CHAPTER IV

RESULT AND DISCUSSION

The copolymers of styrene (S) and methyl methacrylate (MMA) grafted onto natural rubber (NR) were prepared by using the emulsion polymerization. The influences of the main process parameters such as emulsifier concentration, initiator concentration, mode of monomer addition, and reaction temperature were investigated. The grafted natural rubber was blended with PVC resin at various contents of the grafted natural rubber. Finally, the mechanical properties of the blended were investigated to find the optimum ratio of grafted natural rubber and PVC resin which gives suitable properties.

4.1 Properties of Natural Rubber Latex

The natural rubber latex was the product of Thai Rubber Latex Corporation (Thailand) Public Co., Ltd. The average dry rubber content of latex may range between 60.0 % and 61.0 %. The typical properties of natural rubber is shown in Table 4.1. The average molecular weights of natural rubber latex determined by the GPC are as follows : $\overline{M}_n = 116,991$, $\overline{M}_w = 669,863$, $\overline{M}_z = 2,235,420$, $\overline{M}_w/\overline{M}_n = 5.72$.

Table 4.1 The properties of natural rubber latex

　　　Type of latex : high ammonia

Properties	Test results
Total Solids Content, %	61.98
Dry Rubber Content, %	60.05
Non Rubber Content, %	1.64
Ammonia Content (on Total Weight), %	0.75
Ammonia Content (on Water Phase), %	1.97
pH Value	10.70
KOH Number	0.52
Volatile Fatty Acid Number (VFA)	0.021
Mechanical Stability Time @ 55% TS., (Sec.)	1,020
Specific Gravity at 25 °C	0.945
Magnesium Content, (ppm.)	15

Source : Thai Rubber Latex Corporation (Thailand) Public Co.,Ltd.

4.2 Preparation of Grafted Natural Rubber

The grafted natural rubber was prepared by emulsion graft copolymerization process. The mechanism of graft copolymerization was studied by using natural rubber as the core and styrene and methyl methacrylate as the shell monomers. In this experiment, the water-soluble potassium persulfate ($K_2S_2O_8$) and sodium dodecylsulfate as an emulsifier were used. The appropriate conditions were investigated to yield high percent conversion and high grafting efficiency for the preparation of graft copolymer of styrene and methyl methacrylate onto natural rubber.

The parameters investigated in this experiment are as follows :

4.2.1) Effect of monomer content

4.2.2) Effect of emulsifier concentration

4.2.3) Effect of initiator concentration

4.2.4) Effect of reaction temperature

4.2.1 Effect of Monomer Content

In this work, the grafted natural rubber particles consisting of a polyisoprene core and compatibilizing styrene and methyl methacrylate monomers shell were prepared by emulsion polymerization. The natural rubber latex was used as an seed latex of cis-1,4-polyisoprene from which the isoprene monomer was polymerized first, and the mixture of styrene and methyl methacrylate monomers was subsequently added to continue the polymerization within the seed particle. The key process lies in the grafting of a significant portion of the growing styrene-methyl methacrylate random copolymer radicals onto the double bonds of the existing elastomeric components. The grafting between the plastic and elastomer components led to the compatibility of the system, resulting in a favorable state of dispersion and also bonding the phases together. Upon the polymerization, the second monomer mixed with phase separation to yield the complex inner morphology [24]. Emulsion grafting to small particles exhibited a closed shell of graft copolymer on their surface, and no inclusion was visible in the images either before or after the mixing process. If the closed shell of grafted rubber latex was formed incompletely, coagulation in the acid solution would occur.

One and a half parts by weight of emulsifier, 1.5 parts by weight of initiator, per 100 parts of natural rubber, the reaction temperature and time at 50°C and 8 hours produced a complete formation of core-shell structure. The complete formation of core-shell was tested by the coagulation reaction of grafted latex in an acid solution. If the

formation was complete, the coagulation could not occur. The result of the graft copolymerization is summarized in Table 4.2

The result indicated that the complete closed shell formed at above 100 parts by weight of monomers. The result of core-shell formation and the dispersion of particles of grafted natural rubber latex are shown in Figure 4.1 and 4.2, respectively.

Table 4.2 Effect of styrene and methyl methacrylate monomer content on the closed shell of grafted natural rubber latex.

Expt. No	Natural Rubber	Monomers (MMA : S = 75 : 25)	Coagulation in acid solution
1	100	50	+
2	100	75	+
3	100	100	-
4	100	120	-
5	100	150	-

+ : The grafted natural rubber latex was coagulated in the acid solution.

- : The grafted natural rubber latex was not coagulated in the acid solution.
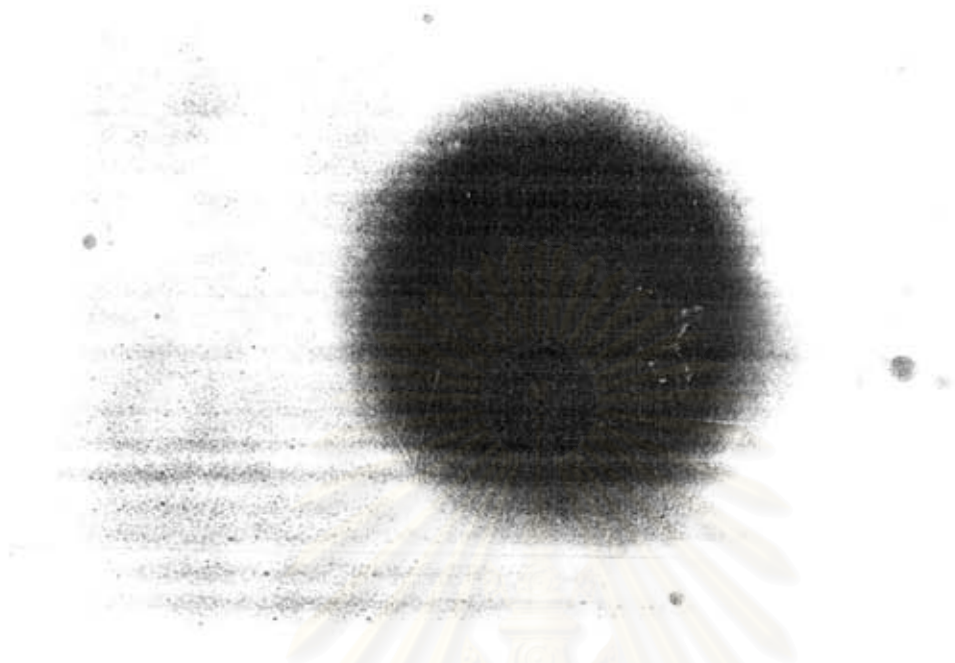
Figure 4.1 Transmission electron micrograph of the completed closed shell of the grafted natural rubber latex
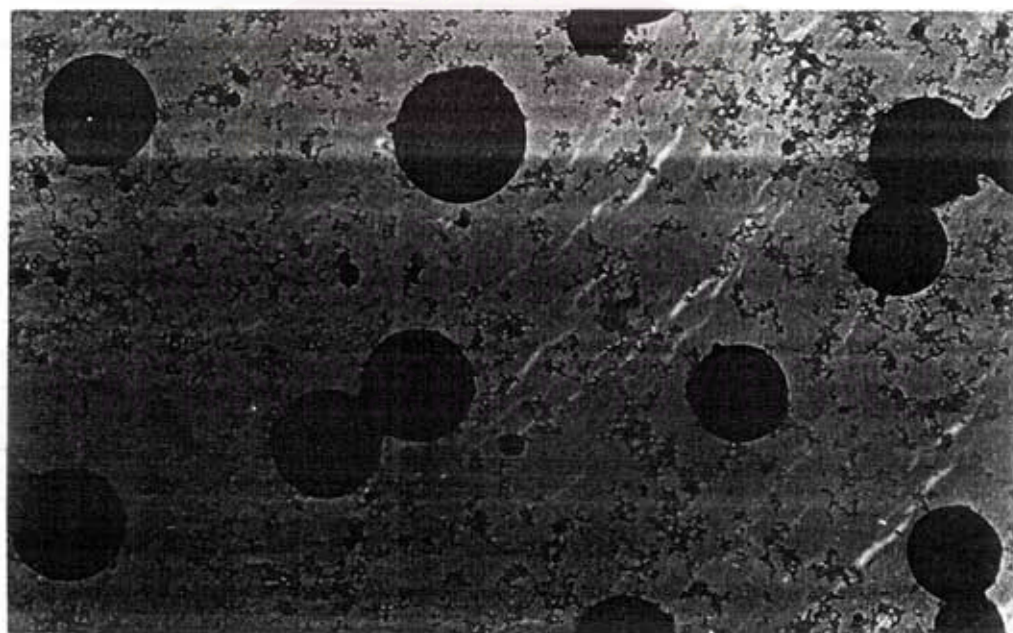

Figure 4.2 Transmission electron micrograph of the grafted natural rubber latex

4.2.2 Effect of Emulsifier Concentration

The effects of emulsifier concentration on the percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio were investigated by varying the emulsifier concentration of 0.5, 1.0, 1.5, 2.0, and 2.5 parts by weight (per 100 parts of rubber content). The parameters were kept constant as follows :

-amount of styrene and methyl methacrylate monomers (25 : 75)   : 100 parts by weight.

-rubber content   : 100 parts by weight.

-initiator concentration   : 1.5 parts by weight.

-reaction temperature   : 50 °C

-reaction time   : 8 hours.

The degree of monomer conversion is defined as the mass of S/MMA formed (grafted and free) divided by the initial mass of monomers. The grafting efficiency is readily defined as the mass of the grafted S/MMA divided by the total mass of grafted latex produced. The graft ratio is calculated from the mass of styrene and methyl methacrylate monomers which was grafted on the backbone polymer divided by the rubber which formed grafts with styrene and methyl methacrylate monomers [21]. The details of all of the above data and calculations are shown in the Appendix B. The effect of emulsifier concentration on the percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio is summarized in Table 4.3 and Figures 4.3a- 4.3c.

Figure 4.3a shows the effect of emulsifier concentration on percent grafted natural rubber, percent free natural rubber, and percent free S/MMA. It can be seen that, the grafted natural rubber and free natural rubber decrease with increasing emulsifier concentration. But the S/MMA homopolymer increases with increasing emulsifier concentration. This means that homopolymers are formed more readily than the grafted copolymer.

In Figure 4.3b the degree of monomer conversion increases with an increase in the emulsifier concentration. Higher than 1.0 parts by weight of emulsifier, the degree of monomer conversion increases only slightly.

In Figures 4.3b and 4.3c below the 57.1% and 0.89 at 1.5 parts by weight of emulsifier region decrease in grafting efficiency and graft ratio are observed. As a result of the decreasing of emulsifier concentration a coagulation occurs. If the coagulation takes place at decreasing emulsifier concentrations, the total surface area decreases leading to the direct effect of the grafting efficiency and graft ratio.

In Figures 4.3b and 4.3b (above the maximum value of grafting efficiency and graft ratio) the grafting efficiency and graft ratio decrease, due to the presence of more free micelles in the water phase. These micelles can be initiated to form a new crop of particles, so there will be less monomer left for grafting [17]. The appropriate emulsifier concentration of 1.5 parts by weight was found.

Table 4.3 Effect of emulsifier concentration on the percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio. : latex = 1:1; initiator 1.5 parts by weight; temp. = 50°C; time = 8 hours

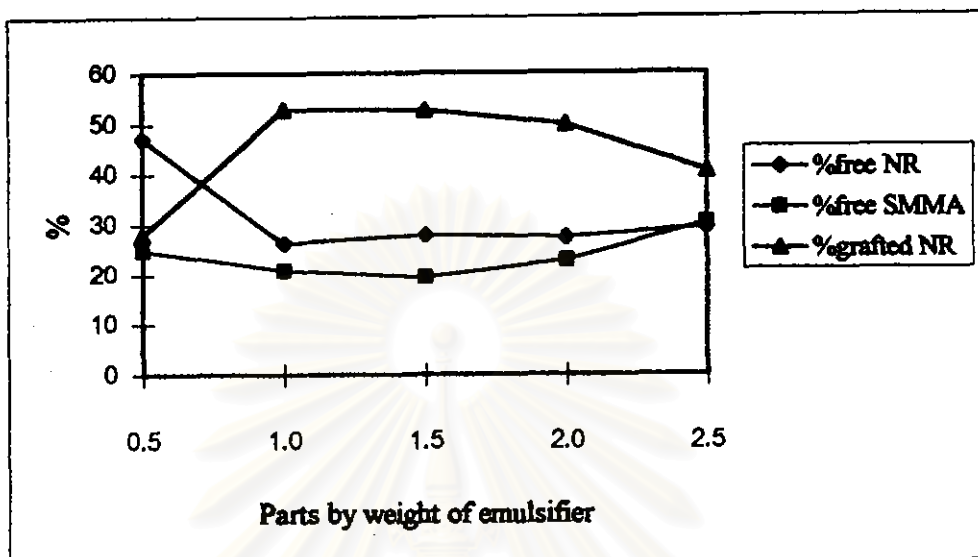| Grafting Properties	Parts by weight of emulsifier				
	0.5	1.0	1.5	2.0	2.5
Grafted Natural Rubber (%)	27.9	52.9	52.6	49.8	40.5
Free Natural Rubber (%)	47.1	26.3	28.0	27.4	29.3
Free S/MMA (%)	24.9	20.8	19.4	22.8	30.3
Degree of monomer conversion (%)	48.1	72.2	74.9	76.2	76.9
Grafting efficiency (%)	23.5	49.7	57.1	51.5	36.6
Graft ratio $(g.g^{-1})$	0.38	0.77	0.89	0.81	0.63

Figure 4.3a Effect of emulsifier concentration on the percent grafted NR, percent free NR, and percent free S/MMA.
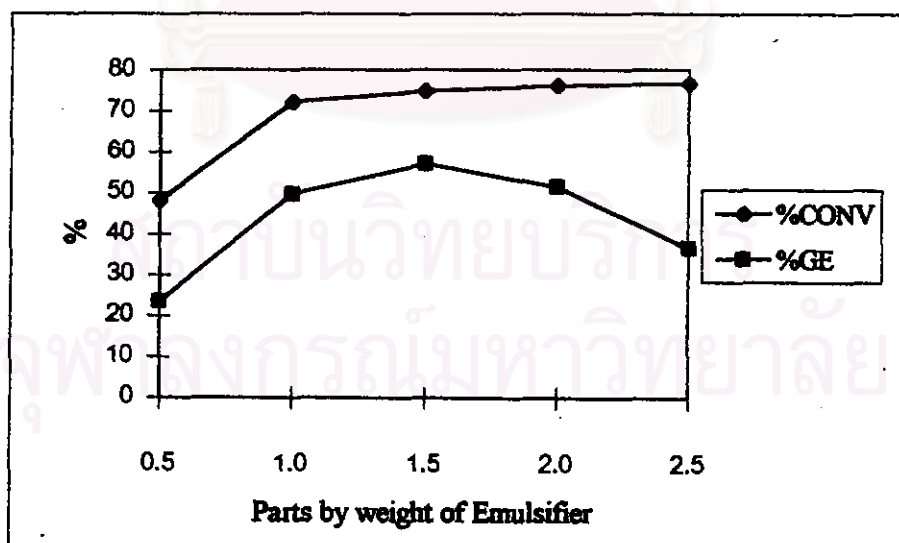

Figure 4.3b Effect of emulsifier concentration on the degree of monomer conversion and grafting efficiency.
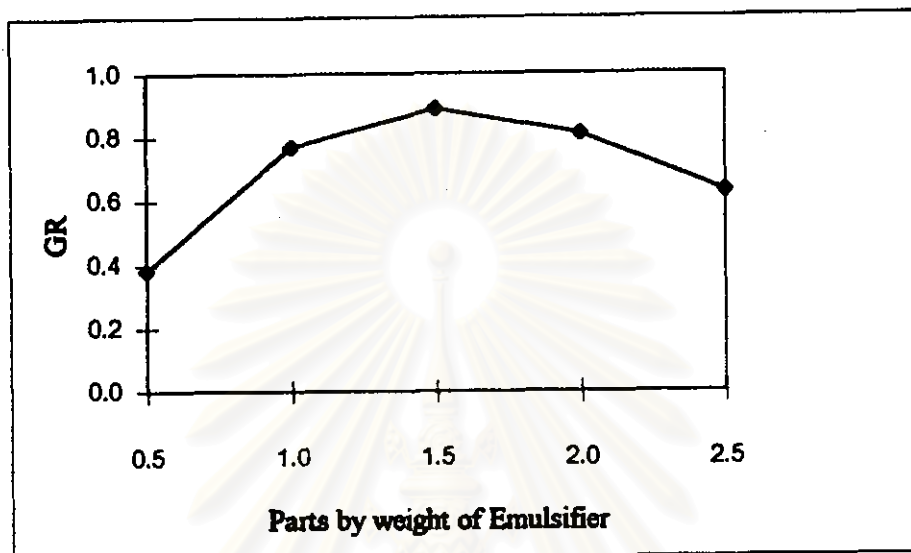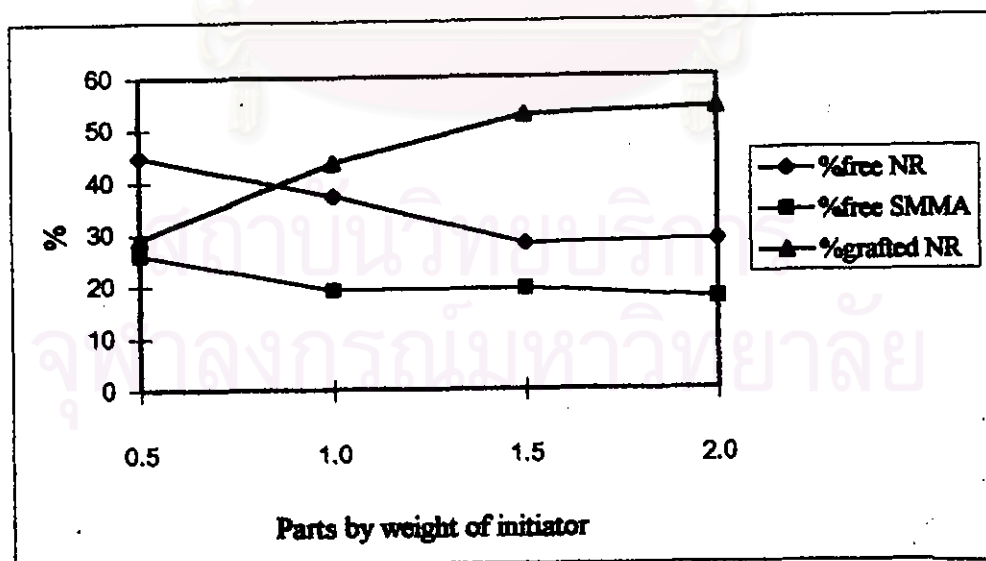
Figure 4.3c Effect of emulsifier concentration on the graft ratio.

4.2.3 Effect of Initiator Concentration

The effects of initiator concentration on the percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio are shown in Table 4.4 and Figure 4.5 and 4.6. The details of all data and calculations are shown in Appendix B. The parameters of graft copolymerization were obtained as follows :

-amount of styrene and methyl methacrylate monomers (25 : 75) : 100 parts by weight.

-rubber content   : 100 parts by weight.

-emulsifier concentration   : 1.5 parts by weight.

-reaction temperature   : 50°C

-reaction time   : 8 hours.

In Figures 4.4a-4.4c the percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio increase rapidly with increasing the amount of initiator concentration initially, and slowly increase at high concentration.

Initially, the increase in the initiator concentration produces more grafting sites for styrene/methyl methacrylate random copolymers or styrene, methyl methacrylate to graft. Therefore, percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio can, of course, increase. At the higher initiator concentrations, an abundance of initiator radical is produced and radical recombination can occur to some extent slightly increase all the reaction properties in terms of lower increasing conversion, shorter grafted chains and lesser graft ratio [13].

Table 4.4 Effect of initiator concentration on the percent grafted natural degree of monomer conversion, grafting efficiency, and graft ratio. : latex = 1:1; emulsifier 1.5 parts by weight; temp. = 50°C; time = 8 hours

Grafting Properties	Parts by weight of initiator			
	0.5	1.0	1.5	2.0
Grafted Natural Rubber (%)	29.1	43.6	52.6	53.9
Free Natural Rubber (%)	44.8	37.2	28.0	28.6
Free S/MMA (%)	26.0	19.2	19.4	17.4
Degree of monomer conversion (%)	48.0	65.5	74.9	78.1
Grafting efficiency (%)	18.3	49.7	57.1	59.9
Graft ratio (g.g^{-1})	0.26	0.81	0.89	0.94

Figure 4.4a Effect of initiator concentration on the percent grafted NR, percent free NR, and percent free S/MMA.
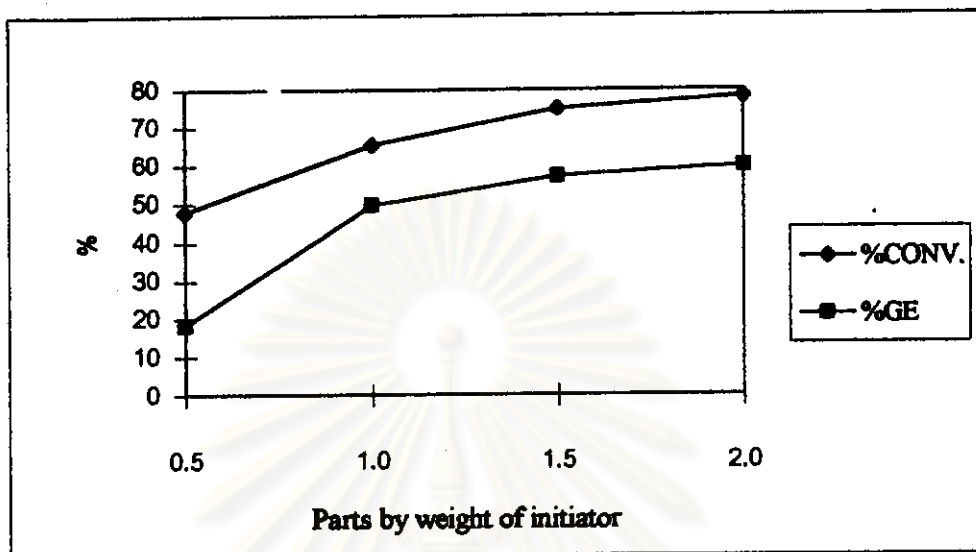
Figure 4.4b Effect of initiator concentration on the degree of monomer conversion and grafting efficiency.
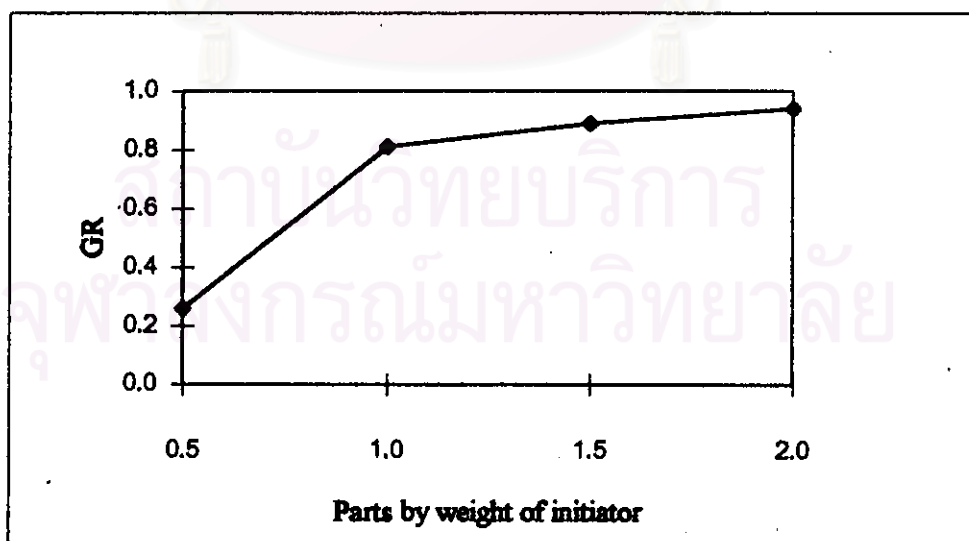

Figure 4.4c Effect of initiator concentration on the graft ratio.

4.2.4 Effect of Reaction Temperature

The reaction temperature imposes a strong effect on the grafted natural rubber product, because the reaction temperature affects the reactivity ratio of monomers and ratio of styrene and methyl methacrylate monomer in the aqueous phase. The effects of reaction temperature on grafted natural rubber were investigated by varying the reaction temperatures of 40, 50, 60, and 70°C. The effects of temperature on the grafting characteristics, the copolymer composition and the thermal properties of grafted natural rubber (NR-g-S/MMA, after the solvent extraction of the grafted natural rubber product) were investigated.

The grafted natural rubber was prepared in emulsion polymerization for 8 hours using the following basic formulation :

-amount of styrene and methyl methacrylate monomers (25 : 75) : 100 parts by weight.

-rubber content   : 100 parts by weight.

-emulsifier concentration   : 1.5 parts by weight.

-initiator concentration   : 1.5 parts by weight

4.2.4.1 Effect of Reaction Temperature on Percent grafted natural rubber, Degree of monomer conversion, Grafting efficiency, and Graft ratio

The effects of reaction temperature on percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio are shown in Table 4.5. The details of all data and calculations are shown in Appendix B.

With increasing temperature, decomposition of initiator increases, it results an increased number of free radicals and the rates of polymerization and grafting increase. In Figures 4.5a-4.5c the percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio increase with increase of the reaction temperature value. A slight increase in percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio increasing the reaction temperature above 50°C.

Table 4.5 Effect of reaction temperature on the percent grafted natural rubber, degree of monomer conversion, grafting efficiency, and graft ratio.: latex = 1:1; emulsifier 1.5 parts by weight; initiator 1.5 parts by weight, temp. = 50°C; time = 8 hours

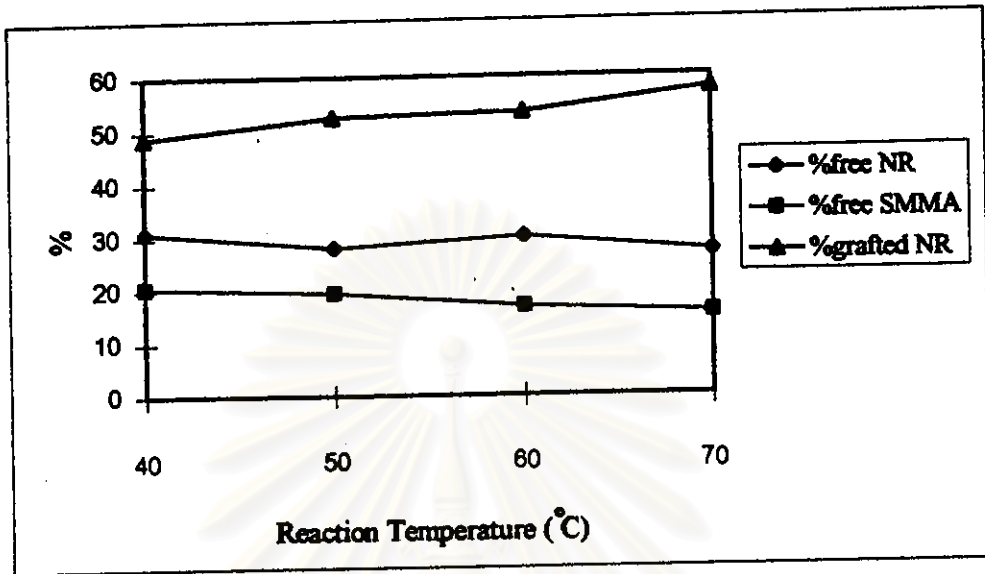| Grafting Properties	Reaction Temperature (°C)			
	40	50	60	70
Grafted Natural Rubber (%)	48.7	52.6	53.3	57.6
Free Natural Rubber (%)	30.9	28.0	29.9	27.0
Free S/MMA (%)	20.5	19.4	16.8	15.4
Degree of monomer conversion (%)	54.1	74.9	76.3	79.5
Grafting efficiency (%)	41.1	57.1	61.0	65.3
Graft ratio (g.g^{-1})	0.41	0.89	0.97	0.99

Figure 4.5a Effect of reaction temperature on the percent grafted NR, percent free NR, and percent free S/MMA.
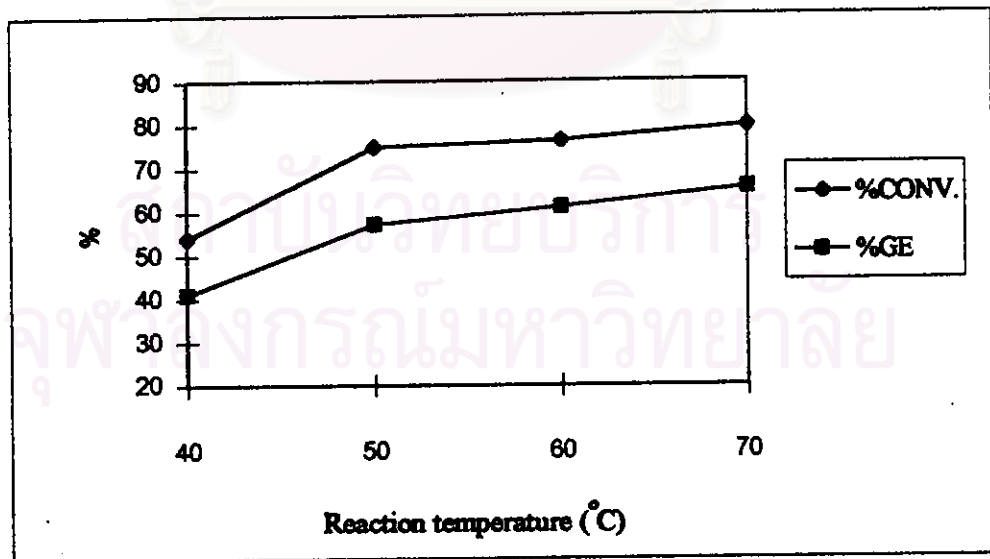

Figure 4.5b Effect of reaction temperature on the degree of monomer conversion and grafting efficiency.
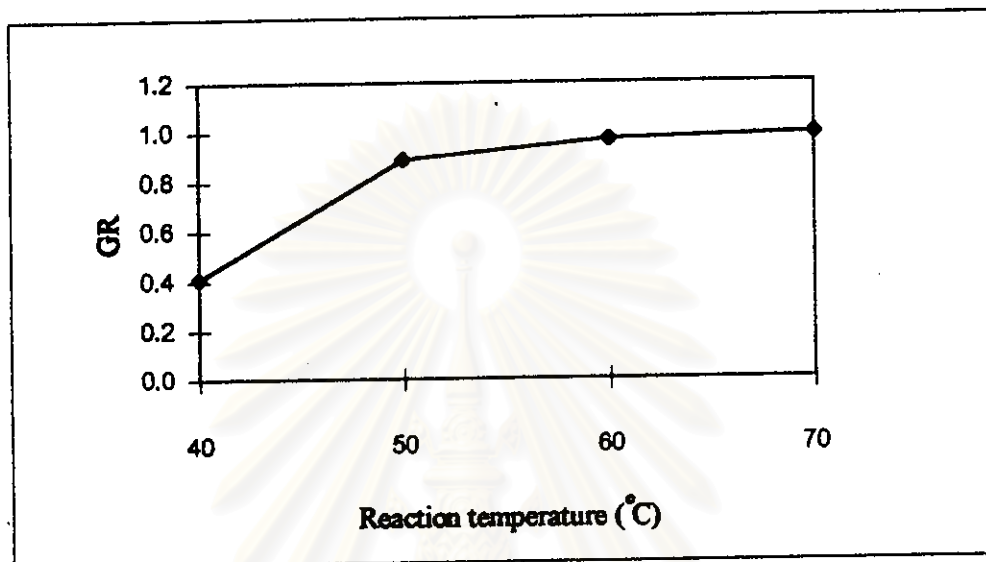
Figure 4.5c Effect of reaction temperature on the graft ratio.

4.2.4.2 Effect of Reaction Temperature on the Free S/MMA Chain Length and Graft Frequency

The free S/MMA chain length was determined by the method of H. Nai-Jen and C.S. Donald [20]. The ungrafted S/MMA was clearly evidence in the low molecular weight peak, eluting at about 800-1,000 sec. After appropriate peak fitting, this distribution was analyzed for molecular weight parameter using the MAXIMUM-820 software supplied with the chromatography and utilizing the results from column calibration with narrow distribution PS standard (Scientific Polymer Products). For the reaction temperature of 40°C the molecular weight of free S/MMA determined by GPC method were as follows : $\overline{M}_n$ = 121,907, $\overline{M}_w$ = 677,630, $\overline{M}_z$ = 2,174,102, $\overline{M}_w/\overline{M}_n$ = 5.55. The effect of reaction temperature on the average molecular weight of free S/MMA is shown in Table 4.6 and Figure 4.6. The free S/MMA chain length is proportional with the molecular weight. The details of all data are shown in Appendix C.

The graft frequency is the number of backbone polymer repeating units between graft chains. The graft frequency was calculated by knowing the total number of graft chains per backbone chain, both derived from the molecular weight analysis. The effect of reaction temperature on the graft frequency is shown in Table 4.6 and Figure 4.7. The details of all data and calculations are shown in Appendix B.

The value of graft frequency decreased with increasing reaction temperatures because at high temperature, the initiator could easily decompose to form free radicals. These newly-formed free radicals are very active to abstract hydrogen radicals on the natural rubber backbone. Many active sites are then produced with a few reeating units between two chains. Therefore, the repeating units between grafted chains decreased with increasing the reaction temperature.

Table4.6 Effect of reaction temperature on molecular weight of free S/MMA and graft frequency.

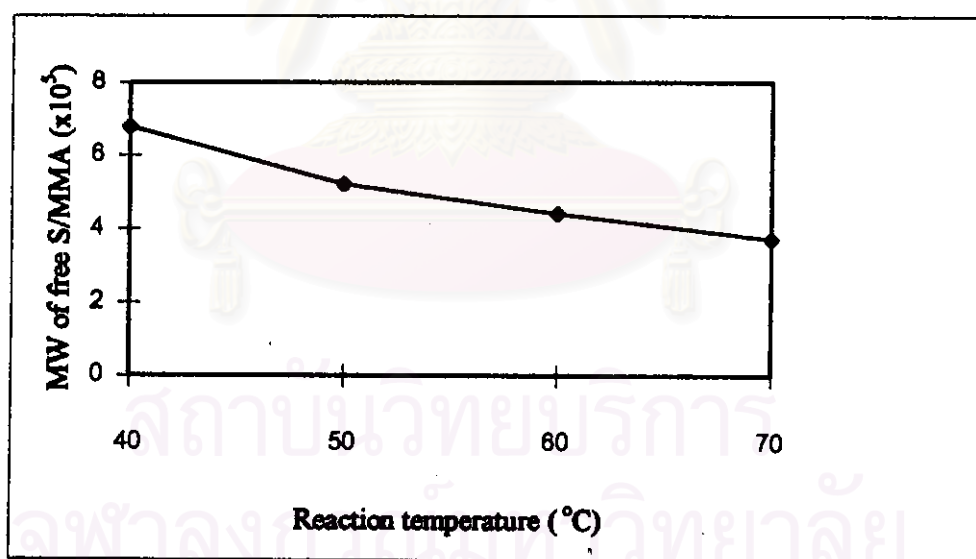| Temp.	MW of free S/MMA				Graft
(°C)	$\overline{M_n}$	$\overline{M_w}$	$\overline{M_z}$	$\overline{M_w}/\overline{M_n}$	Frequency
40	121,907	677,630	2,174,102	5.55	4,349
50	91,790	520,691	2,146,770	5.67	1,734
60	101,063	439,117	1,549,824	4.34	1,538
70	87,546	370,165	1,503,207	4.22	1,303

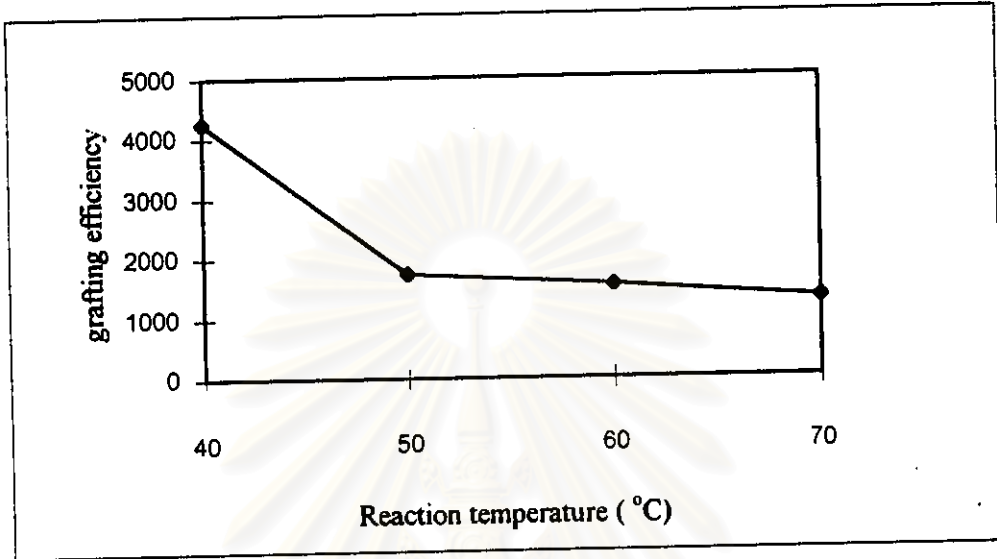Figure 4.6 Effect of reaction temperature on molecular weight of free S/MMA.

Figure 4.7 Effect of reaction temperature on the graft frequency.

4.2.4.3 Effect of Reaction Temperature on the Copolymer Composition of Grafted Natural Rubber (NR-*g*-S/MMA)

The composition of grafted natural rubber was determined by FT-IR, FT-NMR, and CHO analyzer. FT-IR was used to study the functional groups in the grafted natural rubber. FT-NMR and CHO analyzer were used to determine the percent of styrene, isoprene, and methyl methacrylate in the grafted natural rubber.

1. Functional Groups in the Grafted natural rubber

The functional groups in the grafted natural rubber were investigated by FT-IR. The FT-IR spectrum in the region of 4000-500 cm^{-1} for grafted natural rubber was shown in Figure 4.8 and the assignment was given in Table 4.7. It exhibited the characteristic absorption bands of $R_2C=CHR$ of isoprene at 810 cm^{-1} and C=O stretching vibration at 1750 cm^{-1} and C=C stretching vibration at 1510 cm^{-1}. The peaks in grafted natural rubber appeared at 1750 and 1510 cm^{-1}, due to carbonyl group (C=O stretching) of methyl methacrylate and C=C stretching of benzene ring of styrene which methyl methacrylate and styrene were grafted onto natural rubber backbone. This confirms the occurance of grafting.

Table 4.7 The important characteristic assignment peaks for the FT-IR spectrum of the grafted natural rubber.

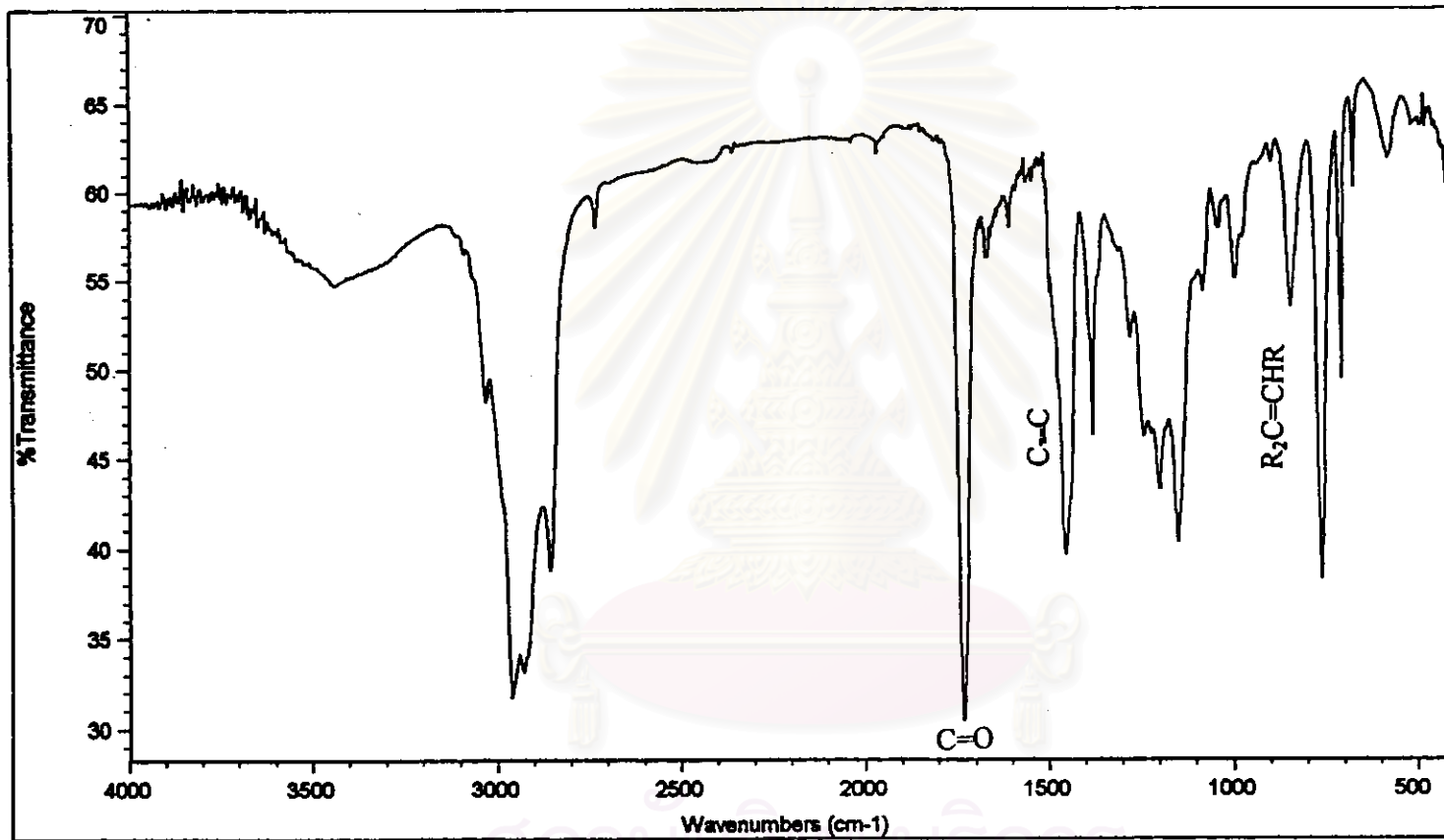| Wave number (cm^{-1})	Assignment
810	$R_2C=CHR$ of isoprene
1510	C=C stretching of benzene ring of styrene
1750	C=O stretching of methyl methacrylate

Figure 4.8 The FT-IR spectrum (KBr) of grafted natural rubber.

2. NMR Measurement

The copolymer composition of grafted natural rubber was determined by NMR. The grafted natural rubber samples were dissolved with CDCl$_3$. The methyl methacrylate/isoprene/styrene ratio of grafted natural rubber was determined by the signal area of ^{1}H-NMR spectra.

Signal area at

7.0 ppm : aromatic protons of styrene

5.2 ppm : C=CH proton of isoprene

3.6 ppm : OCH$_3$ protons of methyl methacrylate

From the different signal areas, the methyl methacrylate/isoprene/styrene ratio can be calculated by using the following equations [17] :

styrene (S)   = $A_{\delta = 7.0}$ / 5

isoprene (I)   = $A_{\delta = 5.2}$ / 1

methyl methacrylate (MMA)   = $A_{\delta = 3.6}$ / 3

where A_δ is the total signal area.

The ratio of styrene, isoprene, and methyl methacrylate in the grafted natural rubber are shown in Table 4.8 at various reaction temperatures. The details of all data are shown in Appendix D.

3. Elemental Analyzer

The Elemental analyzer was also used to measure and calculate the copolymer composition. The ratios of styrene, isoprene, and methyl methacrylate were calculated by using the number of moles C, H, and O in the grafted natural rubber obtained from the analysis. The results of elemental analysis are shown in Table 4.8. The details of all data and calculations are shown in Appendix E.

Figure 4.9 a) (NMR method) and b) (Elemental analysis) show the effect of reaction temperature on the ratio of styrene, isoprene, and methyl methacrylate in the grafted natural rubber. The methyl methacrylate content increased with increasing the reaction temperature. The maximum of methyl methacrylate content was 24.6% (Elemental analysis) and 29.40% (NMR method) at 70°C. The styrene content also slightly increased with increasing the reaction temperature from 40 to 60°C and reached the maximum value at 70°C. These result imply that high reaction temperatures accelerated the less bulk species to polymerize than to graft on the rubber backbone.

Table 4.8 Effect of reaction temperature on the composition of grafted natural rubber.

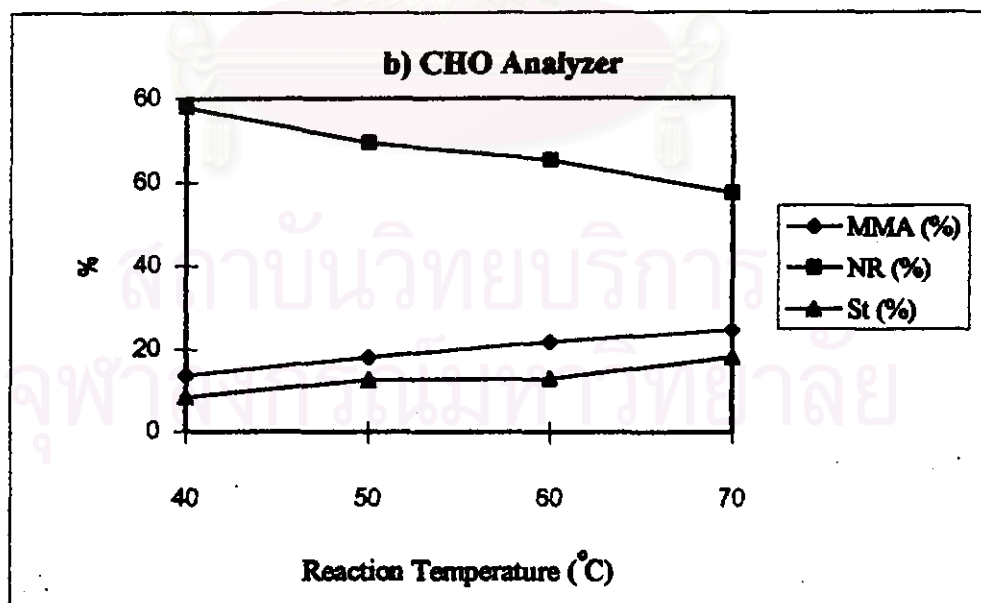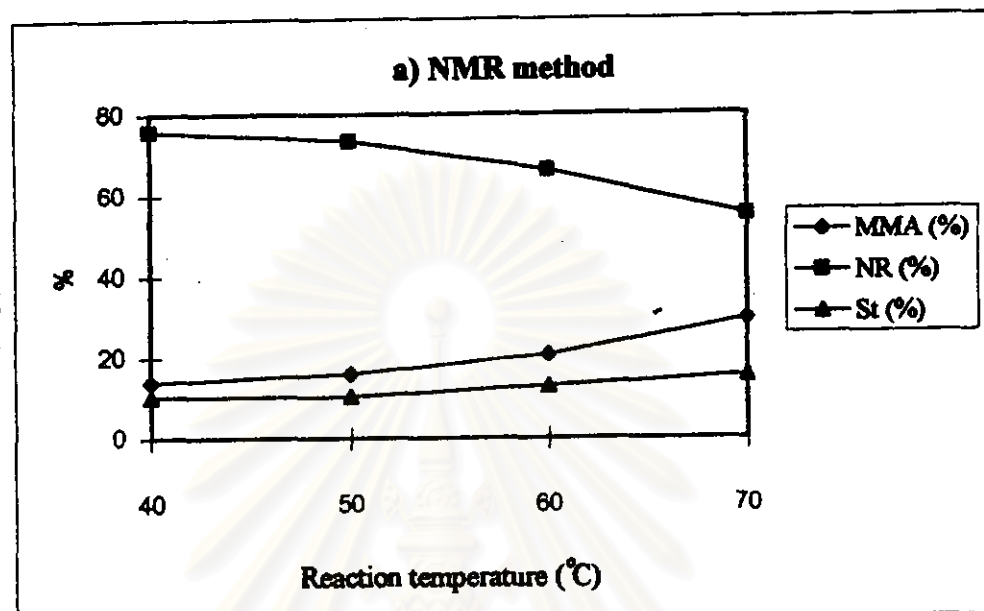| Reaction Temperature	Methyl methacrylate/Isoprene/Styrene	
(°C)	NMR method	CHO method
40	13.9 : 75.8 : 10.3	13.6 : 78.0 : 8.3
50	16.0: 73.5 : 10.5	18.0 : 69.4 : 12.7
60	20.7 : 66.3 : 13.0	21.8 : 65.3 : 12.9
70	29.4 : 55.1 : 15.5	24.6 : 57.4 : 18.0

Figure 4.9 Effect of reaction temperature on the composition of grafted natural rubber

a) NMR measurement b) Elemental analyzer

4.3 Thermal Properties of Grafted natural rubber

In the study, Differential Scanning Calorimetry (DSC), was used to obtain the glass transition temperature T_g (°C) of the grafted natural rubber. Figure 4.10 shows the DSC thermogram of grafted natural rubber synthesized at 70°C for 8 hours. The DSC measurements showed that T_g of natural rubber was observed at -65.4°C and single narrow transitions exhibited at 105.0°C, which was the T_g value of the random copolymers of styrene and methyl methacrylate [25].
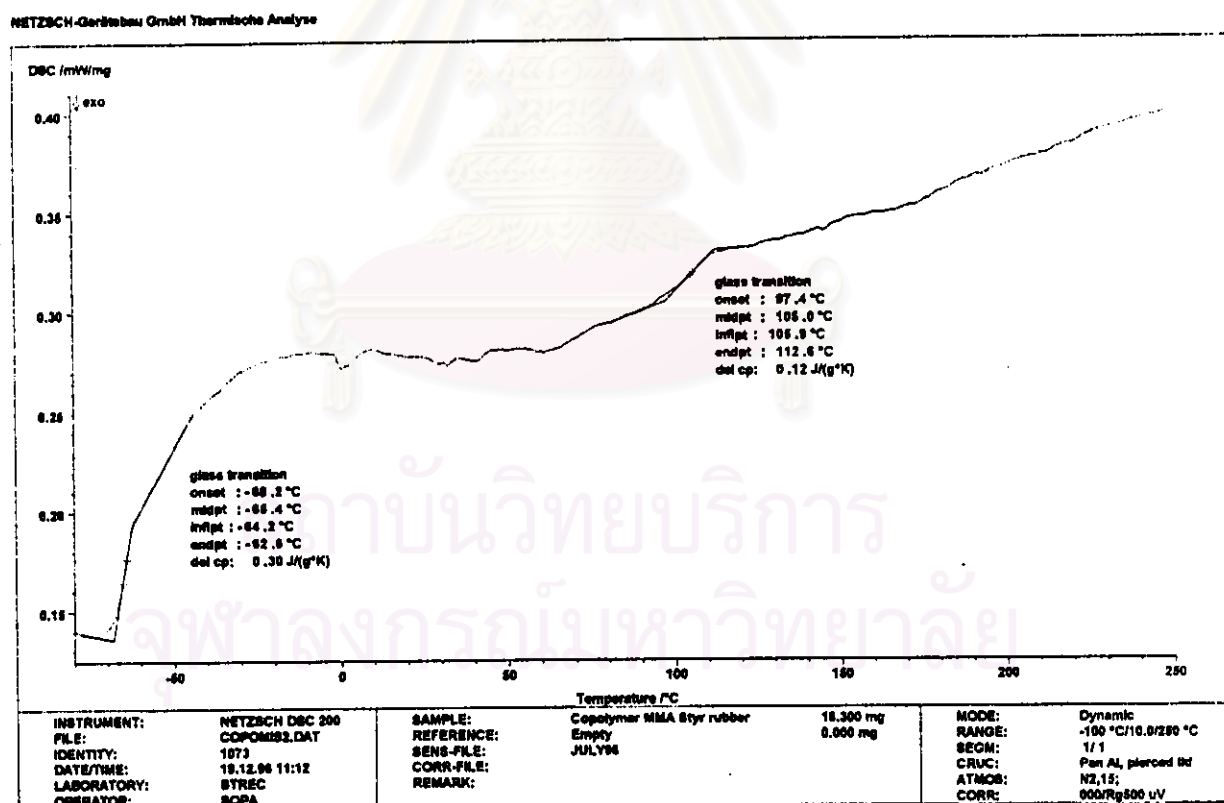

Figure 4.10 DSC thermogram of the grafted natural rubber : polymerization at 70°C

4.4 Blending of Grafted Natural Rubber and PVC

4.4.1 Properties of PVC and Grafted Natural Rubber Product

A suspension-type homopolymer of PVC having an intermediate average molecular weight or a K-value of 66 was used. It was supplied by Thai Plastic and Chemical Public co., Ltd. (TPC). Typical data of SG660 are shown in Table 4.9.

Table 4.9 Typical data of PVC SG660.

Properties	Test results
K-value	66 ± 1
Apparent bulk density	$0.547 \ kg/m^3$
Volatile matters	$< 0.2\%$
Impurities and foreign matter	2 point
Particle size	140 micrometer
Degree of polymerization	~ 1,000
Specific viscosity	0.55 g/cyclohexanone 25 °C

Source : Thai Plastic and Chemicals Public Co., Ltd. Samutprakarn. Tel.3859459.

The grafted natural rubber product was prepared by emulsion polymerization for 8 hours at 70°C. The basic formulation is as follow.

-amount of MMA and S (75 : 25)   : 100 parts by weight

-rubber content   : 100 parts by weight

-emulsifier concentration   : 1.5 parts by weight

-initiator concentration   : 1.5 parts by weight

The properties of the grafted natural rubber are shown in Table 4.5 and 4.8.

The grafted natural rubber products (5, 10, 15, and 20 phr) and PVC were prepared. The mechanical properties were investigated. The properties of MBS and PVC blends were compared.

4.4.2 Mechanical Properties of the PVC Blended with Grafted Natural Rubber Product and MBS

1. Tensile properties

The effects of the composition of PVC/grafted NR product blends and PVC/MBS blends on the mechanical properties were investigated. The value of tensile properties, impact strength, and hardness are shown in Table 4.10 and 4.11.

The effect of the impact modifier contents, grafted NR product and MBS on the tensile properties of PVC blends are shown in Figure 4.11a, 4.11b, and 4.11c. In Figure 4.11a and 4.11c, the tensile strength and the modulus decrease with increasing the grafted NR product and MBS content. Above 10 phr of grafted NR product and MBS, the tensile strength decrease slightly with increasing impact modifier content. The tensile strength and modulus decrease with increasing rubber content. This can be explained that the high toughness is obtained by the addition of an amorphous rubbery phase, but the stiffness and strength of the PVC are degraded.

In Figure 4.11b, the elongation at break increase with increasing the grafted NR product and MBS content. This can be explained that PVC is brittle thermoplastic (low percent strain), therefore the rubber component in grafted NR product and MBS, improved this elongation property of PVC component.

2. Hardness

The hardness of PVC/grafted NR product blends and PVC/MBS blends are presented in Figure 4.12. The hardness of blends decreased slightly with increasing rubber content. This can be explained that the rubber component in grafted natural rubber product and MBS had more elastic property, consequently the blends deformed easily.

3. Impact strength

From Figure 4.13, the impact strength increases with increasing impact modifiers (grafted NR product and MBS) content. At 20 phr impact modifier of grafted NR and MBS reaches maximum value of 427.3 and 455.4 respectively. Above 15 phr of impact modifiers, the impact strength increased slightly. Comparison between grafted NR product and MBS impact modifier, impact strength of PVC/MBS blends are higher than PVC/grafted NR product blends.

Impact strength is essentially a function of how readily cracks can be propagated within the matrix. When grafted NR product and MBS are present as impact modifier, they stretch as the crack passes by, thus dissipating much of the energy necessary to develop the new surface of the growing crack. The effect of a large number of impact modifiers content is to dissipate a large amount of energy. This makes crack propagation more difficult, leading to the increased impact strength.

The more grafted NR product and MBS content, the higher the impact strength of the blends. The appropriate impact modifiers (grafted NR product and MBS) content used are in the range of 10 and 15 phr.

For 15 phr of grafted NR product and PVC blend, the mechanical properties are as follow:

-Tensile strength   38.8 MPa

-Elongation at break   88.2 %

-Modulus   10236.5 MPa

-Hardness   35.5 N

-Impact strength   374.0 kJ/m^2

Table 4.10 Effect of grafted NR product content on the mechanical properties of the PVC/grafted natural rubber product blends.

Property	Grafted NR product content (phr)				
	0	5	10	15	20
Tensile strength (MPa)	48.9±0.39	41.9±0.32	40.2±0.36	38.8±0.25	37.7±0.22
Elongation at break (%)	61.4±0.40	68.7±0.27	71.9±0.24	88.2±0.24	97.8±0.24
Modulus (MPa)	20856.2±6.07	15096.7±2.11	13455.5±4.16	10236.5±2.87	6783.2±3.18
Hardness (N)	37.7±0.20	36.8±0.20	36.0±0.10	35.3±0.12	34.1±0.20
Izod impact strength (kJ/m^2)	270.2±0.17	288.8±0.05	303.9±0.18	374.0±0.12	427.3±0.06

Table 4.10 Effect of MBS content on the mechanical properties of the PVC/MBS blends.

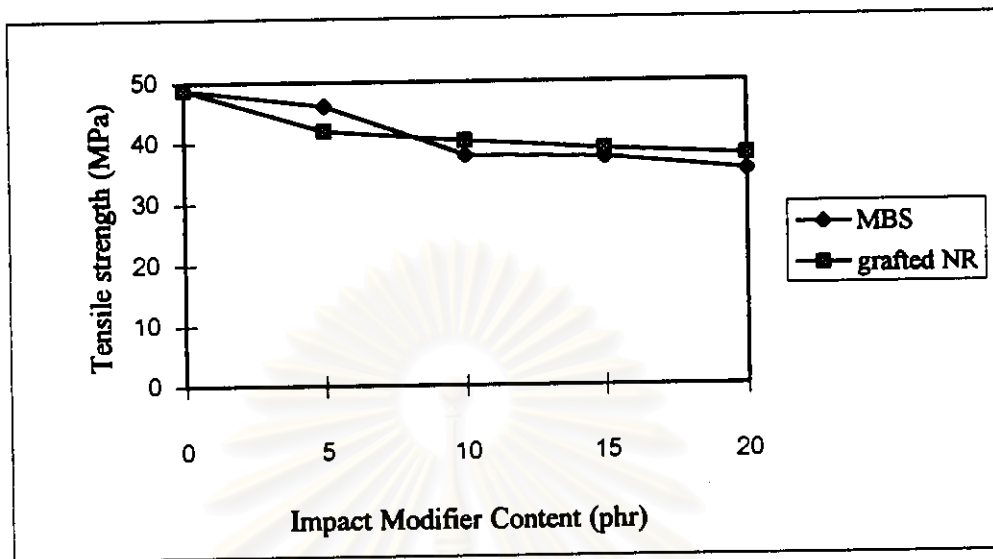| Property	MBS content (phr)				
	0	5	10	15	20
Tensile strength (MPa)	48.9±0.39	46.0±0.17	37.9±0.15	37.5±0.34	35.4±0.44
Elongation at break (%)	61.4±0.40	65.1±0.24	73.5±0.48	92.3±0.45	113.4±0.43
Modulus (MPa)	20856.2±6.07	17443.4±5.08	14285.0±2.88	11755.9±2.76	7775.4±2.52
Hardness (N)	37.7±0.20	36.8±0.12	36.1±0.20	35.1±0.10	34.6±0.20
Izod impact strength (kJ/m^2)	270.2±0.17	279.0±0.15	423.1±0.13	446.6±0.07	455.4±0.08

Figure 4.11a The tensile strength of PVC/grafted NR product blends and PVC/MBS blends.
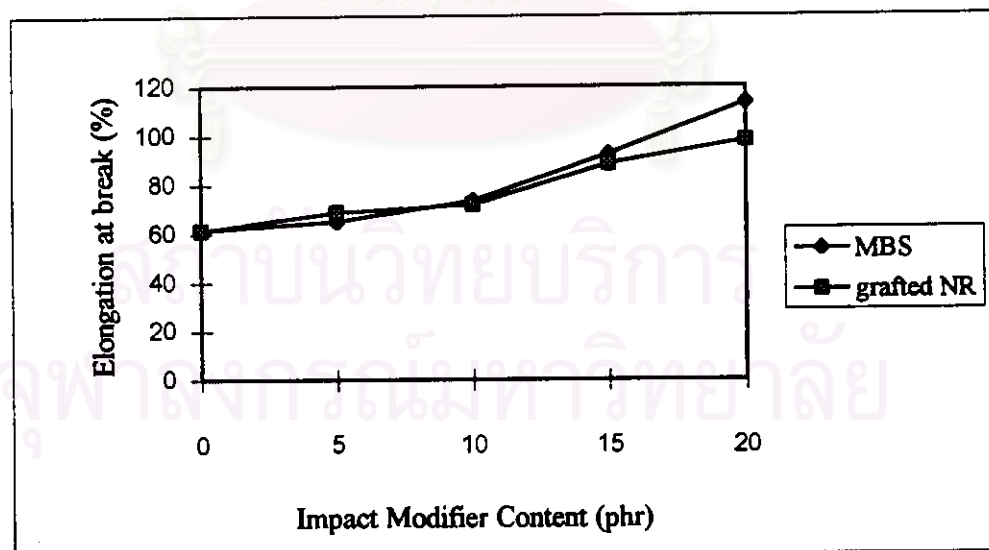

Figure 4.11b The elongation at break of PVC/grafted NR product blends and PVC/MBS blends.
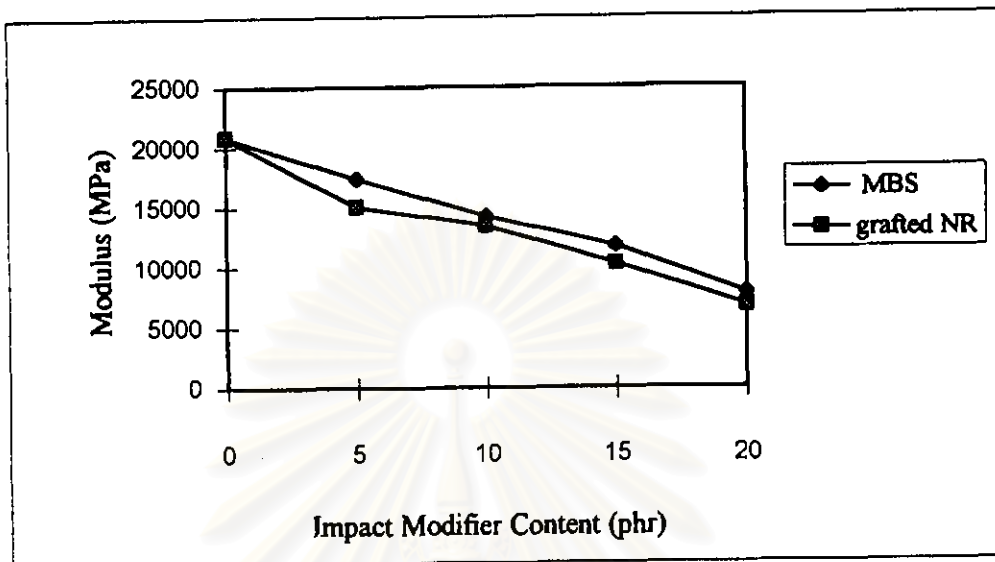
Figure 4.11c The modulus of PVC/grafted NR product blends and PVC/MBS blends.
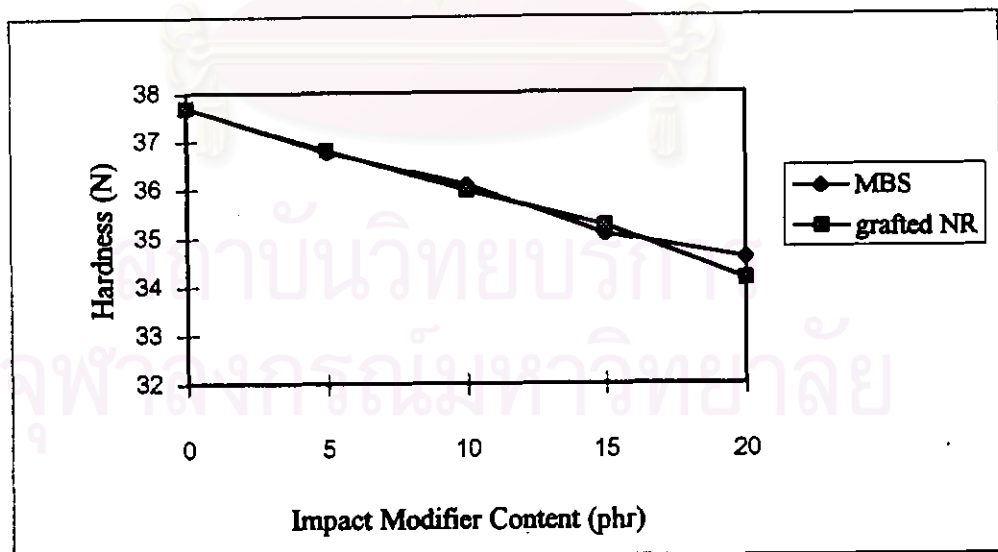

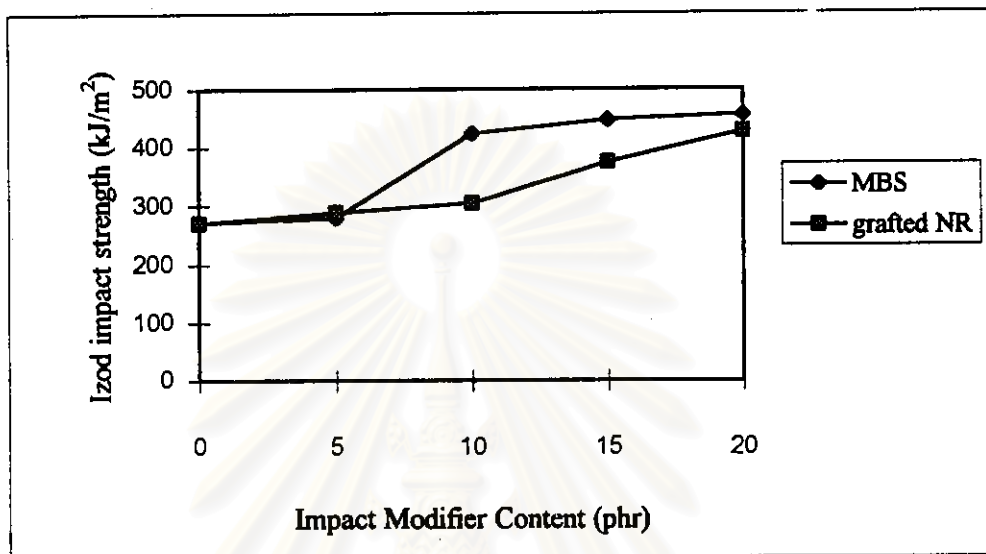**Figure 4.12** The hardness of PVC/grafted NR product blends and PVC/MBS blends.

Figure 4.13 The impact strength of PVC/grafted NR product blends and PVC/MBS blends.

4.4.3 Scanning Electron Microscopy (SEM)

The scanning electron microscope was employed to investigated the fracture surface of the specimen from the impact strength test. Figure 4.19 and 4.20 show the fracture surface of PVC/MBS blend and PVC/grafted NR product blend at 1.5 phr of MBS and grafted natural rubber product.

At 5000 x magnification, the SEM electron micrograph of the PVC/MBS blend (Figure 4.19) shows the distribution of MBS particles in PVC matrix. It can be seen the smooth fracture surface and well MBS particles distribution of the PVC/MBS blend.

At 5000 x magnification, the SEM electron micrograph of the PVC/grafted NR product blend (Figure 4.20) shows the distribution of grafted NR in PVC matrix. It can be seen the rough fracture surface of the PVC/grafted NR product blend. It seems to be a bulk grafted NR distribute in PVC matrix.
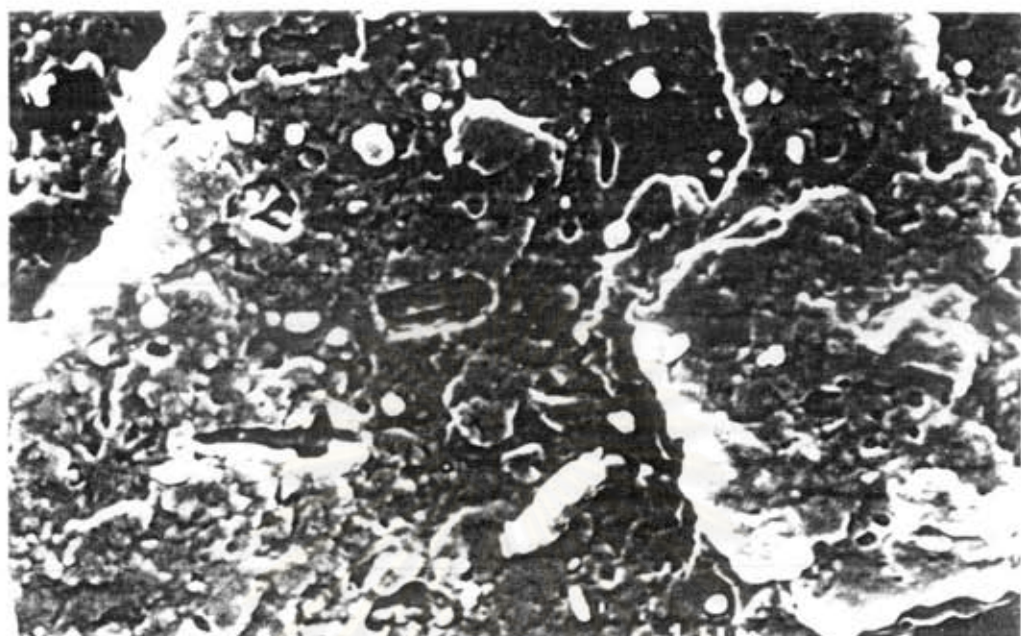
Figure 4.19 SEM photomicrograph of fracture surface of the PVC/MBS blend.

Figure 4.19 SEM photomicrograph of fracture surface of the PVC/grafted NR product blend.