising route to produce new polymeric materials. The technique provides many more varied physical properties than do the individual polymers. Polymer blends may be classified as miscible and immiscible. The behavior of the miscible blends are similar to those of homopolymers or random copolymers. Most commercial polymer blends are thermodynamically immiscible. The immiscible blend systems have high interfacial tension and poor adhesion between phases. Poor adhesion leads, in part, to very weak and brittle mechanical behavior. And they are frequently characterized by more than one glass transition temperatures.

Blending is commonly used to improve mechanical property, thermal property and processability or to reduce cost. Development of new multiphase polymer blends has been related to two key variables: control of microstructure (morphology) and control of interfacial properties. The poor mechanical properties of blends are often attributed to weak adhesion at the interface of the blend components. Therefore, compatibilizing agents are normally employed to enhance interfacial adhesion. They are capable of increasing physical and/or chemical interaction with each component of the blend depending on the blending methods and chemical properties of the compatibilizer s used.

In this study, the focus was on the improvement of the mechanical properties of polypropylene (PP)/Nylon 6/ethylene vinyl acetate (EVA) blends by adding polypropylene grafted with maleic anhydride (PP-g-MA) as a compatibilizer. Although the PP/Nylon 6 blends or nylon 6/EVA were reported in the literatures [4,13], this work is the first to investigate the ternary PP/Nylon 6/EVA blends. It was hypothesized that EVA would improve flexibility and toughness to the blends. PP-g-MA was used in the blend ranging from 0 to 20 phr. Tensile strength, degree of elongation, impact strength and melt flow index of the blends were measured. Its miscibility and morphology were also evaluated.

1.2 Objective

The objective of this work is to evaluate the effect of a compatibilizer, polypropylene grafted with maleic anhydride on the mechanical properties and compatibility of the PP/Nylon 6/EVA blend.

1.3 Scope of the Research

1. Preparation of maleated polypropylene (PP-g-MA) by a laboratory single screw extruder. The amount of MA in maleated polypropylene concentrations was varied to be 3 , 5 and 10 phr.

2. Preparation of PP/Nylon 6/EVA blends by a laboratory single screw extruder. The concentrations of the blends were 90:10:5, 80:20:5, 70:30:5, 90:10:10, 80:20:10, 70:30:10, 90:10:15, 80:20:15 and 70:30:15.

3. Determination of mechanical properties of PP/Nylon 6/EVA blends as well as to evaluate blend miscibility by analysing morphology using the techniques of scanning electron microscopy (SEM). Then select one blend

formula that provided high mechanical strength to be studied in the next step.

4. Preparation of polymer blends of PP/Nylon 6/EVA with PP-g-MA as a compatibilizer using a single screw extruder. The concentrations of PP-g-MA in the blends were varied from 5, 10, 15 and 20 phr.

5. Determination of the mechanical properties of PP/Nylon 6/EVA blends and morphology using SEM.

6. Analyzing the results and writing up a report.

CHAPTER II

THEORY AND LITERATURE REVIEWS

For polymer blends, the dispersion of one component in the others is a very important mixing process. It is therefore essential for a material scientist to understand the phenomena in a typical liquid–liquid dispersion. When immiscible polymers are blended, morphologies are developed during the mixing process. In order to understand the morphology development of the blends during processing, information concerning droplet deformation breakup is reviewed here.

2.1   Liquid–liquid dispersion

A liquid–liquid dispersion consists of dispersed phase and continuous or matrix phase. Physical parameters which affecting the dispersion of minor component are viscosity, elasticity, interfacial tension, solubility and diffusion. All molten polymers have low diffusion coefficients, of about 10^{-12} to 10^{-14} cm^2/s. Therefore, the diffusion rates in molten polymer systems are extremely small, and the relative penetration depths in the blending process are also small.

The deformation and dispersion starts after the component of blends, major and minor components, are fed into a mixing equipment and heated until the temperature of system is above their melting points or glass temperature. The hydrodynamic force is the deforming and disruptive force, and the interfacial tension force is the cohesive

force the dispersed phase. The ratio of these two forces or stresses is called the capillary number, Ca : [1],[4]

$$Ca \quad = \quad \sigma d \,/\, \Gamma \qquad\qquad (2.1)$$

Where $\sigma = \eta_m \gamma$, σ is a shear stress, γ is a shear rate, Γ is an interfacial tension, η_m is a viscosity of the continuous phase and d is a droplet diameter.

In the first state of mixing, the dispersed phase is deformed and broken up into small droplets. As the blending proceeds, the sizes of droplets of the dispersed phase decrease due to the equilibrium between cohesive interfacial tension and disruptive hydrodynamic forces.

2.2   Compatibilization

Immiscible blend systems exhibiting a multiphase structure which normally has coarse and unstable phase morphology. Because immiscible blends have high interfacial tension and poor adhesion between phases, it is almost impossible to obtain satisfactory mechanical properties. This interfacial tension also contributes to the difficulty of imparting the desired degree of dispersion to random mixtures. Poor adhesion leads to very weak and brittle mechanical behavior[1,3]. It is widely known that the mechanical properties of many immiscible blends are highly sensitive to the quality of the polymer-polymer interface. So the interfaces between phases need to be modified.

Better dispersion in blends may be achieved by a) changes in the processing condition. This approach is the most widely studied. Ideally, the compatibilizer chosen should be able to reduce the interface tension, enhance adhesion between phases, and stabilize morphology against high stress and strain processing such as injection molding. b) the addition of a compatibilizer which induce in situ chemical reaction between blend components (reactive blending).

2.2.1 Methods of compatibilisation

Thermodynamic miscibility

Miscibility between polymers is determined by a balance of enthalpic and entropic contributions to the free energy of mixing. For small molecules the change of entropy upon mixing is high enough to ensure miscibility. For polymers the change of entropy is almost zero, causing the enthalpic term to be decisive in determining miscibility. The change in free energy in mixing (ΔG_{mix}) is written as

$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix} \tag{2.1}$$

Where ΔH_{mix} is enthalpy of mixing, ΔS_{mix} is entropy of mixing and T is temperature. For miscible mixing, ΔG_{mix} must be negative, and thus

$$\Delta H_{mix} - T\Delta S_{mix} < 0$$

This mean that exothermic mixture will mix miscible.

Addition of block and graft copolymer

In this approach a blend comprising polymer A and B is modified with a block copolymer of A and B. The component A of the copolymer is miscible with phase A of the blend, while the component B is miscible with phase B. The block copolymer of A and B will try to reduce the number of unfavourable contacts between the polymer and the dissimilar copolymer block thus reducing the interaction energy. This results in localization of the copolymer at the interfacial tension between the polymer which leads to a reduction in the average size of the dispersed phases [1,5].
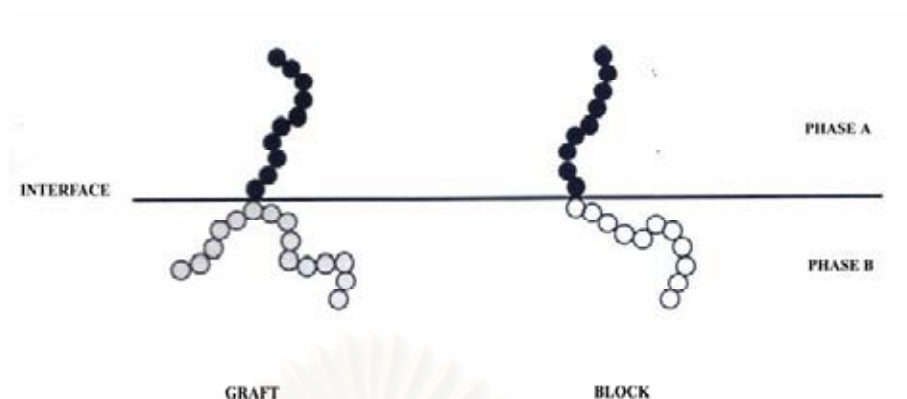
Figure 2.1 Location of block and graft copolymer at phase interfaces

Reactive Blending

Reactive blending or reactive extrusion differs from other compatibilisation routes in that the blend component themselves are either chosen or modified so that reaction occurs during melt blending, with no need for addition of a separate compatibilizer. A wide variety of materials have been prepared with this technologies. The advantages of reactive blending by reactive extrusion as opposed to alternative technologies include little or no used of solvent, simple product isolation, short reaction time, continuos process and relatively low cost. Nevertheless, some potential disadvantages or difficulties associated with reactive extrusion relate to the need to achieved intimate mixing of reactant and substrate, the high reaction temperature necessary to form a polymer melt, and the extent of polymer degradation or crosslinking that may accompany during processing.

Addition of functional polymer

In this method, one of the blend component is chemically modified to contain a functional or reactive unit. This unit can have an increased affinity for the second

blend component. This affinity is usually the ability to chemically react with the second blend component, but other types of interaction are also possible. The reaction may take place in a chemical batch reaction or in a modified extrusion process. Extrusion process has advantages in continuous production, better temperature control and allowing the removal of unwanted reaction products by volatilization. The highly reactive maleic anhydride (MA) functionalized polymers such as polyethylene-grafted-MA (PE-g-MA), polypropylene-grafted-MA (PP-g-MA), styrene ethylene-butylene styrene-g-MA have been widely used as reactive compatibilizers [3].

2.3 Polymer Functionalization and Functional Group Modification

Reactive extrusion has been used to introduce a variety of functional groups into a polymer and to modify existing functional groups. The polymer may be functionalized with an unsaturated acid or anhydride via a free radical mechanism in the presence of a peroxide initiator. The reaction may take place either in a chemical batch reaction or in a modified extrusion process. The latter has advantages in better temperature control, continuous production and allow the removal of unwanted reaction products by volatilization. Functionalization of a polymer by grafting of potentially polymerizable monomer, such as polypropylene-grafted-MA (PP-g-MA), was used to improve mechanical properties of immiscible blends.
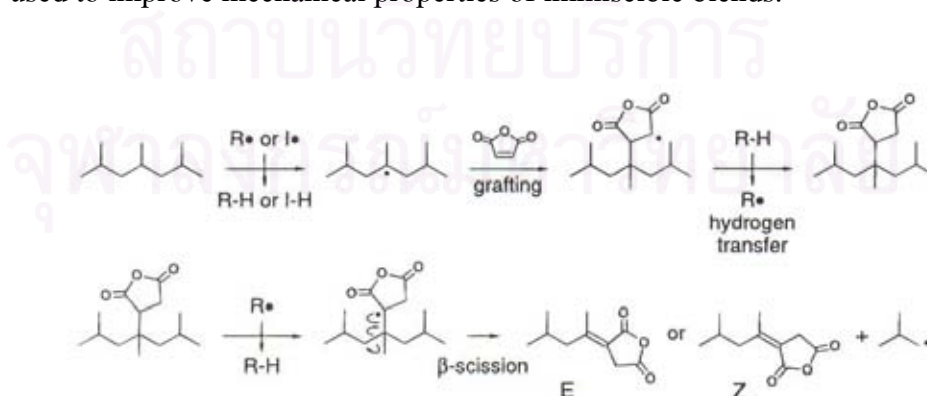
Figure 2.2 Free radical grafting process

2.4   Ethylene vinyl acetate (EVA)

Ethylene vinyl acetate copolymer are products of low density polyethylene (LDPE) technology. Their properties depend on the percentage content of EVA and the melt index. EVA may be represented by:

$$-[CH_2-CH_2-CH_2-CH]_n-$$
$$|$$
$$O$$
$$|$$
$$CH_3-C=O$$
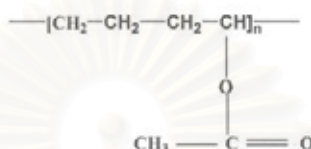
Figure 2.3 Ethylene vinyl acetate copolymer

In general, EVA copolymers are thermoplastic consisting of an ethylene chain incorporating 5 to 50% vinyl acetate (VA). The VA content controls the resin's crystallinity and flexibility. The lower crystallinity resins have lower melting points and heat-seal temperature, along with reduced stiffness, tensile strength and hardness. EVA resins are more permeable to oxygen, water vapor and carbon dioxide. Chemical resistance is similar to LDPE, with somewhat better resistance to oil and grease for EVA resin with a higher VA content. The VA groups contribute to improved adhesion in extruder or hot-melt-adhesive formulation.

2.5   Polypropylene (PP)

The major practical development of polypropylene blends has been the addition of ethylene-propylene rubber (EPR) to improve impact strength at room and low temperature, environmental stress-crack resistance. The major application is in the automobile industry, sport equipment, and tool handles.

Most commercial PP is isotactic PP. The polymer is highly crystalline but usually contains a small proportion of atactic PP as a contamination.

$$-[H_2C-CH]_n-$$
$$|$$
$$CH_3$$
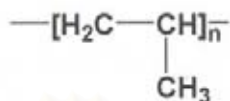
Figure 2.4 Polypropylene

2.6   Nylon 6

Nylon 6 is formed by ring-opening polymerization of caprolactam. Nylon resin are tough, hard thermoplastics, attributed by to its hydrogen bonding between the polymeric chains. They are inherently resistance to lubricants, engine fuels, paint solvents.

$$-[NH(CH_2)_5-\ C-]_n$$
$$\|$$
$$O$$
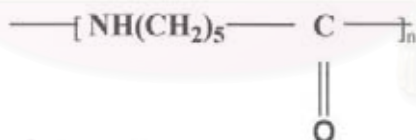
Fig. 2.5   Nylon 6

2.7 Literature Reviews

Moon, H. S. et al [8]   studied the nonisothermal crystallization of molten blends of two semicrystalline polymer, namely PP and Nylon-6. The effect of concentration of the compatibilizing agent, PP-g-MA, on the crystallization behaviors.

was studied. The crystallization thermograms showed one or two crystallization peak, which were significantly affected by the presence of the compatibilizer. The crystallization temperature of Nylon 6 leveled off down as the concentration of PP-g-MA increased, whereas that of PP stayed at a roughly constant temperature.

Dean Shi, J. Y. et al [9] studied the chemical structure and molecular parameter of grafted materials of PP-g-MA, which prepared by melt reactive extrusion, by using electrospray ionization-mass spectrometer and gel permeation chromotograghy. It was found that the initial radical, due to homolitic scission of dicumly peroxide cloud be combined with the maleic anhydride monomer as well as PP molecular chains. The homopolymerization of MAH cannot occur and the MAH radicals reaction under the processing condition $(180 - 190\ ^{\circ}C)$.

Other type of polymer grafted with MA were also reported. Tseng, F.P. et al studied poly(oxypropylene)-amide grafted polypropylene(POP-g-PP) as a novel compatibilizer for PP and PA6 blends. POP-g-PP copolymer was prepared by the reaction of poly(oxypropylene) damides and maleated PP (PP-g-MA) in an reactive extrusion. The morphologies show a decreasing size of dispersed PA6 particles as the molecular weight of POP diamine in PP-g-MA-co-POP increasing. These compatibilizer improved the mechanical properties, including Izod impact strength and tensile toughness, over a conventional compatibilizer, because POP and amide functionalities in the compatibilizer can facilitate the formation of hydrogen bonding with PA6 [10].

La mantia, F.P. et al [11] studied thermomechanical degradation of compatibilized and uncompatibilized Nylon 6/PP blends. Two types of functionalized PP were studied, PP-g-MA and PP-g-AA (acrylic acid). It was found that the structure, morphology and properties of these blend depended on the type of compatibilizer and the process time. The thermolabillity of PP-g-AA gives rise to a larger decrease of compatibilization efficiency and the properties of the blend than that observed for the blend with a PP-g-MA.

Wong, X. et al [12] studied the cooperative toughening and cooperative compatibilization in Nylon 6/ethylene-co-vinyl acetate/ethylene-co-acrylic acid blends. An ethylene-co-acrylic acid (EAA) was needed as a compatibilizer for Nylon 6 and ethylene-vinyl acetate copolymer (EVA) blends. Neither EVA nor EAA is compatible with Nylon 6, however, the combination of the two resulted in a toughened Nylon 6. The compatibilization was revealed by the dramatic increase in impact strength, and the smaller particle size and finer dispersion of EVA in the Nylon 6 matrix in the presence of EAA. The degree of toughening was evaluated through its effect on the mechanical, morphological and rheological properties, by changing the proportion of the components in the Nylon 6/EVA/EAA blends. Because EAA is a compatibilizer for Nylon 6/EVA and EVA a compatibizer for Nylon 6, both the toughening and the compatibilization are cooperative.

Kudva, R. A. et al [13] studied morphology and mechanical properties of compatibilized Nylon 6/polyethylene blends. Blends of Nylon 6 and polyethylene (PE) were investigated over a range of composition. The PE used was grafted with maleic anhydride and, thus, have the potential to react with the amine end group of Nylon 6 during melt processing. It was found that the impact properties of these blends are strongly influenced by the amounts and types of maleated polyethylene used. A low viscosity maleated polyethylene was shown to be ineffective in toughening Nylon 6 because the propensity of polyethylene to become continuous even when Nylon 6 was the major component. Two higher viscosity maleated polyethylenes were able to produce blends with high impact strength and excellent low temperature toughness over a broad range of composition. It was demonstrated that polyethylene containing very low degree of anhydride functionality can generate blends with excellent impact properties. The impact properties of these blends improved as the Nylon 6 molecular weight increased and as the ratio of maleated polyethylene to nonmaleated polyethylene increased.

CHAPTER III

EXPERIMENTAL

3.1 Materials

1. Polypropylene (PP) grade 3240H (Thai Petrochemical Industry Public Co., Ltd.)

2. Nylon6 grade 7331 JNC (Dupont)

3. Ethylene-vinyl acetate copolymer (EVA) grade N8038F containing 24 wt% vinyl acetate (Thai Petrochemical Industry Public Co., Ltd.)

4. Dicumyl peroxide (Akzo Chemie)

5. Maleic anhydride (Grand Union Chem Co., Ltd.)

3.2 Instrument

Major instruments used are listed below:

1. Single screw extruder diameter 18 mm. (Model BX 18, Axon ab)

2. Drum tumber dry mixer (Model IXER 50, Bosco)

3. Pendulum impact testing machine (Model 6546, Ceast)

4. Universal testing machine (Model H 50 KS, Hunsfield)

5. Compression machine (Model LP 50, Labtech Engineering)

6. Melt flow index tester (Model 6542, Ceast)

7. Scanning electron microscope (Model JSM-5800LV, JEOL)

8. Fourier transform infrared spectroscopy (Model Nexus 470, Nicolet)

3.3 Experimental

3.3.1 Preparation of PP/Nylon6/EVA Blend

PP, Nylon 6 and EVA were premixed in a dry mixing, drum tumbler, and then compounded in a single screw extruder (screw diameter 18 mm.). The barrel temperatures were : 190 $^{\circ}$C, 200 $^{\circ}$C, 210 $^{\circ}$C, 220 $^{\circ}$C for zone 1, 2, 3 and 4 respectively and the melt temperature at the die was 230 $^{\circ}$C. The screw speed was fixed at 30 rpm. The extruded strands were cooled at 15 $^{\circ}$C by water slide system and subsequently chopped in the form of granules using a pelletizer. The ratio of PP, Nylon 6, EVA used in this work are shown in Table 3.1 [14, 16, 17].

Table 3.1 : The contents of PP, Nylon 6 and EVA in the ternary blends

Item	Ratio of PP : Nylon6	EVA (phr)
1	100 : 0	0
2	90 : 10	5
3	80 : 20	5
4	70 : 30	5
5	90 : 10	10
6	80 : 20	10
7	70 : 30	10
8	90 : 10	15
9	80 : 20	15

3.3.2 Synthesis of PP-g-MA

PP, maleic anhydride and dicumyl peroxide (2 phr) were weighed according to Table 3.2 into a plastic bag. All ingredients were premixed for 15 minutes. The mixed materials were fed into a hopper of the single screw extruder. The barrel temperature were : 170 $^{\circ}$C, 180 $^{\circ}$C, 185 $^{\circ}$C, 190 $^{\circ}$C for zone 1, 2, 3 and 4 respectively. The temperature at the die was 200°C. The screw speed was fixed at 30 rpm. The extruded strands were cooled at 15 $^{\circ}$C by a water slide system and subsequently chopped in the form of granules using a pelletizer. The amount of PP and MA used in this work are shown in Table 3.2 The resulting grafted PP was analyzed by FTIR spectroscopy [18 - 22].

Table 3.2 : The amount of PP and MA used to prepare PP-g-MA

Item	PP (phr)	MA (phr)
1.	100	3
2.	100	5
3.	100	7

3.3.3 Preparation of PP/Nylon6/EVA blended with PP-g-MA

PP, Nylon6, EVA and PP-g-MA were premixed in a dry mixing drum tumbler, and then compounded in a single screw extruder. The barrel temperature were : 190 $^{\circ}$C, 200 $^{\circ}$C, 210 $^{\circ}$C, 220 $^{\circ}$C for zone 1, 2, 3 and 4 respectively. The temperature at the die was 230 $^{\circ}$C. The screw speed was fixed at 30 rpm. The extruded strands were cooled at 15 $^{\circ}$C by a water slide system and subsequently chopped in the form of

granules using a pelletizer. The amounts of PP-g-MA mixed into the ternary blend were 5, 10, 15 and 20 phr [8,9,23].

3.4 Characterization of blends

3.4.1 Melt flow index (MFI) measurements

MFI measurement was made on Ceast model 6542 at 230 $^{\circ}$C with the hammer load of 2.16 kg in accordance to ASTM 1238 (Figure 3.1). Firstly, the polymer sample (8 g) was weighed and then fed into the cylinder within 1 min with a weight portion according to the expected flow rate, as given in the ASTM. Place the weight piston in position, and start timing the extrudate when a requirement for piston position was met. Next, collect the extruded portion exactly according to the time interval given in the ASTM. Then, weigh the extrudate and multiply the weight by the factor shown in ASTM to obtain the flow rate in gram per 10 min.

3.4.2 Tensile testing

Tensile testing of the specimens were performed according to ASTM D 638 on a universal testing machine using model H50 KS (Figure 3.2). First, measure the width and thickness of sample with a suitable micrometer at several points along their narrow section. Next, place the specimen in the grip of the testing machine. Set the speed of testing at the proper rate as required in the ASTM, and start the machine. All reported data were averaged from at least 10 specimens.

Figure 3.1   Melt flow index tester

Figure 3.2   Universal testing machine

3.4.3 Izod impact strength testing

Impact testing was performed using ASTM D 256 Izod impact method (Figure 3.3). First, prepare the specimens according to the ASTM, and then a sample was notched accurately to 0.025 mm by notching machine on one side of them. Keep the samples at room temperature for 48 hours. Measure the width and the thickness of each specimen and place it between the clamps. Tighten the clamps. Release the pendulum and record the excess energy after breaking the specimens. Calculate the average impact strength.

3.4.4 Morphology of polymer blends

Scanning electron microscope (SEM) was used to observe the morphology of the polymer blends. The sample bars were fractured in liquid nitrogen. The fractured surfaces were coated with gold and examined under the microscope[24].

3.5 Degree of grafting determination

3.5.1 Titration technique

Unreacted MA in the PP-g-MA granules was eliminated by evaporation using heat treatment technique. Pellet samples of PP-g-MA were placed in a vacuum oven at $130\,^{\circ}\mathrm{C}$ for 6 hours

A small amount (0.5 g) of purified PP-g-MA was dissolved in 75 mL of boiling xylene in a conical flask. A few drop of water were added to hydrolyze all anhydride functional groups. Afterwards, the hot solution was then titrated with 0.005 N potassium hydroxide solution in methanol using phenophthalene as an indicator until

the color change from colorless to pink. Then 1 mL excess KOH solution was added. The deep pink color was back titrated to a colorless end point using 0.005 N isopropanolic HCL solution. The weight percentage of MA grafting on PP was calculated by Equation (3.1). Therefore, the average values of MA content in the grafted polymer reported subsequently are those already substracted by the blank value (PP) [18 - 22].

$$\%MA = \frac{(\text{mole of KOH} - \text{mole of HCL}) \times 98 \times 100}{2 \times \text{weight of sample}} \qquad (3.1)$$

3.5.2 Fourier transform infrared spectroscopy (FTIR)

The FTIR spectra were recorded on a Nicolet Nexus 470 FTIR Spectrometer with resolution of 4 cm^{-1} after 128 scans. The sample was processed in the form of compression molded film. The films were dried at 110 $^{\circ}C$ for 24 h under vacuum before analysis. From the IR spectrum, the carbonyl group of 5-membered ring anhydride appeared at 1790 cm^{-1}. The C-H bending of -CH_3 group in PP was located 1167 cm^{-1}. These absorbances were used to calculate the carbonyl index (CI) as follows

$$CI = A_{1790} / A_{1167} \qquad (3.2)$$

Wher A_{1790} is the absorbance at 1790 cm^{-1}, characteristic of carbonyls in the five-member cyclic anhydride and A_{1167} is the absorbance at 1167 cm^{-1} [22].

Figure 3.3 Izod impact tester

Figure 3.4 Single screw extruder
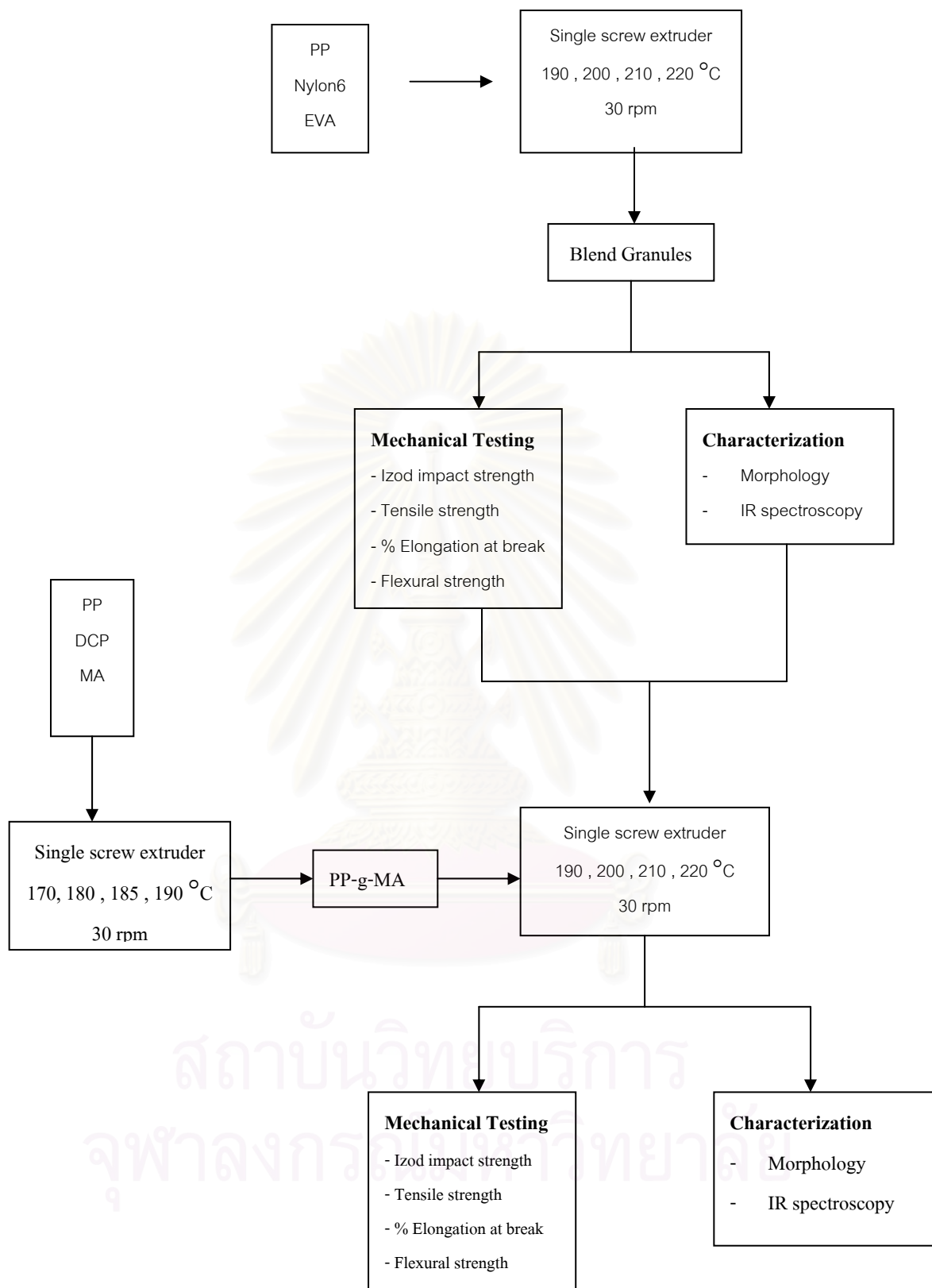
Figure 3.5   Diagram of the experiment procedure to improve mechanical properties of

PP/Nylon6/EVA

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Mechanical Properties of PP/Nylon 6/EVA Blends

The effect of EVA on mechanical properties of the blends was investigated. Four parameters were investigated for all blends (Table 4.1).

Table 4.1 : Effect of EVA on the mechanical properties at various PP/Nylon 6 blend compositions.

Item	PP/Nylon 6/ EVA	Impact strength (J/M)	Tensile strength (MPa)	Elongation (%)	Flexural strength (MPa)
1	100:0:0	22.48 ± 4.45	31.90 ± 2.97	247.25 ± 2.66	25.82 ± 3.99
2	90:10:5	33.01 ± 4.98	21.90 ± 2.84	8.91 ± 3.15	22.50 ± 3.40
3	80:20:5	43.46 ± 4.00	20.79 ± 3.21	4.80 ± 2.23	23.60 ± 3.82
4	70:30:5	45.43 ± 3.38	16.96 ± 3.83	3.92 ± 1.13	18.41 ± 5.80
5	90:10:10	36.13 ± 4.88	17.38 ± 4.72	6.75 ± 2.40	23.14 ± 4.27
6	80:20:10	45.77 ± 4.51	17.00 ± 3.80	6.36 ± 1.96	21.35 ± 4.47
7	70:30:10	46.95 ± 4.02	14.99 ± 2.94	6.04 ± 1.10	18.87 ± 3.67
8	90:10:15	37.34 ± 3.85	16.11 ± 4.63	6.79 ± 1.58	21.04 ± 3.67
9	80:20:15	48.81 ± 4.73	14.98 ± 3.15	5.77 ± 1.58	20.41 ± 3.54
10	70:30:15	49.70 ± 3.79	11.66 ± 3.67	4.49 ± 1.23	18.64 ± 3.65

4.1.1 Tensile Strength and elongation of PP/Nylon 6/EVA Blends

A representative stress-strain curve of PP/Nylon 6/EVA is show in Figure 4.1.
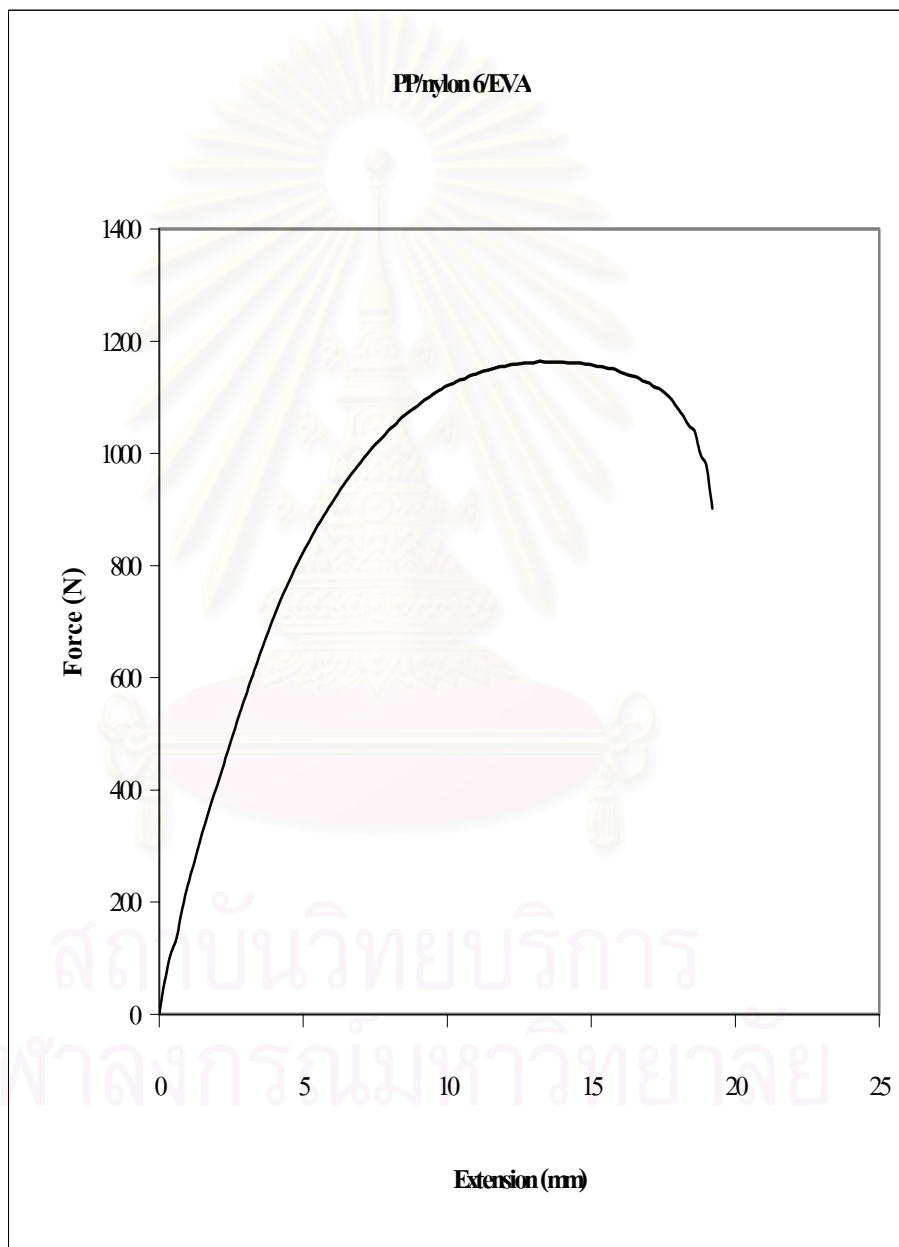
Figure 4.1 Stress – strain curve of PP/Nylon 6/EVA (80:20:5)

Tensile strength and % elongation at break decreased when the EVA content increased (Figure 4.2 and 4.3). Since EVA is a thermoplastic elastomer, the presence of such a copolymer will reduce the tensile strength of the blend. The drop in tensile strength of blends may be due to a reduction of the crystallinity of the blend as a result of the bulky vinyl acetate group in EVA. In addition, the reduction of tensile strength could be caused by the incompatibility between the polar segment of Nylon and the non polar segment of EVA and PP. The latter reason also explains the drop of % elongation at break in the ternary blends (Figure 4.3).
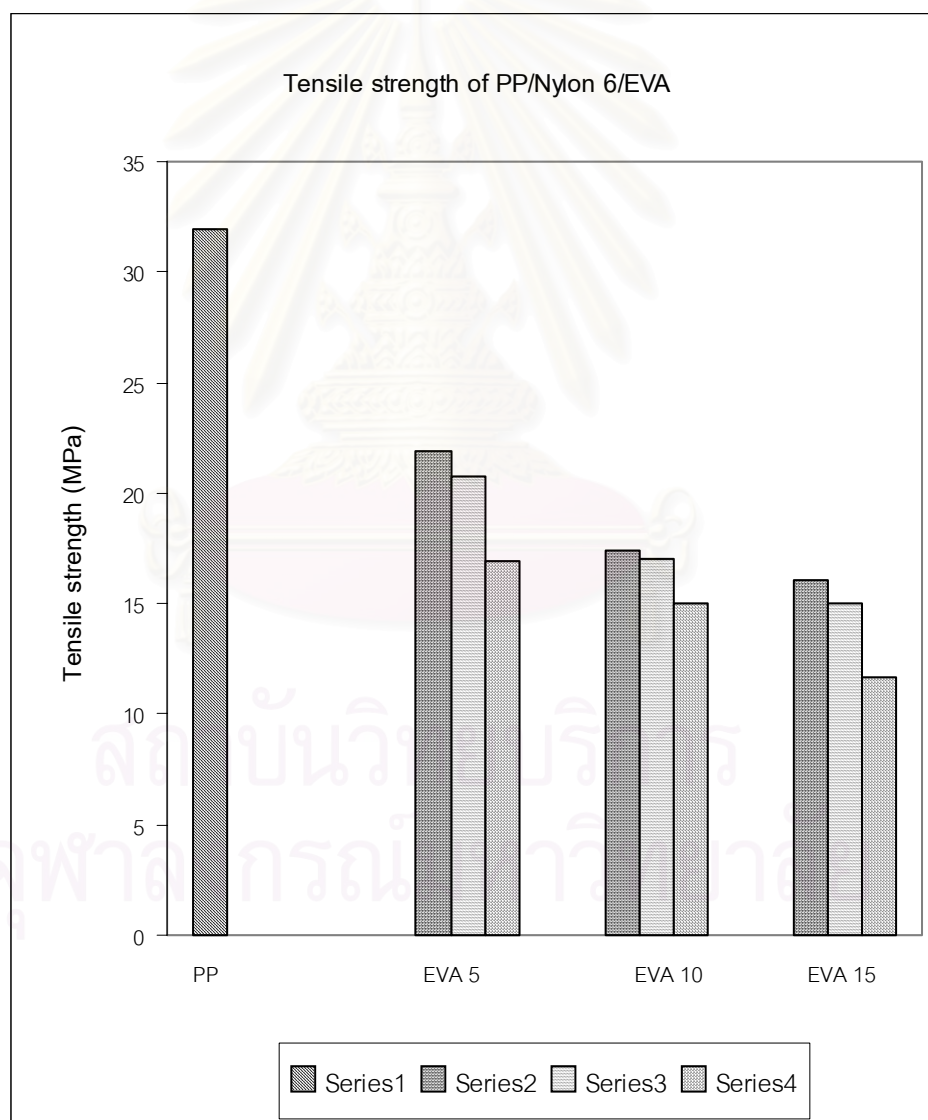
Figure 4.2 : Effect of EVA on tensile strength at various PP/Nylon 6 blends

Elongation at break of PP/Nylon 6/EVA blends
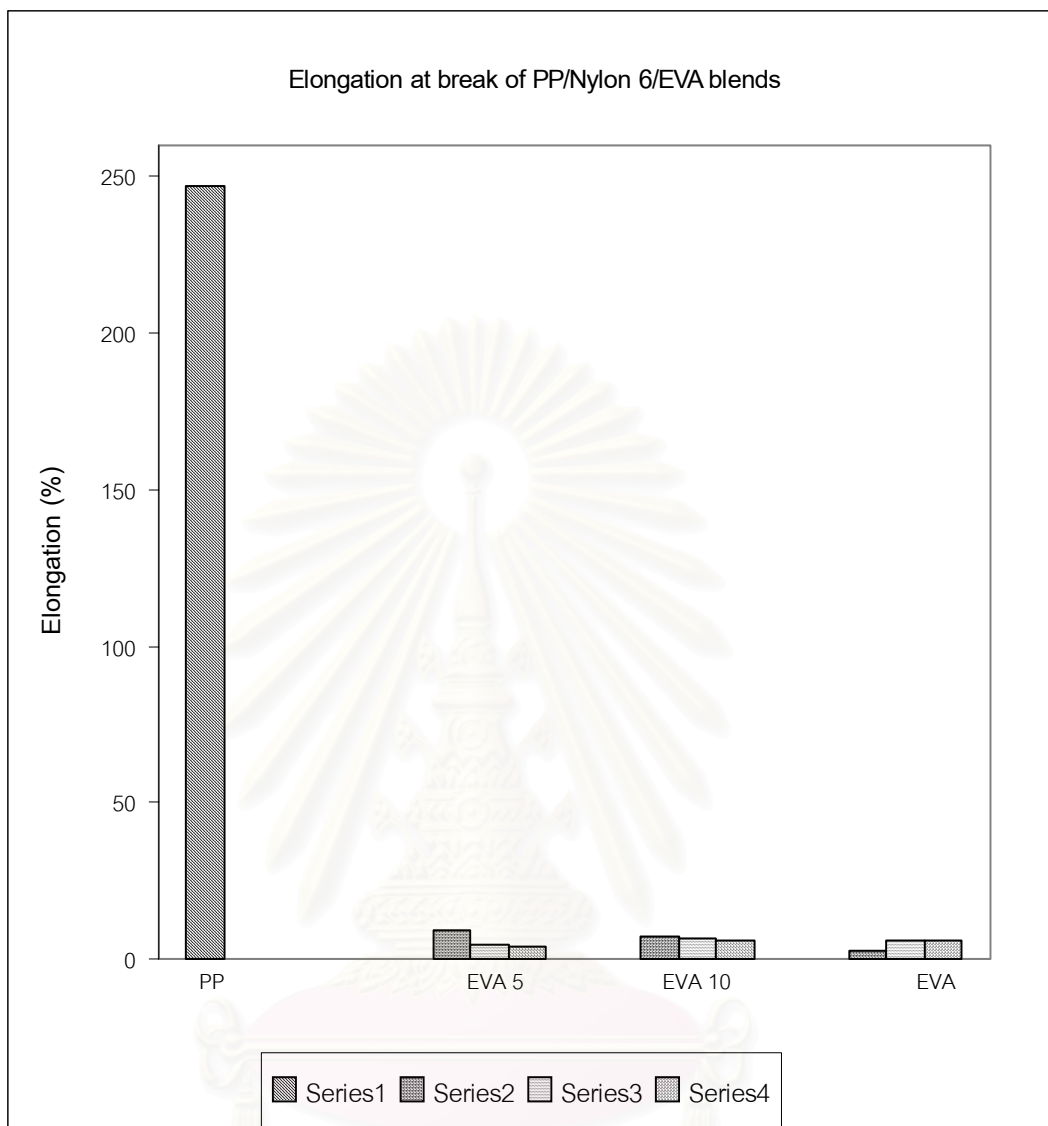
Figure 4.3 : Effect of EVA on % elongation at break at various PP/Nylon 6 blends

4.1.2 Flexural Strength of PP/Nylon 6/EVA Blend

The universal tester was employed to measure the flexural strength of the blends (Table 4.1). The correlations between flexural strength and blend compositions (Figure 4.4) were similar to one another at all EVA concentrations studied. The

presence of EVA caused a drop in the flexural strength. This could be due to the interference of hydrogen bonding on the Nylon 6 chains by the segments of EVA and PP. And more importantly, the incompatibility between the polar segment of Nylon 6 and non polar of EVA and PP could be a major cause, as mentioned earlier.
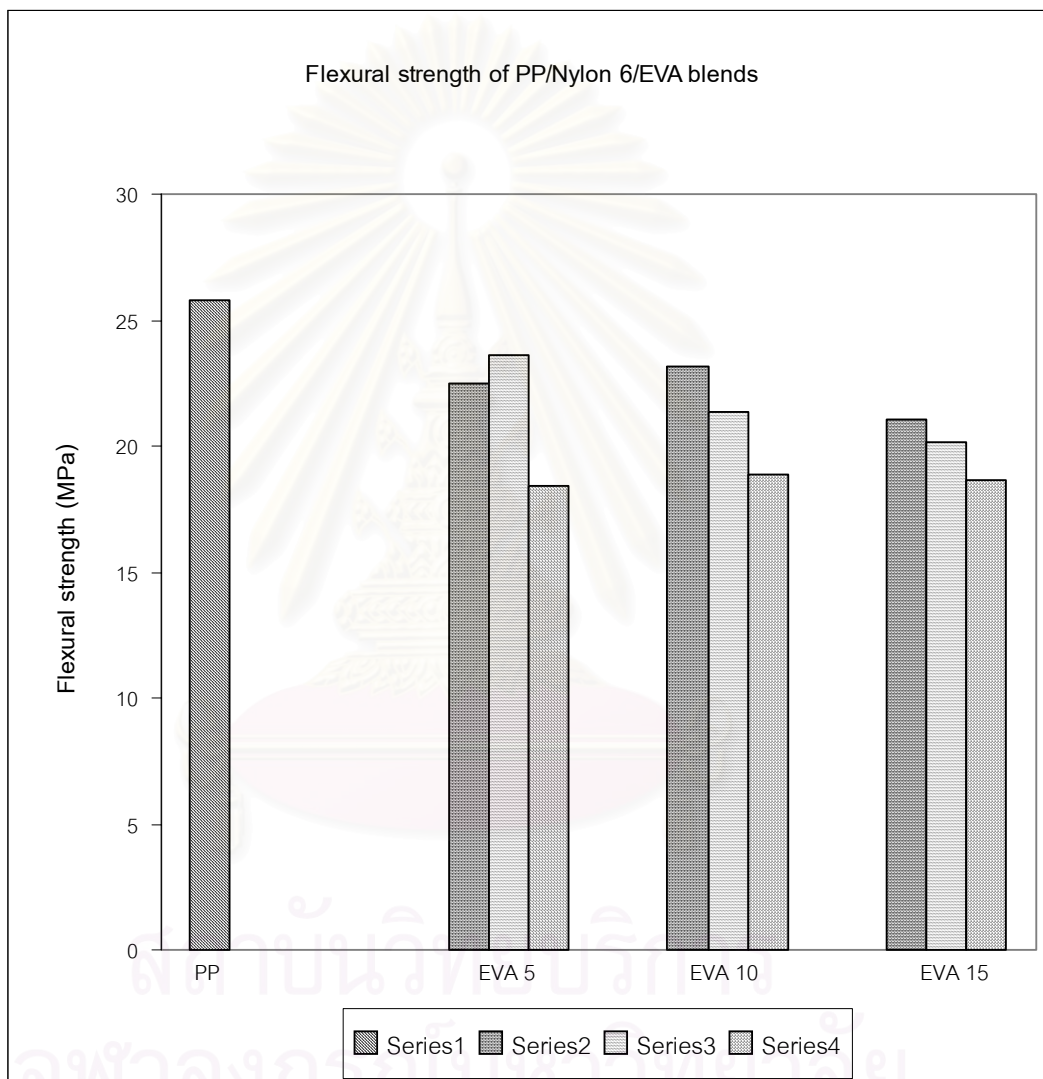
Figure 4.4 : Effect of EVA on flexural strength at various PP/Nylon 6 blends

4.1.3 Impact Strength of PP/Nylon 6/EVA Blend

The notched impact strength of the blend systems was shown in Table 4.1 and was plotted against the blend composition in Figure 4.5. It can be seen that the impact strength of the blends increased with the Nylon content increased. The value of the impact strength for 5, 10 and 15 phr EVA content in blends were also compared. It was apparent that the blends having higher EVA content was a better impact modifier than that having lower content. From the results obtained, a ratio of PP/Nylon 6/EVA of 80:20:5 (formula 3) was chosen to improve its mechanical properties by using PP-g-MA compatibilizer. Although this selected ratio has a lower impact strength than that of formula 4, 6, 7, 9 and 10, it has a higher flexural strength than that of the other formula.
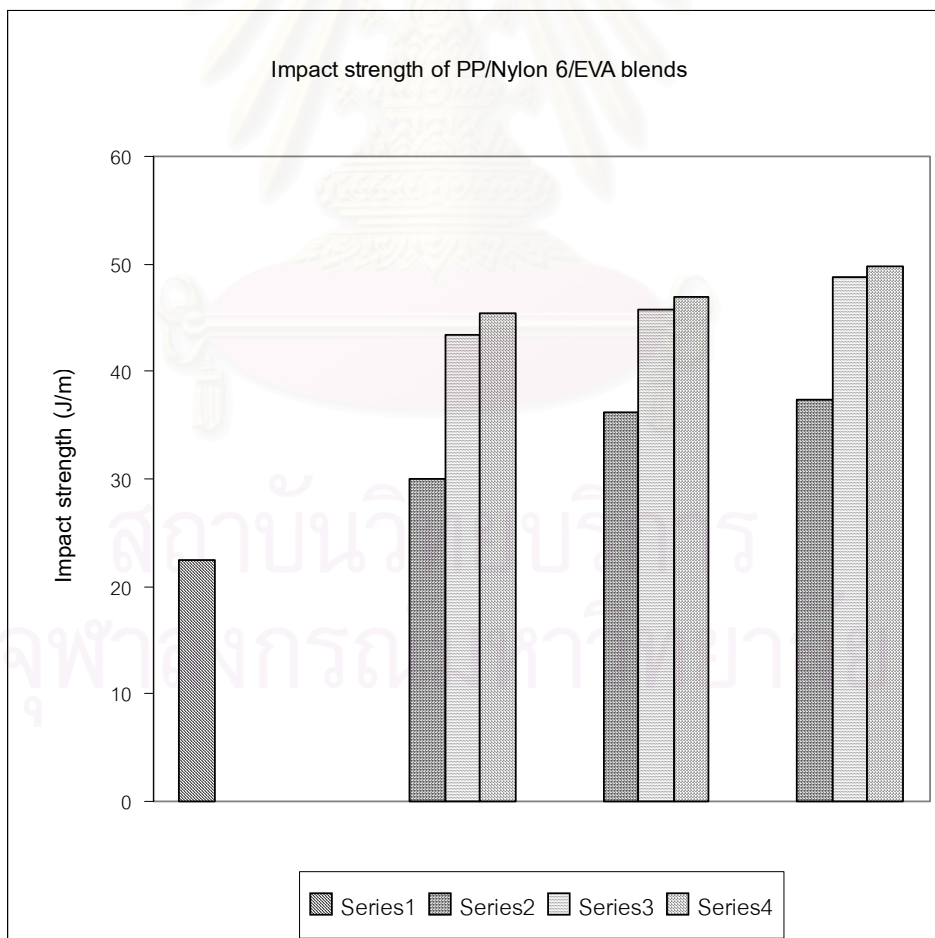
Figure 4.5 : Effect of EVA on impact strength at various PP/Nylon 6 blends

4.2 Melt Flow Index (MFI) of PP/Nylon 6/EVA

The melt flow index (MFI) of blends with different PP/Nylon 6/EVA ratio is shown in Table 4.2. and Figure 4.6. MFI did not change much when Nylon 6 and EVA content was increased
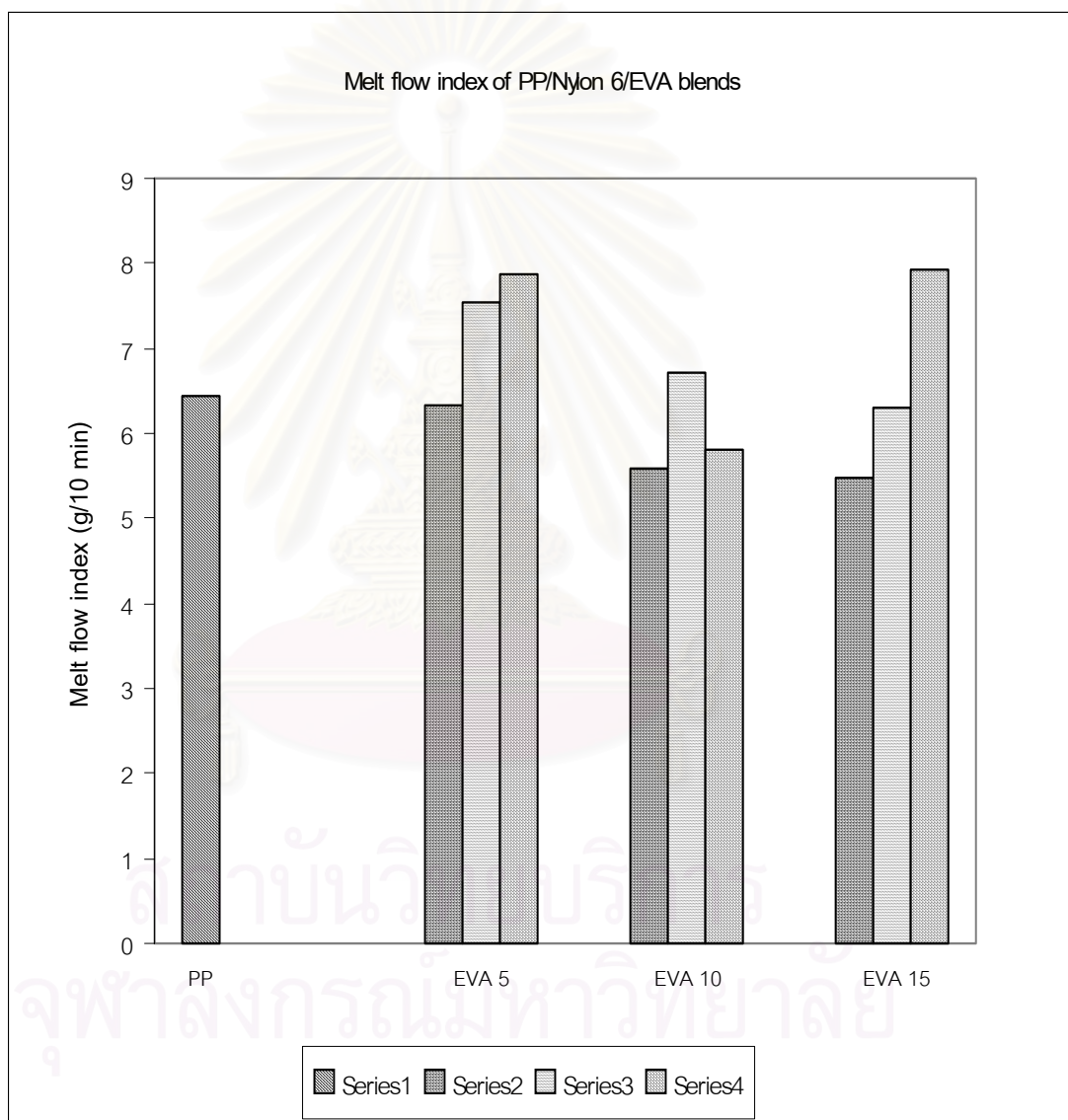
Figure 4.6 : Effect of EVA on melt flow index at various PP/Nylon 6 blend

Table 4.2 : Effect of EVA on melt flow index at various PP/Nylon 6 blends

Item	PP/Nylon 6/EVA	Melt flow index (g/10 min)
1	100:0:0	6.44 ± 0.43
2	90:10:5	6.33 ± 0.34
3	80:20:5	7.55 ± 0.24
4	70:30:5	7.88 ± 0.23
5	90:10:10	5.60 ± 0.29
6	80:20:10	6.71 ± 0.26
7	70:30:10	5.80 ± 0.28
8	90:10:15	5.47 ± 0.24
9	80:20:15	6.29 ± 0.25
10	70:30:15	7.93 ± 0.30

4.3 Grafting of maleic anhydride on PP

Grafting of maleic anhydride onto PP was performed through reactive processing by using dicumyl peroxide as an initiator. The amount of MA added into the extruder was varied at 3, 5, and 7 phr. The degree of MA grafted onto PP was determined through infrared spectra, presented in Figure 4.8, 4.9 and 4.10. Quantification of maleic anhydride was performed through measurement of the carbonyl index (CI), as described in the experimental procedure and a calibration curve were constructed to obtain the absolute values of reacted maleic anhydride (Figure

4.7). The cyclic anhydride carbonyl band was clearly observed at 1790 cm^{-1} and aliphatic C-H stretching was clearly observed at 1167cm^{-1}. Table 4.3 shows % MA grafted onto PP indicating that % MA grafted onto PP increased with the feeded MA.
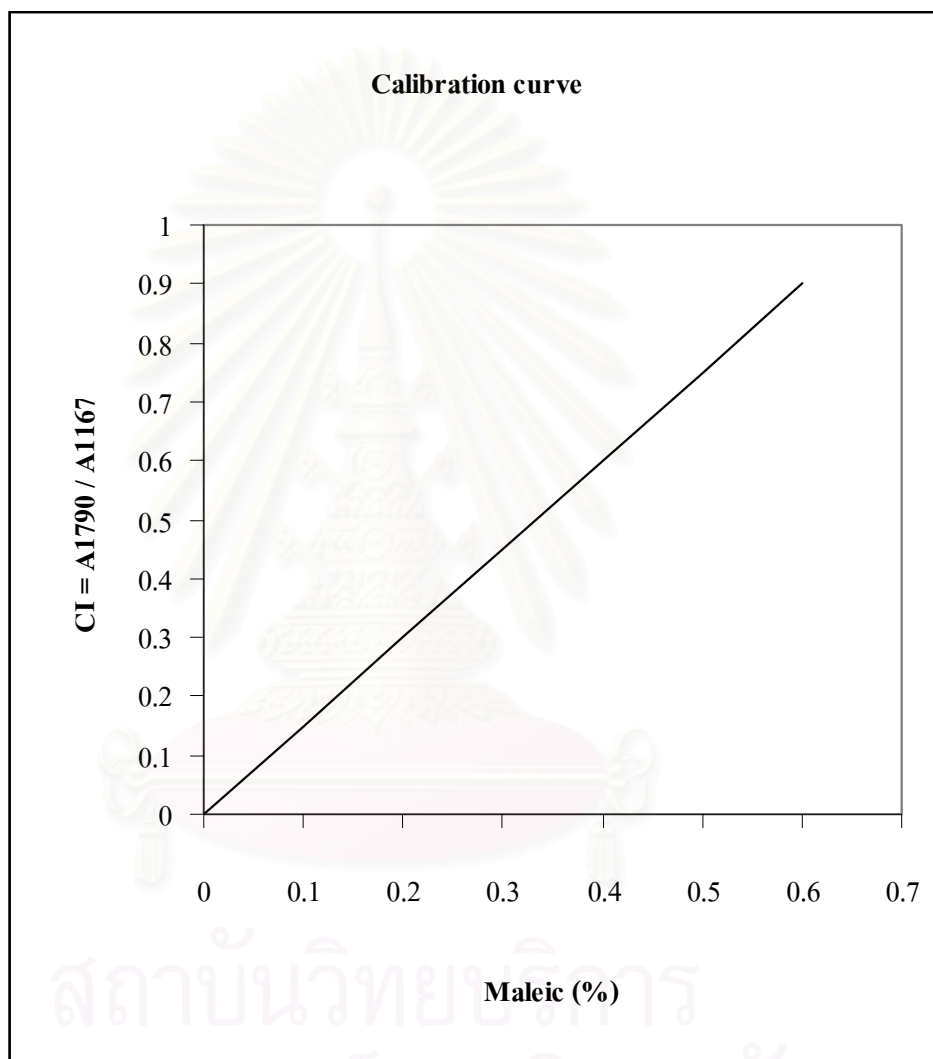
Figure 4.7 Calibration curve
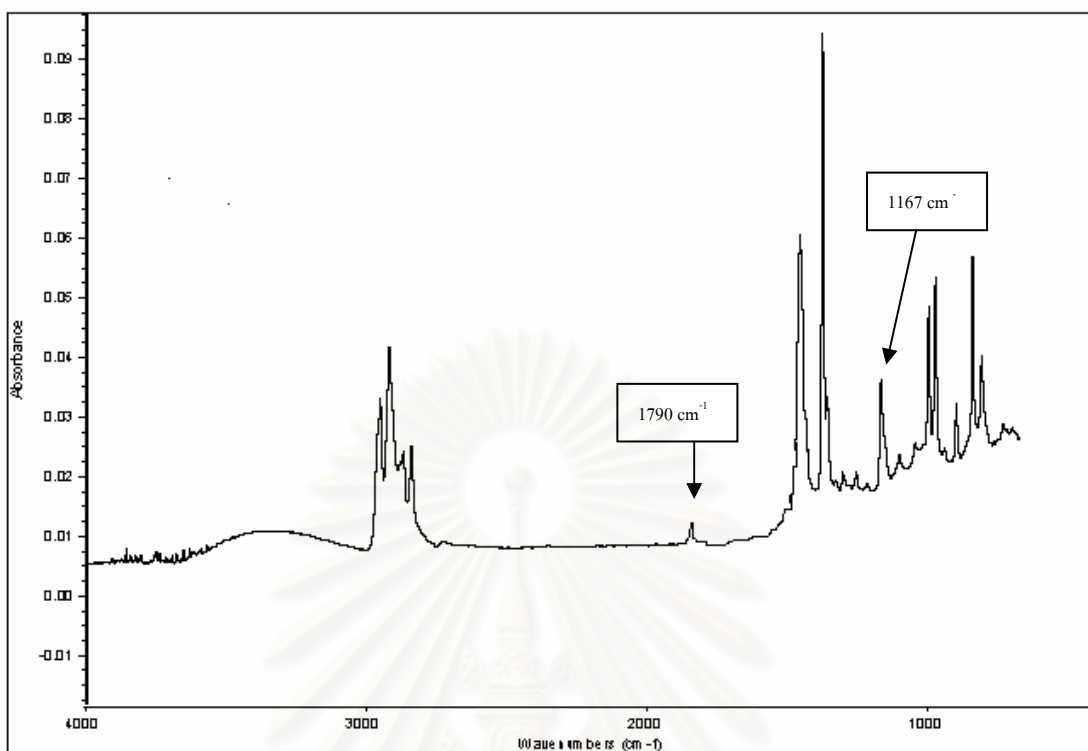
Figure 4.8 Infrared spectra of PP-g-MA 3
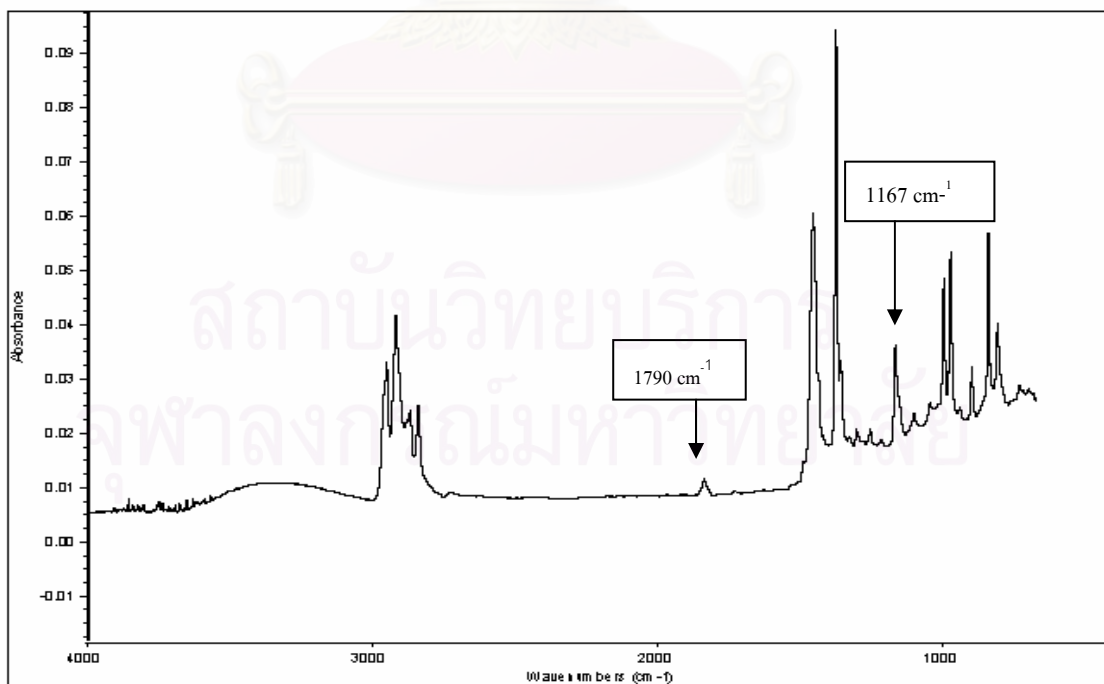
Figure 4.9 Infrared spectra of PP-g-MA 5
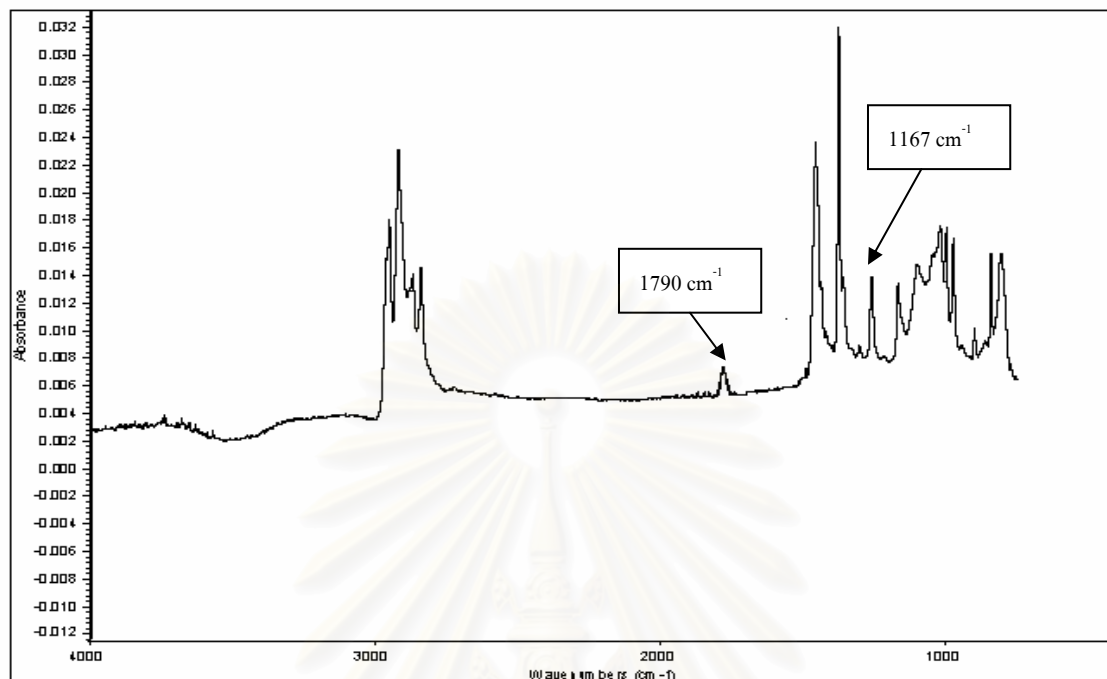
Figure 4.10 Infrared spectra of PP-g-MA 7

Table 4.3 : Grafting level of MA onto PP

Item	MA (phr)	CI index	MA grafted onto PP (%)
1	3	0.28	0.187
2	5	0.48	0.285
3	7	0.57	0.380

Low amount of MA grafted onto PP in this study was possibly due to the choice of single screw extruder used. Higher grafting content of MA onto PP was earlier reported by utilizing a twin screw extruder nitrogen atmosphere [22].

4.4. Mechanical Properties of PP/Nylon 6/EVA Blends with PP-g-MA as a compatibilizer

The effect of EVA on mechanical properties of the blends was investigated. Four parameters were investigated for all blends (Table 4.4).

Table 4.4 : Effect of PP-g-MA on mechanical properties at various PP/Nylon 6/EVA (80:20:5) blend compositions.

Item	Amount of PP-g-MA	Impact strength (J/M)	Tensile strength (MPa)	Elongation (%)	Flexural strength (MPa)
PP/Nylon 6/EVA (80:20:5)	0	22.48 ± 4.45	20.79 ± 3.21	4.80 ± 2.23	23.60 ± 3.82
PP-g-MA 3 (phr)	5	51.94 ± 1.23	23.02 ± 0.69	114.3 ± 9.00	23.92 ± 1.14
	10	54.12 ± 1.35	22.50 ± 1.00	115.6 ± 12.21	23.59 ± 1.57
	15	56.78 ± 0.86	21.54 ± 0.89	113.3 ± 10.03	23.21 ± 1.95
	20	58.65 ± 1.05	19.94 ± 0.59	118.5 ± 18.27	23.56 ± 1.7
PP-g-MA 5 (phr)	5	57.84 ± 1.31	22.10 ± 1.08	126.2 ± 11.62	24.36 ± 1.35
	10	62.12 ± 1.45	21.51 ± 0.68	129.5 ± 12.46	24.98 ± 1.23
	15	64.68 ± 1.83	20.89 ± 0.81	129.2 ± 11.12	24.22 ± 1.52
	20	68.32 ± 1.20	19.38 ± 1.47	121.1 ± 14.55	24.63 ± 1.28
PP-g-MA 7 (phr)	5	64.72 ± 1.74	21.47 ± 1.08	117.1 ± 9.48	23.78 ± 2.11
	10	65.39 ± 1.35	21.33 ± 1.3	115.0 ± 10.90	24.35 ± 1.74
	15	67.70 ± 0.95	20.03 ± 0.58	129.6 ± 15.76	24.47 ± 1.30
	20	69.91 ± 1.87	17.84 ± 0.44	122.6 ± 12.25	24.08 ± 1.95

4.4.1 Tensile Strength and elongation of PP/Nylon 6/EVA Blends with PP-g-MA

A representative stress-strain curve of PP/Nylon 6/EVA with PP-g-MA is show in Figure 4.11, 4.12 and 4.13.
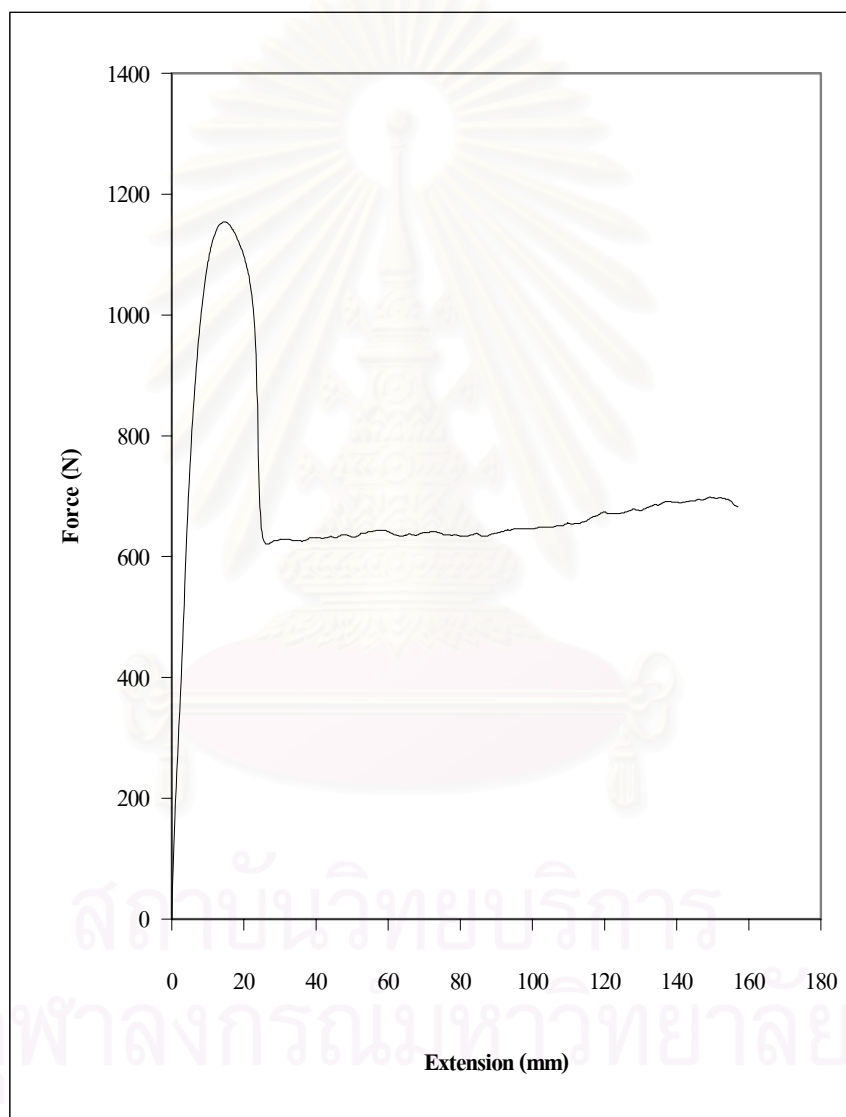
Figure 4.11 : Stress – strain curve of PP/Nylon 6/EVA/PP-g-MA 3
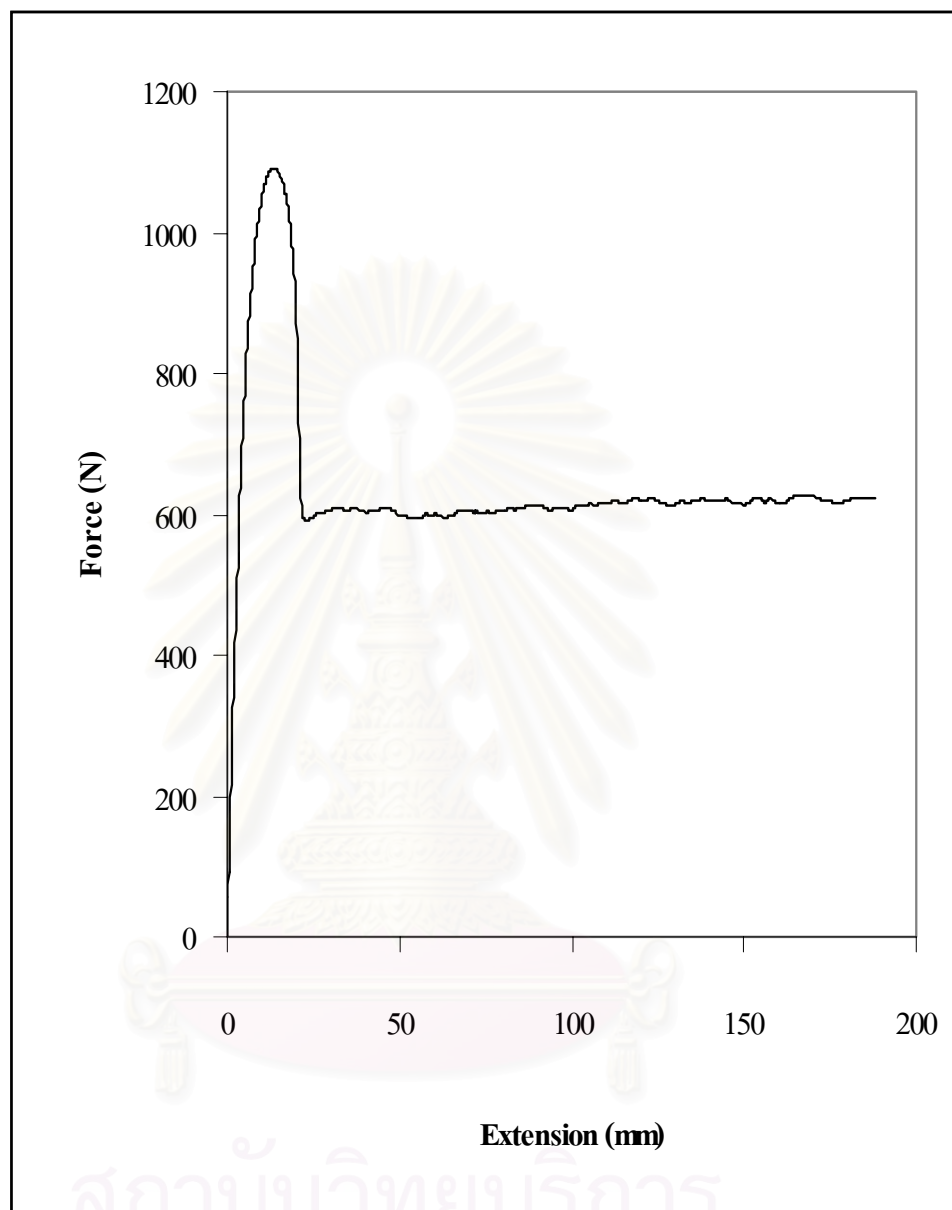
Figure 4.12 : Stress – strain curve of PP/Nylon 6/EVA/PP-g-MA 5
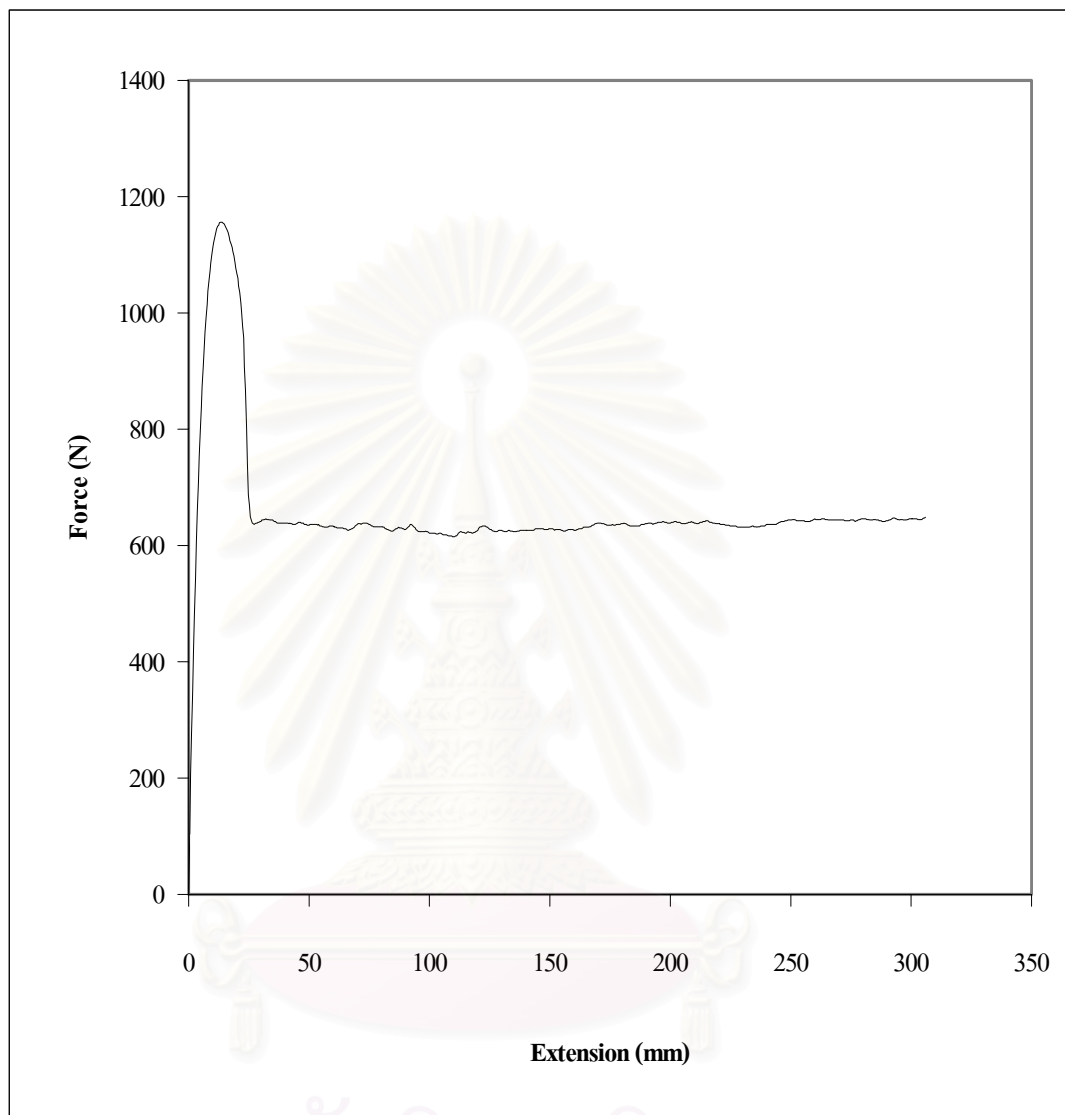
Figure 4.13 : Stress – strain curve of PP/Nylon 6/EVA/PP-g-MA 7

The effect of PP-g-MA on tensile strength and elongation of PP/Nylon 6/EVA (80:20:5) blend is shown in Table 4.5, Figure 4.14. and Figure 4.15.

Addition of PP-g-MA to the ternary blends at 5 phr tended to increase the tensile strengths of the polymer blends. Adding more PP-g-MA, however, caused the tensile strength to decrease further but only slightly. PP-g-MA also increase the elongation at break of the ternary blends up to 130 %, when increasing the amount of the compatibilitzer. These results imply that the toughness (or energy to break) of the blends increases with increasing PP-g-MA contents. Maleic anhydride moiety possibly reacted with the amino end group of Nylon 6, and/or generate more hydrogen bonds between its $C = O$ and $N - H$ of the amide groups within the Nylon chain.
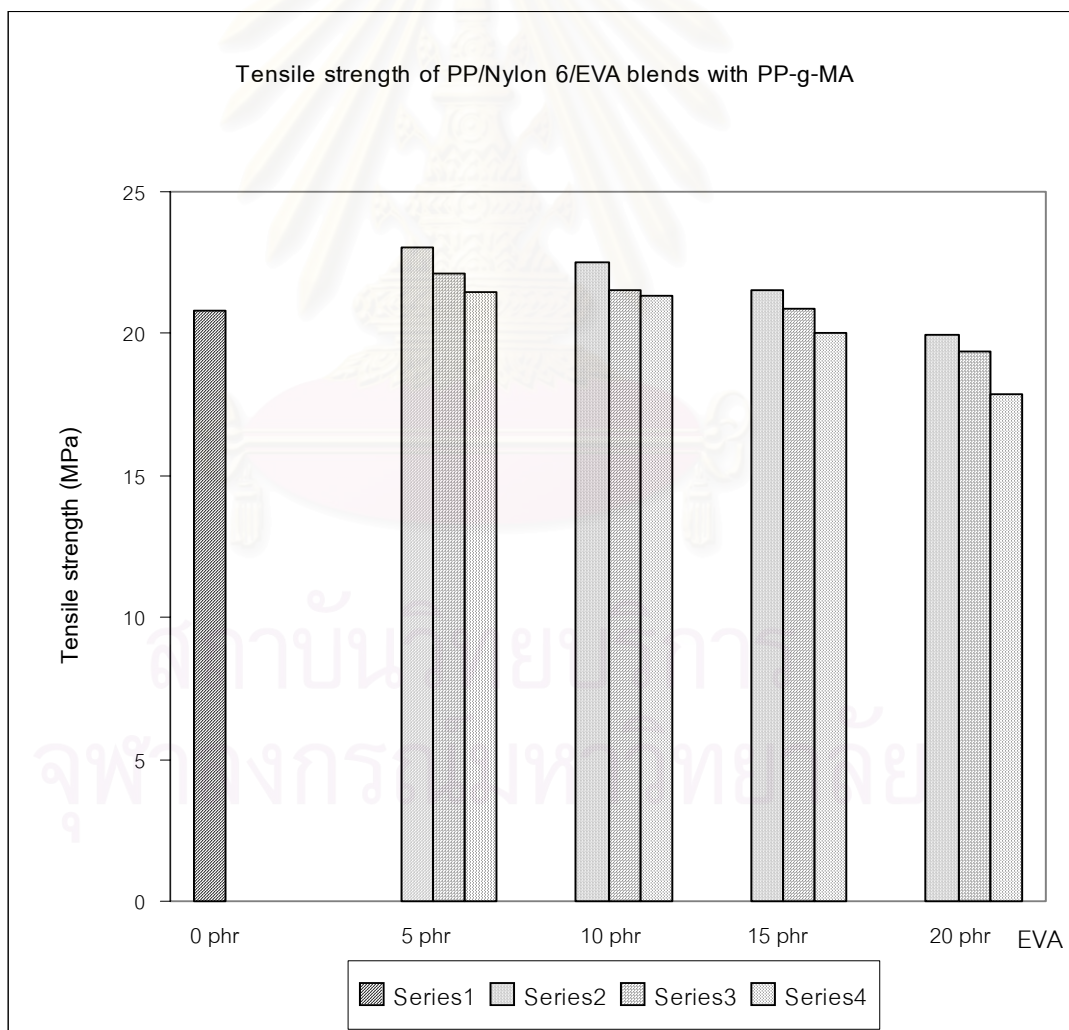
Figure 4.14 : Effect of PP-g-MA on the tensile strength of PP/Nylon 6/EVA (80:20:5)
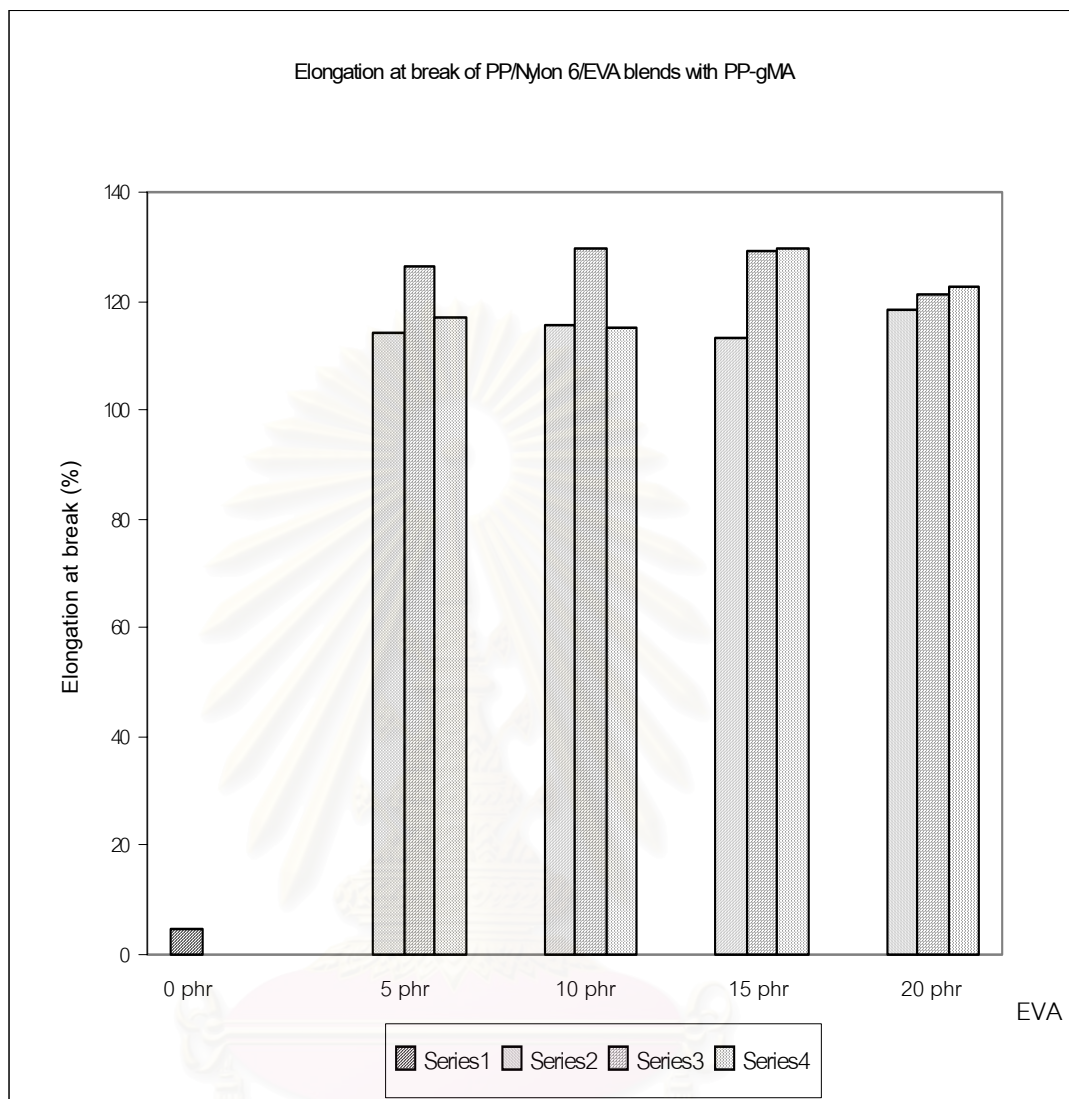
Figure 4.15 : Effect of PP-g-MA on the elongation at break of PP/Nylon 6/EVA (80:20:5) blend

4.4.2 Flexural Strength of PP/Nylon 6/EVA with PP-g-MA

Table 4.4 shows the effect of PP-g-MA on the flexural strength of blends. The amount of compatibilizer used in this study apparently had no effect on the blends. This could be due to poor transfer of stress between the interfaces of the blends [1, 2, 3].
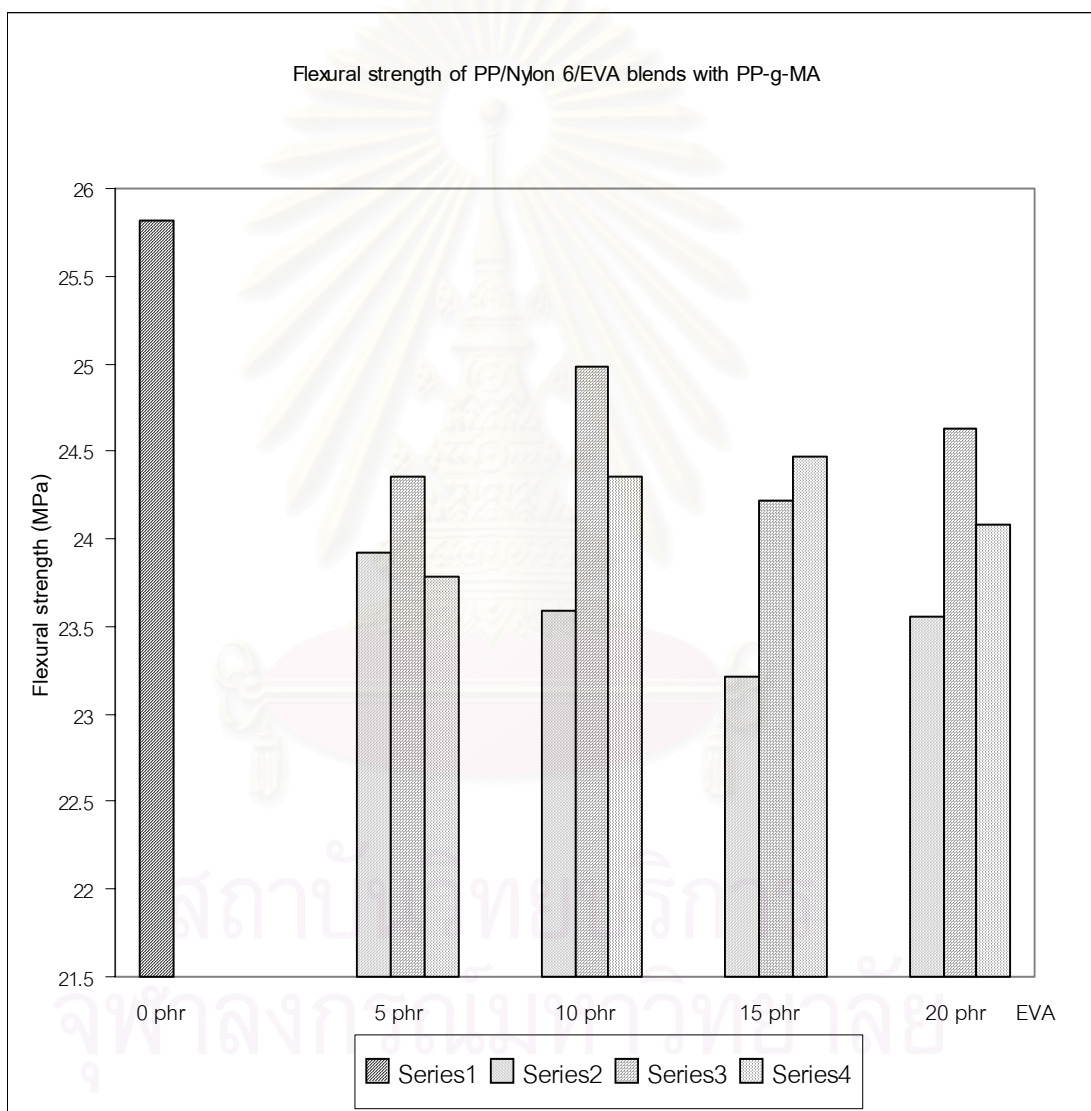
Figure 4.16 : Effect of PP-g-MA on flexural strength of PP/Nylon 6/EVA (80:20:5) blends

4.4.3 Impact strength of PP/Nylon 6/EVA Blends with PP-g-MA

Effect of PP-g-MA on Izod impact strength is shown in Table 4.4 and Figure 4.17. The impact strength of the blends containing the compatibilizer was significantly increased with the increasing PP-g-MA contents. This implied that the poor phase morphology of the ternary blends was also improved. PP-g-MA seemed to be a good candidate for the impact strength improvement of this ternary blend composition. Because maleic anhydride moieties generates H-bond and/or reacted with the amine group of Nylon 6, which increaesd the compatibility with PP and EVA.
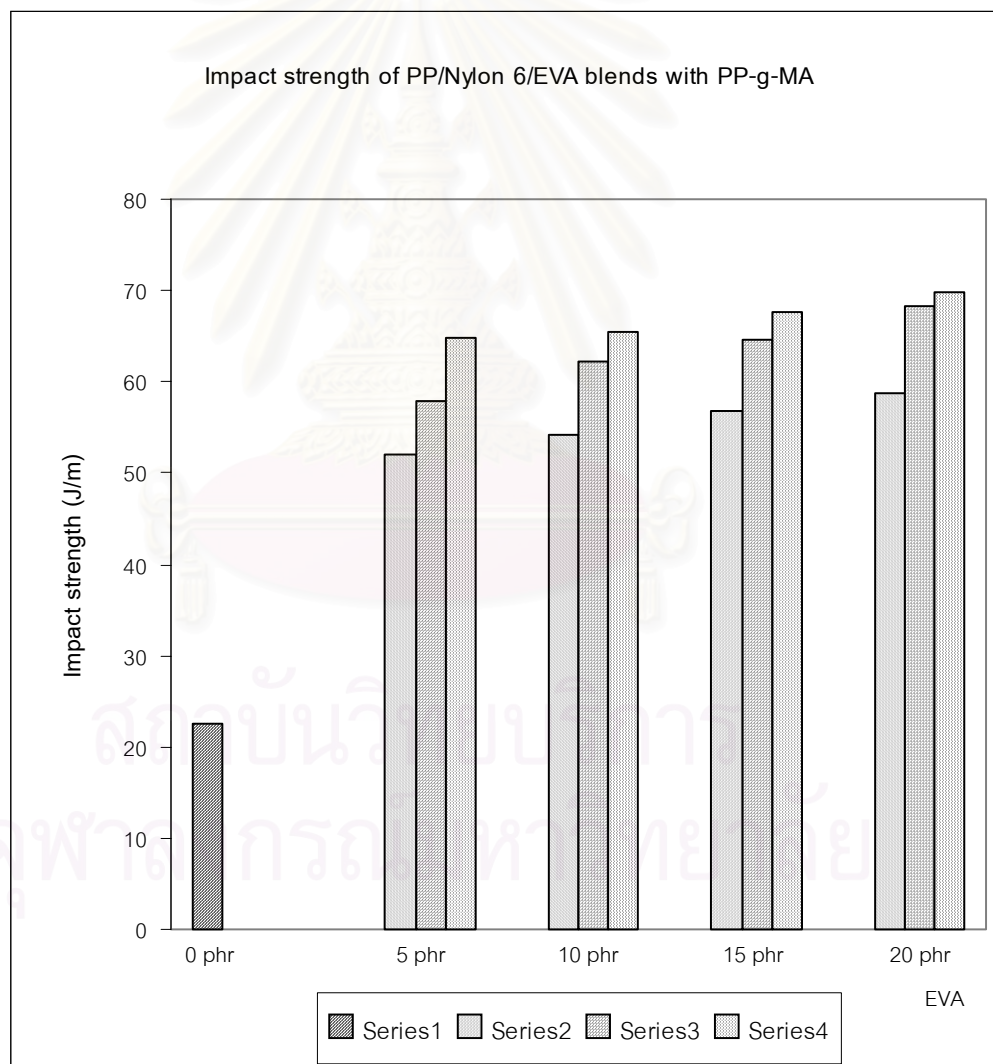
Figure 4.17 : Effect of PP-g-MA on impact strength of PP/Nylon 6/EVA (80:20:5) blends

4.5 Melt Flow Index (MFI) of PP/Nylon 6/EVA/PP-g-MA

The effect of PP-g-MA on melt flow index of blends is shown in Table 4.5 and Figure 4.18. It was found that the MFI of blends slightly decreased with the increasing of PP-g-MA contents. The decrease of MFI with added PP-g-MA is probably due to reaction between the anhydride moieties and the amine end groups of Nylon 6. This reaction, therefore, increased the molecular weight and the degree of branching to the polymer. The decreased of MFI when PP-g-MA was added into the with blends constitutes and evidence for increased compatibility of the blends .
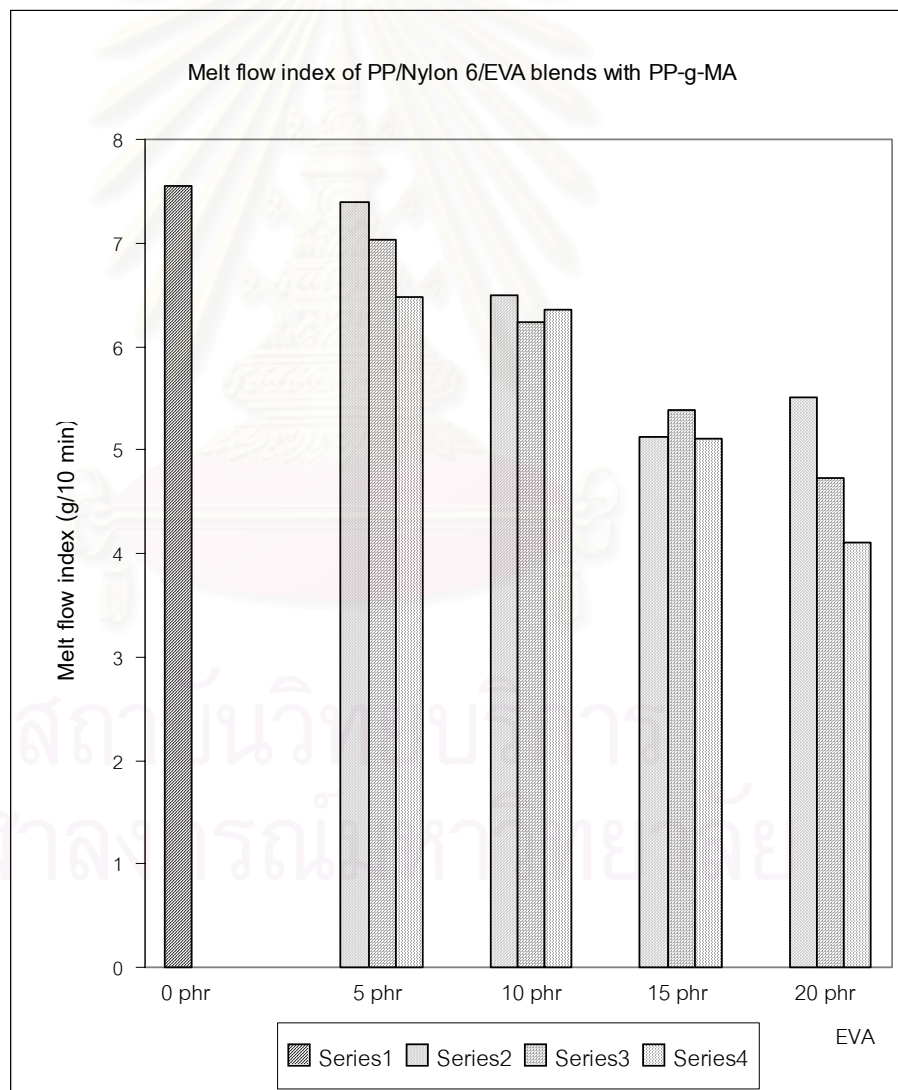
Figure 4.18 : Effect of PP-g-MA on MFI of PP/Nylon 6/ENA (80:20:5) blend

Table 4.5 : Effect of PP-g-MA on melt flow index of PP/Nylon 6/EVA (80:20:5) blend

Item	Amount of PP-g-MA (phr)	Melt flow index (g/10 min)
-	0/100	7.55 ± 0.24
PP-g-MA 3 (phr)	5/100	7.39 ± 0.28
	10/100	6.49 ± 0.09
	15/100	5.12 ± 0.17
	20/100	5.59 ± 0.14
PP-g-MA 5 (phr)	5/100	7.027 ± 0.97
	10/100	6.23 ± 0.23
	15/100	5.38 ± 0.24
	20/100	4.72 ± 0.12
PP-g-MA 7 (phr)	5/100	6.48 ± 0.13
	10/100	6.36 ± 0.18
	15/100	5.11 ± 0.16
	20/100	4.10 ± 0.20

4.6 Physical appearance of PP/Nylon 6/EVA blends

The physical appearance of the blends was investigated by scanning electron microscopy technique (SEM). The fracture surface of PP/Nylon 6/EVA blends at various contents of the compatibilizer are shown in Figure 4.20, 4.21 and 4.22.

The average size of the dispersed Nylon 6 droplets in the PP matrix of the ternary blends without a compatibilizer are large and non-uniform (Figure 4.19). The non-uniform dispersion of Nylon 6 is thus resulted in poor contact and transfer of stress between the phases at the interfaces. These immiscible blends usually show inferior mechanical properties, when compared to the individual polymers. The compatibility between the three components was improved by introducing PP-g-MA (Figure 4.20, 4.21, 4.22). When PP-g-MA was mixed into the blends, the size of dispersed Nylon 6 droplets in the PP matrix became smaller and more uniformly distributed. Additional micrograghs of the blends were archived in Appendix B.

Figure 4.19 Morphology of PP-Nylon 6/EVA (80:20:5)
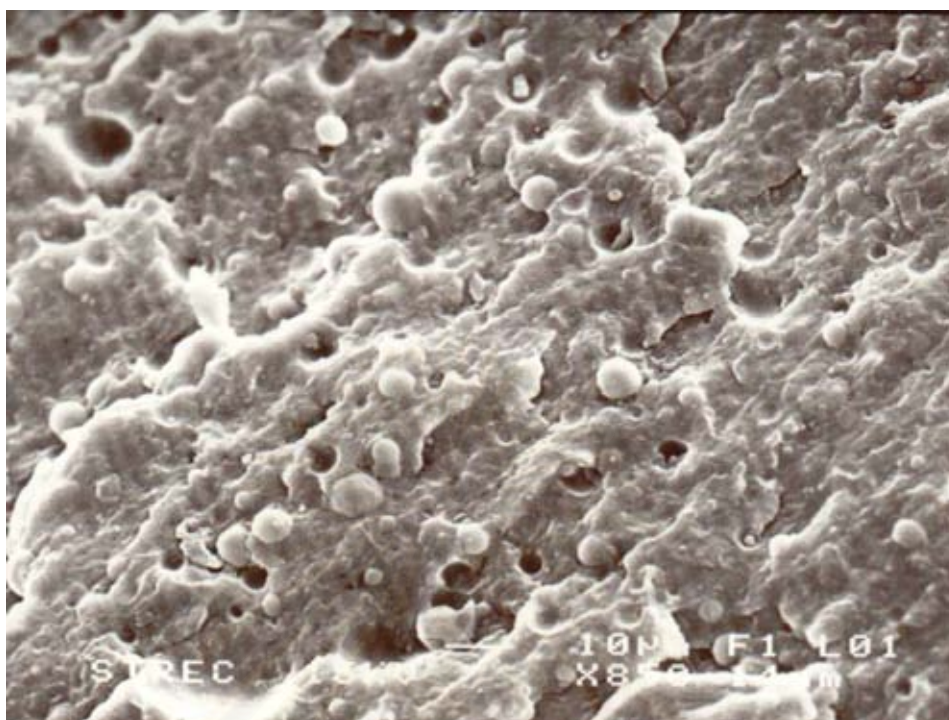
Figure 4.20 Morphology of PP/Nylon 6/EVA (80:20:5) with PP-g-MA 3 (5 phr)
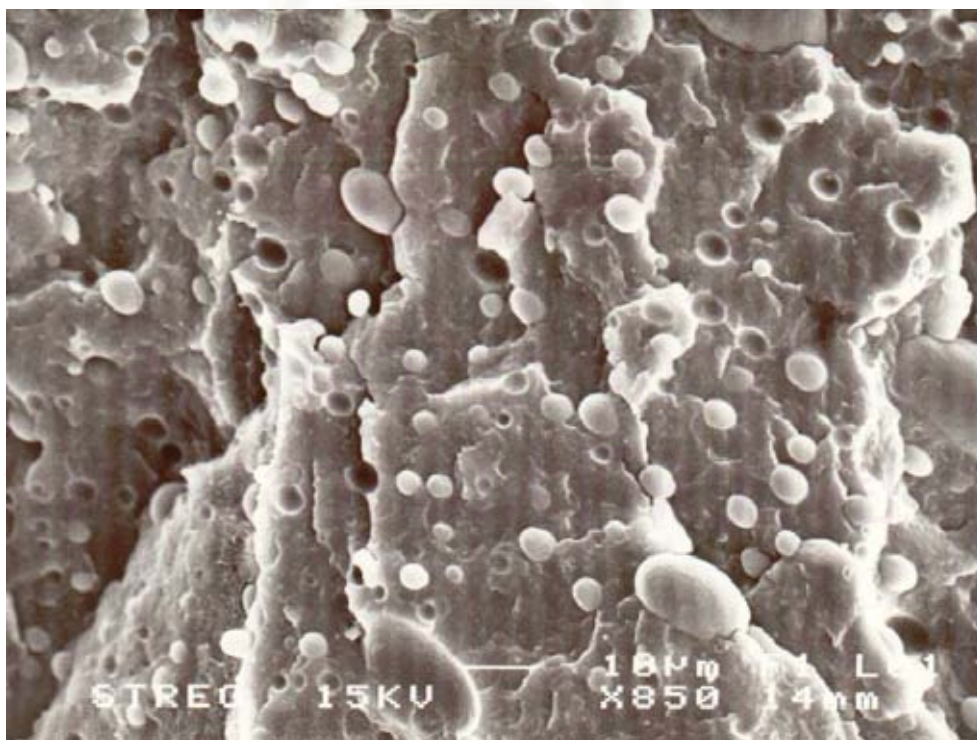
Figure 4.21 Morphology of PP/Nylon 6/EVA (80:20:5) with PP-g-MA 5 (5 phr)
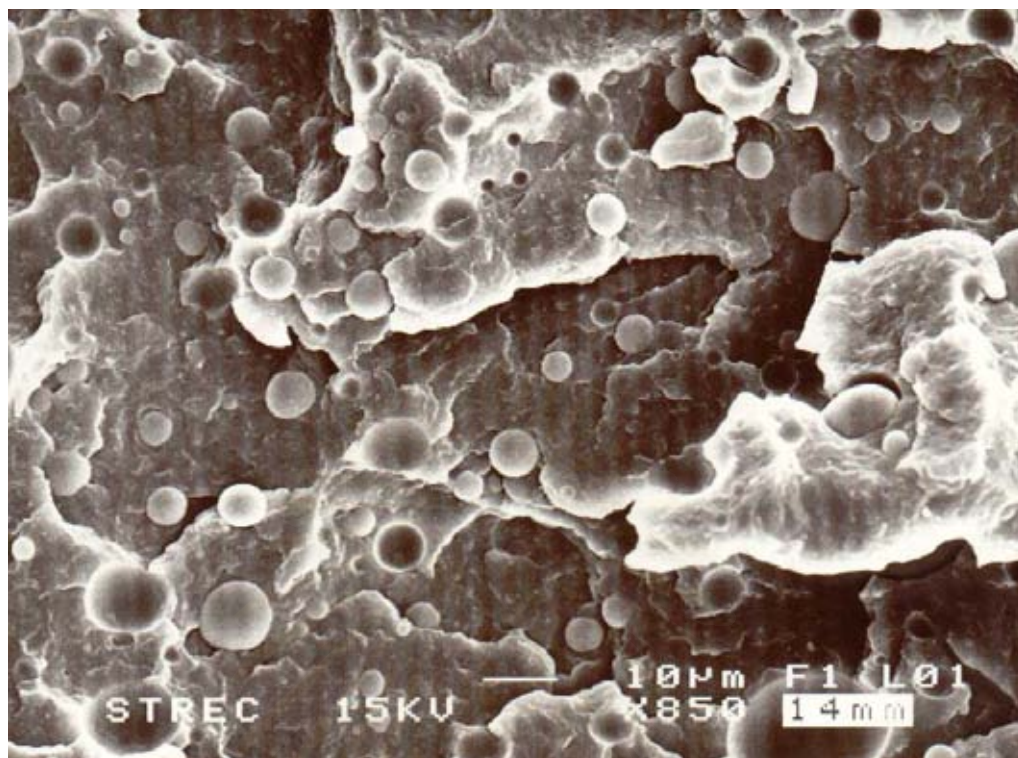
Figure 4.22 Morphology of PP/Nylon 6/EVA (80:20:5) with PP-g-MA 7 (5 phr)

CHAPTER V

CONCLUSION AND SUGGESTION FOR FUTURE WORK

5.1   Conclusion

The influence of PP-g-MA on mechanical properties of PP/Nylon 6/EVA blends has been studied. It was found that the impact strength of uncompatibilized blend is the most influenced by the addition of the compatibilizer. There was a significant improvement on the impact strength. Without the compatibilizer, the tensile strength, elongation at break and flexural strength decreased with the presence of EVA in the PP/Nylon 6 blends. FTIR analysis suggested that the amino group from Nylon 6 reacted with the anhydride moity from MA to create a linkage between the polar Nylon phase and the non-polar PP phase. Evidences from SEM micrograms also showed smaller Nylon droplets uniformly distributed in PP phase when PP-g-MA was added to the blends. Therefore PP-g-MA seems to be a good candidate for compatibilizing PP/Nylon 6/EVA blends.

5.2   Suggestion for Further Work

One of the possible research work should be carried out is the use of twin screw extruder to prepare this blend system under nitrogen atmosphere. By this improved method, a better mixing of the blend and the compatibilizer may be accomplished. In addition, the benefit of using PP powder in place of pallets for

preparation of PP-g-MA will give higher grafting MA onto PP because maleic acid would disperse better into the PP powder than it would do in the PP pellet.

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Appendix

APPENDIX A

A.1   Izod imact calculation

The slope of the line connecting the values for impact energy for 0.254 and 1.012 mm notch radius should be calculate as follows

$$b = E_A - E_B / R_2 - R_1$$

where $E_A - E_B$ is average energy to break for the larger and smaller not radii respectively, J/m of notch, R_2 is radius of the larger notch and R_1 is radius of the smaller notch.

A.2   Tensile calculation

Tensile strength   Calculate the tensile strength by dividing the maximum load in newtons by the original minimum cross-section area of the specimen in squre meters.

$$\text{Tensile strength} = \frac{\text{Force}}{\text{Cross section area}}$$

$$\text{Tensile strength at yield} = \frac{\text{Maximum load recorded}}{\text{Cross section area}}$$

$$\text{Tensile strength at yield} = \frac{\text{Load recorded at break}}{\text{Cross section area}}$$

Percent Elongation   at break   Divide the extension by the original gge length and multiply by 100.

$$\%EL \quad = \quad [(L-L_o)/L_o] \times 100$$

where L_o is original distance between gage marks and L distance between gage marks at Any time.

A.3   Flexural strength calculation

A simple beam supported at two points and loaded at the midpoint. The stress may be calculated for any point on the load – deflection curve by the following equation

$$S \quad = \quad 3PL / 2bd^2$$

Where S is stress at midspan, P is load at a given point on the load-deflection curve, L is support span, b is with of beam test and d is depth of beam tested.

Table A-1 Tensile strength data of PP/nylon 6/EVA blends (MPa)

Item	100	90:10:5	80:20:5	70:30:5	90:10:10	80:20:10	70:30:10	90:10:15	80:20:15	70:30:15
1	32.24	25.60	24.04	22.50	18.92	12.00	11.25	22.35	18.69	15.23
2	30.14	25.00	18.74	15.06	23.56	20.70	18.50	20.10	17.50	7.02
3	35.00	18.00	19.60	14.00	22.87	23.00	19.15	12.11	12.25	7.88
4	28.00	19.80	23.45	19.50	17.56	18.56	12.35	15.60	10.50	16.05
5	29.03	24.78	16.50	20.45	14.22	20.70	17.52	18.54	18.25	14.89
6	34.56	23.12	25.60	21.36	12.35	12.57	12.56	11.00	11.23	16.00
7	33.80	21.78	23.95	17.88	13.70	15.14	11.50	11.35	14.50	12.34
8	27.45	20.98	17.60	13.00	24.04	13.83	15.49	21.57	13.66	10.55
9	34.87	22.40	18.00	12.06	12.00	18.40	16.55	14.96	18.81	8.07
10	33.88	17.56	20.40	13.77	14.58	15.05	15.00	13.52	14.41	8.55
X	31.90	21.90	20.79	16.96	17.38	16.99	14.99	16.11	14.98	11.66
SD	2.97	2.84	3.21	3.83	4.72	3.78	2.94	4.26	3.15	3.67

Table A-2 Elongation at break (%) of PP/nylon 6/EVA blends

Item	100:00:00	90:10:5	80:20:5	70:30:5	90:10:10	80:20:10	70:30:10	90:10:15	80:20:15	70:30:15
1	249.55	14.05	5.00	3.04	8	8.22	6.00	6.50	6.00	4.00
2	247.33	12.50	4.98	4.22	6.25	7.76	4.25	6.32	6.50	5.02
3	249.56	6.78	2.00	2.98	6.74	4.25	5.78	8.74	7.00	3.98
4	246.22	6.00	8.12	5.00	3.23	5.13	7.45	5.00	4.56	6.12
5	250.10	7.56	9.00	3.45	8.56	7.06	6.55	7.03	8.01	4.02
6	249.27	13.10	3.45	3.00	7.47	10.10	6.47	8.91	7.49	3.57
7	242.10	7.02	5.22	3.14	4.47	4.88	5.21	5.50	4.55	2.98
8	244.00	6.55	4.01	5.15	10.50	6.67	7.84	6.55	3.84	3.12
9	246.00	6.02	3.26	3.09	3.49	5.50	4.89	4.55	6.30	5.77
10	248.55	9.50	3.00	6.11	8.77	3.98	5.93	8.76	3.41	6.32
X	247.25	8.91	4.80	3.918	6.75	6.36	6.03	6.79	5.78	4.49
SD	2.66	3.15	2.23	1.13	2.40	1.96	1.10	1.58	1.58	1.23

Table A-3 Flexural strength (MPa) of PP/nylon 6/EVA blends

Item	100:00:00	90:10:5	80:20:5	70:30:5	90:10:10	80:20:10	70:30:10	90:10:15	80:20:15	70:30:15
1	25.00	26.00	28.79	17.00	23.14	22.00	16.55	20.15	20.11	17.03
2	29.20	24.87	29.86	19.35	27.94	29.31	18.95	23.74	23.45	18.57
3	21.03	20.98	22.10	24.12	20.11	28.94	21.35	26.00	23.74	25.00
4	22.06	1978	20.56	12.56	18.74	18.10	23.57	19.98	19.84	14.25
5	20.18	24.71	26.22	11.23	19.54	20.58	13.00	24.26	18.54	16.12
6	24.00	25.45	23.70	10.56	26.55	21.55	16.89	19.45	14.00	15.51
7	29.30	24.81	24.51	22.35	28.05	17.13	14.02	17.33	15.46	24.55
8	30.78	23.83	19.00	26.59	16.32	19.41	23.23	18.12	24.37	20.00
9	30.50	16.50	18.75	24.14	27.22	20.00	21.00	25.77	22.46	18.91
10	26.10	18.02	22.55	16.22	23.77	16.50	20.30	15.56	22.11	16.50
X	25.82	22.50	23.60	18.41	23.14	21.35	18.89	21.04	20.41	18.64
SD	3.98	3.40	3.82	5.8	4.27	4.47	3.67	3.67	3.54	3.65

Table A- 4 Izod impact strength (J/m) of PP/nylon 6/EVA blends

Item	100:00:00	90:10:5	80:20:5	70:30:5	90:10:10	80:20:10	70:30:10	90:10:15	80:20:15	70:30:15
1	28.00	39.00	47.23	49.25	41.23	50.42	53.48	43.85	49.80	52.30
2	22.64	26.56	39.46	46.78	32.05	42.35	50.42	35.02	47.42	54.80
3	22.80	40.00	45.28	41.20	42.97	45.98	40.23	37.88	46.87	46.70
4	30.00	33.58	43.26	39.56	40.10	47.89	48.90	42.97	53.23	45.62
5	23.05	34.23	47.86	46.27	32.95	43.25	45.89	34.78	53.40	50.69
6	23.61	35.68	42.13	45.40	42.10	50.00	46.87	35.63	57.89	53.04
7	20.36	30.25	44.85	47.43	30.59	39.56	47.50	36.77	42.36	45.68
8	16.00	33.70	37.06	42.91	31.28	50.55	50.00	40.23	45.88	44.23
9	22.40	33.04	48.52	45.23	33.50	48.97	42.35	32.70	46.23	53.00
10	15.95	24.07	38.98	50.24	34.57	38.72	43.85	33.58	45.00	50.98
X	22.48	33.01	43.46	45.43	36.13	45.77	46.95	37.34	48.81	49.70
SD	4.45	4.98	4.00	3.38	4.88	4.51	4.01	3.85	4.73	3.79

Table A- 5 Melt flow index (g / 10 min) of PP/nylon 6/EVA blends

Item	100:00:00	90:10:5	80:20:5	70:30:5	90:10:10	80:20:10	70:30:10	90:10:15	80:20:15	70:30:15
1	6.39	6.75	8.00	7.95	6.00	7.00	6.02	5.23	6.50	8.20
2	6.34	5.99	7.59	7.94	5.23	6.90	5.57	5.11	6.11	7.50
3	7.02	5.78	7.60	8.02	5.56	6.50	5.43	5.46	6.23	7.64
4	6.55	6.43	7.54	7.56	5.97	6.57	6.20	5.68	6.48	8.11
5	5.80	6.44	7.80	7.88	5.88	6.43	5.98	5.72	6.74	8.00
6	6.79	6.55	7.30	7.64	5.41	6.88	5.87	5.31	6.33	7.75
7	7.12	6.41	7.26	8.10	5.39	7.08	5.66	5.40	6.10	7.60
8	5.98	6.81	7.48	8.32	5.54	6.35	5.40	5.87	5.98	8.00
9	6.30	6.22	7.68	7.66	5.78	6.55	5.81	5.61	6.00	8.10
10	6.12	5.94	7.28	7.77	5.22	6.84	6.10	5.32	6.44	8.44
X	6.44	6.33	7.55	7.88	5.60	6.71	5.80	5.47	6.29	7.93
SD	0.43	0.34	0.24	0.23	0.29	0.26	0.28	0.24	0.25	0.30

Table A- 6 Tensile strength of PP/nylon 6/EVA blends (80:20:5) with PP-g-MA

Item	PP/nylon 6/EVA*	Tensile strength (MPa)										X	SD
		1	2	3	4	5	6	7	8	9	10		
-	0/100	24.04	18.74	19.60	23.45	16.50	25.60	23.95	17.60	18.00	20.40	20.79	3.21
PP-g-MA 3 (phr)	5/100	22.73	23.50	22.89	22.96	23.19	24.02	22.17	24.00	22.87	21.90	23.02	0.63
	10/100	22.67	23.96	22.51	21.07	22.03	23.35	22.58	23.85	21.79	21.23	22.50	1.00
	15/100	21.50	22.77	21.68	21.62	21.76	22.62	21.68	21.64	20.15	20.00	21.54	0.89
	20/100	19.65	20.28	19.90	20.37	19.98	20.50	20.70	19.20	18.80	20.06	19.94	0.59
PP-g-MA 5 (phr)	5/100	23.01	20.55	22.32	21.84	22.83	22.14	21.94	22.55	23.70	20.12	22.10	1.08
	10/100	20.74	20.51	21.07	21.16	21.55	22.22	22.02	21.54	21.58	22.74	21.51	0.68
	15/100	21.88	21.60	19.67	20.09	20.76	20.72	21.88	21.55	20.72	19.98	20.88	0.81
	20/100	21.45	19.57	19.64	21.10	20.82	16.68	18.73	18.10	18.52	19.18	19.38	1.47
PP-g-MA 7 (phr)	5/100	21.60	21.98	21.70	22.12	19.32	20.41	20.88	21.14	23.04	22.50	21.47	1.08
	10/100	20.76	20.86	21.54	21.77	19.95	21.27	21.76	20.11	20.67	24.56	21.33	1.3
	15/100	20.12	20.36	19.98	20.53	20.76	20.24	19.43	20.47	19.37	19.00	20.03	0.58
	20/100	18.39	17.80	17.68	17.63	17.55	17.54	17.48	17.98	18.81	17.55	17.84	0.44

Table A- 7 Elongation at break of PP/nylon 6/EVA blends (80:20:5) with PP-g-MA

Item	PP/nylon 6/EVA*	Elongation at break (%)										X	SD
		1	2	3	4	5	6	7	8	9	10		
-	0/100	5.00	4.98	2.00	8.12	9.00	3.45	5.22	4.01	3.26	3.00	4.80	2.31
PP-g-MA 3 (phr)	5/100	105	167	109	117	109	102	105	108	113	108	114.3	19.00
	10/100	118	105	130	109	114	102	106	109	140	123	115.6	12.21
	15/100	107	109	128	104	129	120	106	120	102	108	113.3	10.03
	20/100	105	106	104	120	108	106	107	150	149	130	118.5	18.27
PP-g-MA 5 (phr)	5/100	144	108	127	126	123	120	120	115	140	139	126.2	11.62
	10/100	121	119	137	145	1231	140	118	116	128	150	129.5	12.46
	15/100	124	115	131	128	118	135	128	156	128	129	129.2	11.12
	20/100	120	130	156	105	119	115	120	127	110	109	121.1	14.55
PP-g-MA 7 (phr)	5/100	105	123	135	108	112	128	109	115	116	120	117.1	9.48
	10/100	97	112	124	110	128	115	10	107	134	114	115.0	10.90
	15/100	105	139	145	148	143	106	127	119	125	139	129.6	15.76
	20/100	130	128	117	109	145	105	127	125	130	110	122.6	12.25

Table A- 8 Flexural strength of PP/nylon 6/EVA (80:20:5) blends with PP-g-MA

Item	PP/nylon 6/EVA*	Flexural strength (MPa)										X	SD
		1	2	3	4	5	6	7	8	9	10		
-	0/100	28.79	29.86	22.10	20.56	26.22	23.70	24.51	19.00	18.75	22.50	23.60	3.82
PP-g-MA 3 (phr)	5/100	25.57	23.56	26.00	24.70	22.96	23.76	23.55	22.81	22.73	23.54	23.92	1.14
	10/100	22.11	23.51	24.83	23.49	24.92	25.00	21.83	23.44	21.00	25.80	23.59	1.57
	15/100	23.96	26.72	25.43	21.07	22.48	20.69	24.08	22.87	23.55	21.25	23.21	195
	20/100	21.10	25.04	23.88	23.77	22.41	26.91	22.47	21.54	24.48	24.00	23.56	1.74
PP-g-MA 5 (phr)	5/100	23.00	23.56	25.83	26.88	23.50	25.05	24.97	23.04	24.78	22.98	24.36	1.35
	10/100	25.58	24.00	25.81	23.56	22.74	26.55	25.49	25.60	26.02	24.44	24.98	1.23
	15/100	22.98	25.00	25.40	26.02	25.49	22.22	23.47	22.72	26.12	22.80	24.22	1.52
	20/100	26.52	23.79	23.21	22.36	24.56	25.80	25.93	24.33	24.80	25.00	24.63	1.28
PP-g-MA 7 (phr)	5/100	25.03	26.25	22.80	21.23	23.87	26.00	25.04	21.05	21.00	25.55	23.78	2.11
	10/100	22.49	25.86	24.48	25.36	22.03	22.03	25.77	23.54	26.89	25.05	24.35	1.74
	15/100	26.00	23.56	25.08	22.40	25.95	23.61	24.32	24.78	26.05	22.97	24.47	1.32
	20/100	22.03	27.89	25.66	22.47	23.54	22.05	23.00	26.00	24.85	23.28	24.08	1.95

Table A- 9 Izod impact strength of PP/nylon 6/EVA blends (80:20:5) with PP-g-MA

Item	PP/nylon 6/EVA*	Izod impact strength (J/m)										X	SD
		1	2	3	4	5	6	7	8	9	10		
-	0/100	47.23	39.46	45.28	43.26	47.86	42.13	44.85	37.06	48.52	38.98	43.46	4.00
PP-g-MA 3	5/100	50.96	53.42	49.87	51.22	52.10	52.66	51.49	53.70	49.73	50.55	51.57	1.38
(phr)	10/100	54.32	55.89	52.80	56.47	56.00	53.96	53.84	56.42	52.78	53.54	54.60	1.50
	15/100	56.00	58.92	57.56	55.84	56.30	55.55	54.73	54.20	57.98	58.00	56.51	1.54
	20/100	60.20	58.65	57.23	59.45	57.48	56.98	58.05	60.00	59.21	58.54	58.58	1.14
PP-g-MA 5	5/100	58.59	56.43	57.25	57.08	60.32	61.05	58.88	57.44	56.10	55.90	57.90	1.76
(phr)	10/100	64.02	63.54	60.12	59.98	61.55	62.20	62.87	63.47	60.61	62.71	62.11	1.47
	15/100	65.50	64.84	63.21	66.73	65.80	64.50	62.81	63.70	65.11	66.02	64.82	1.27
	20/100	70.12	69.23	68.54	68.23	69.57	66.92	65.89	66.75	70.88	69.43	68.56	1.61
PP-g-MA 7	5/100	64.50	66.52	63.87	65.00	65.78	63.44	64.13	62.94	66.20	66.10	64.85	1.26
(phr)	10/100	65.00	67.58	64.20	63.50	66.17	68.02	65.00	64.50	63.98	68.00	65.60	1.73
	15/100	69.25	67.10	65.00	66.42	70.00	68.16	66.88	66.57	67.70	68.23	67.53	1.46
	20/100	69.88	70.02	71.45	68.75	67.52	69.54	68.70	68.02	70.33	72.50	69.67	1.52

Table A- 10 Melt flow index of PP/nylon 6/EVA blends (80:20:5) with PP-g-MA

Item	PP/nylon 6/EVA*	Melt flow index (g / 10 min)										X	SD
		1	2	3	4	5	6	7	8	9	10		
-	0/100	8.00	7.59	7.60	7.54	7.80	7.30	7.26	7.48	7.68	7.28	7.55	0.24
PP-g-MA 3 (phr)	5/100	7.58	7.43	7.82	6.95	7.45	7.39	7.61	7.55	7.10	7.00	7.37	0.28
	10/100	6.50	6.49	6.43	6.49	6.62	6.66	6.40	6.33	6.55	6.50	6.49	0.09
	15/100	5.25	4.98	5.36	4.90	5.33	5.16	5.20	4.89	5.00	5.13	5.12	0.17
	20/100	5.50	5.70	5.71	5.43	5.69	5.74	5.42	5.38	5.65	5.66	5.59	0.14
PP-g-MA 5 (phr)	5/100	7.10	7.20	6.98	6.72	7.30	6.88	6.94	7.02	7.30	6.83	7.03	0.20
	10/100	6.50	6.32	6.10	5.90	6.00	6.27	6.44	6.00	6.50	6.22	6.22	0.22
	15/100	5.40	5.33	5.21	5.60	5.74	5.00	5.10	5.66	5.30	5.50	5.38	0.24
	20/100	4.90	4.77	4.83	4.65	4.50	4.62	4.80	4.70	4.62	4.79	4.72	0.12
PP-g-MA 7 (phr)	5/100	6.50	6.66	6.70	6.39	6.48	6.50	6.47	6.42	6.35	6.30	6.47	0.13
	10/100	6.30	6.45	6.55	6.67	6.23	6.50	6.10	6.24	6.15	6.33	6.35	0.18
	15/100	5.00	5.20	5.30	4.98	4.82	5.18	5.21	5.34	5.00	5.10	5.11	0.16
	20/100	4.20	4.19	4.39	3.87	3.95	4.12	4.26	3.93	3.80	4.32	4.10	0.20
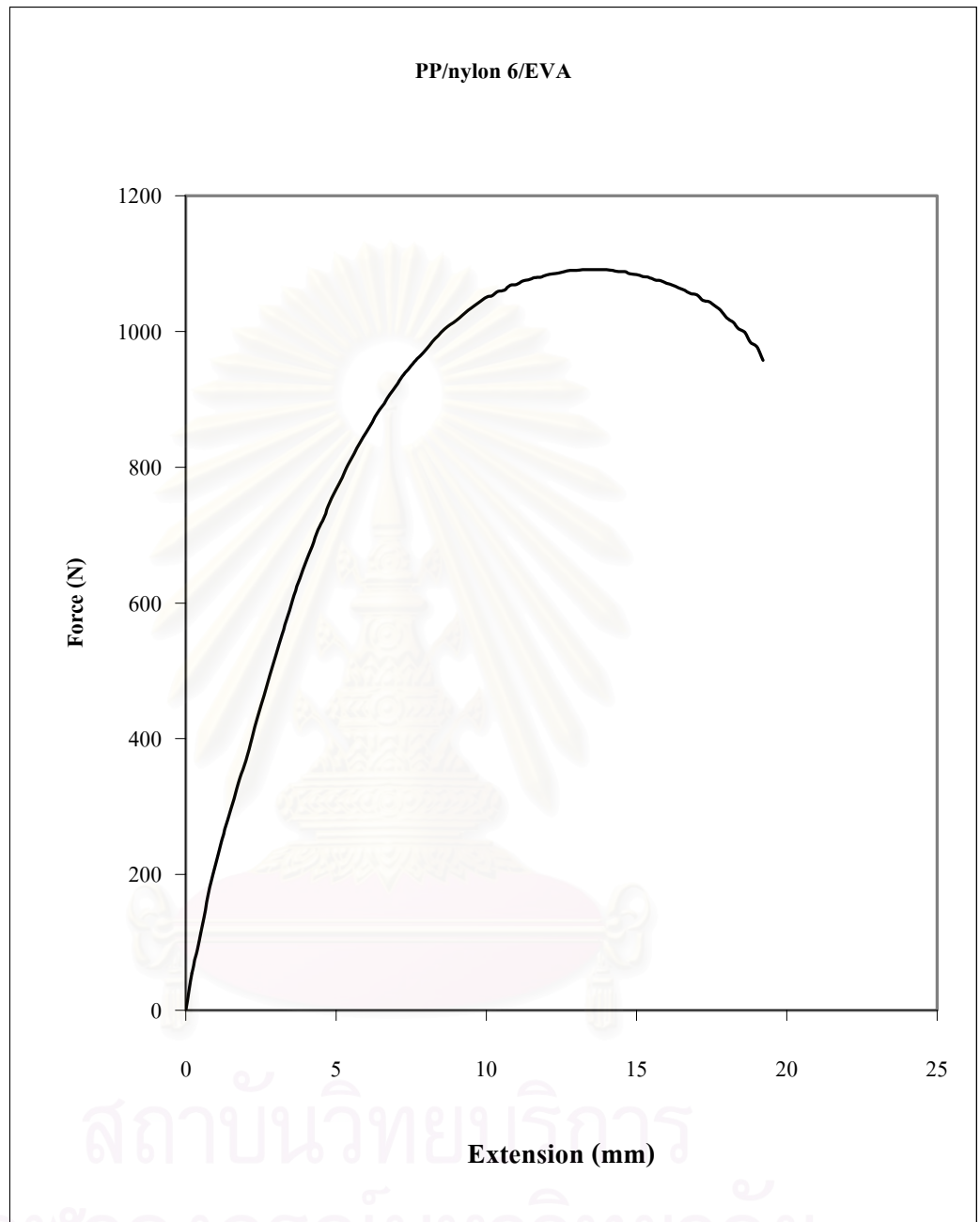
Figure A-1 Stress – strain curve of PP/nylon 6/EVA (80:20:10)
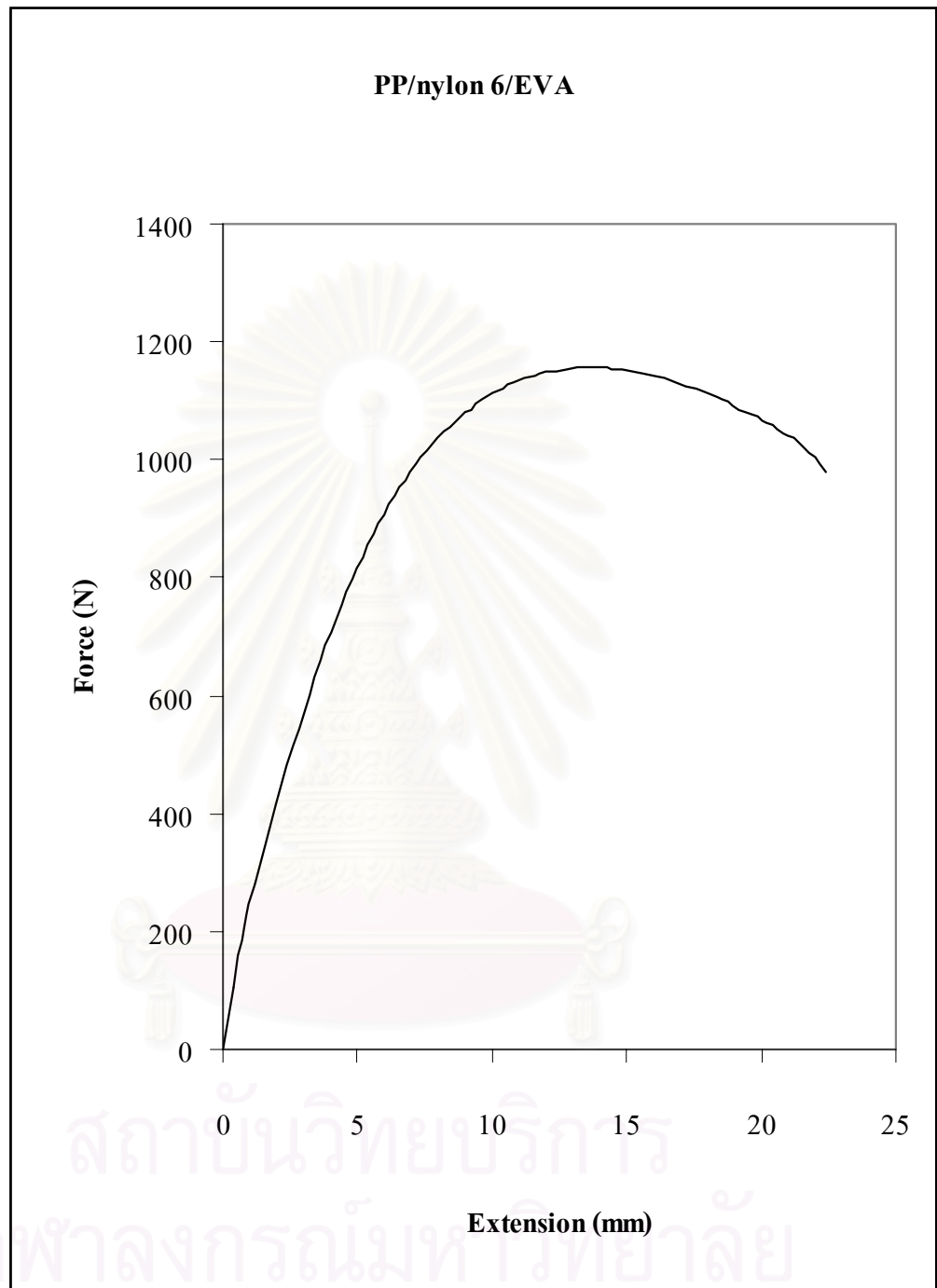
Figure A 2 Stress – strain curve of PP/nylon 6/EVA (80:20:15)
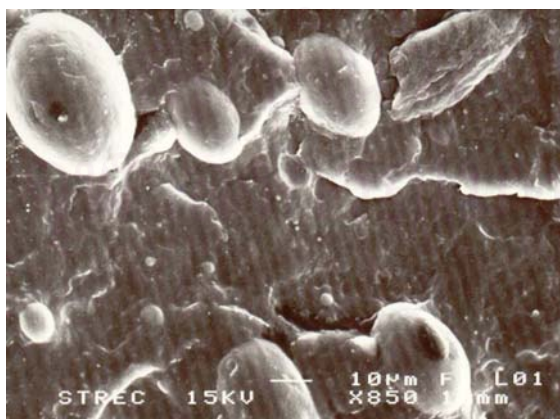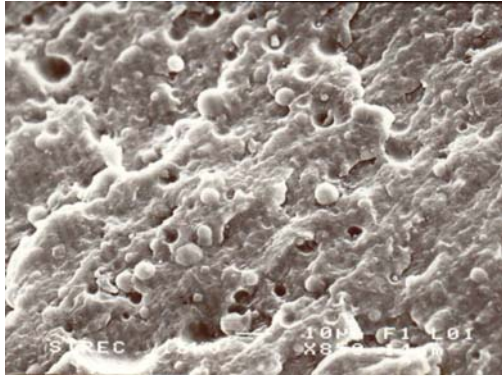
Appendix
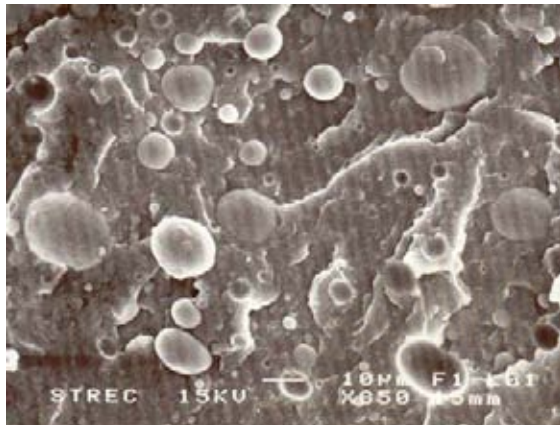
APPENDIX B

Morphology of PP/nylon 6/EVA
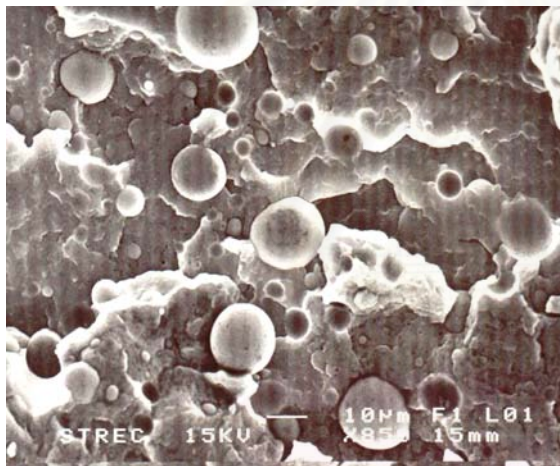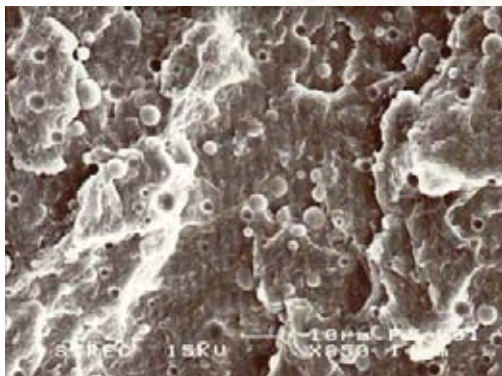
(70:20:10)

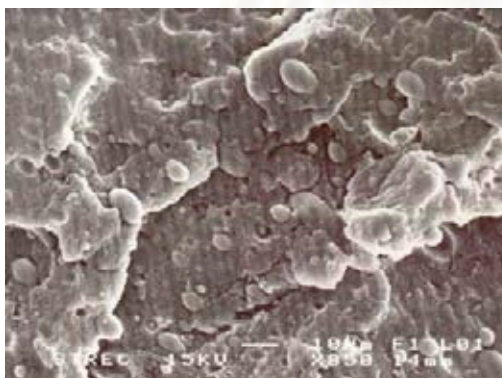Morphology of PP/nylon 6/EVA

(70:20:10)
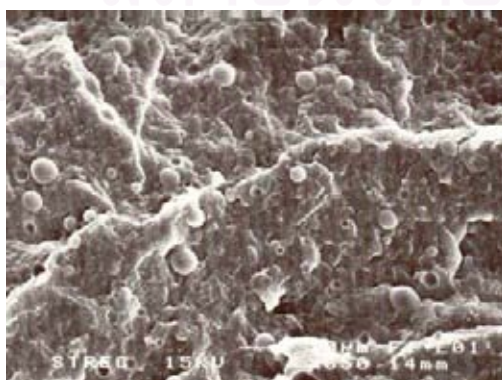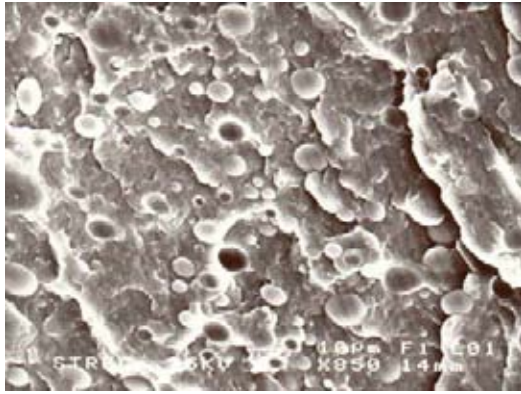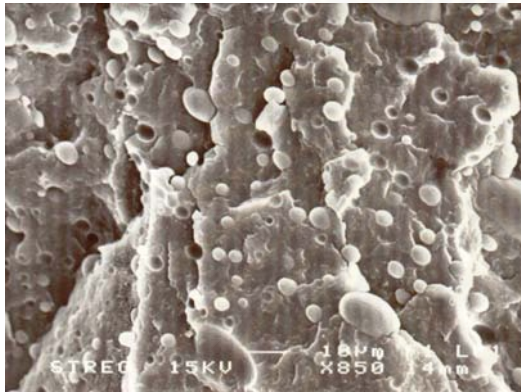

Morphology of PP/nylon 6/EVA

(70:20:15)

PP/nylon 6/EVA /PP-g-MA3

(80:20:5:5)

PP/nylon 6/EVA /PP-g-MA3

(80:20:5:10)

PP/nylon 6/EVA /PP-g-MA3
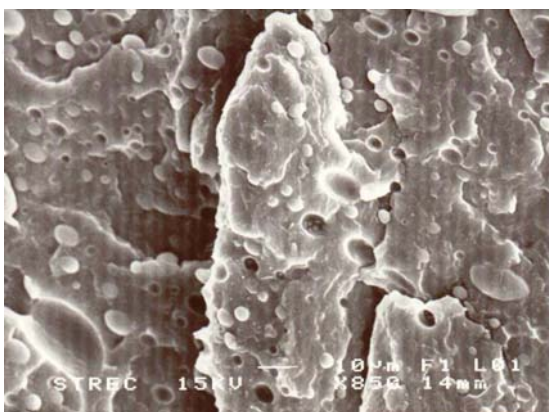
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PP/nylon 6/EVA /PP-g-MA3

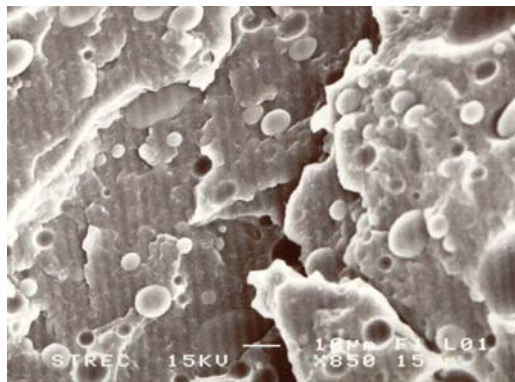(80:20:5:20)

PP/nylon 6/EVA /PP-g-MA5

(80:20:5:5)

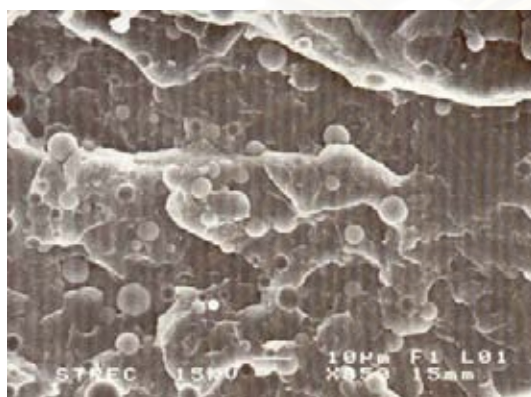PP/nylon 6/EVA /PP-g-MA5

(80:20:5:10)

PP/nylon 6/EVA /PP-g-MA5

(80:20:5:15)

PP/nylon 6/EVA /PP-g-MA5
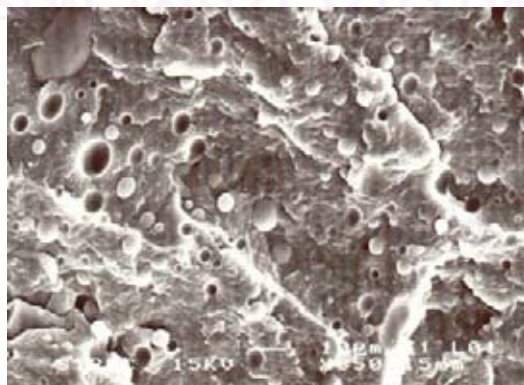
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PP/nylon 6/EVA /PP-g-MA7

(80:20:5:5)

PP/nylon 6/EVA /PP-g-MA7

(80:20:5:10)

PP/nylon 6/EVA /PP-g-MA7

(80:20:5:15)

PP/nylon 6/EVA /PP-g-MA5

(80:20:5:20)

VITA

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