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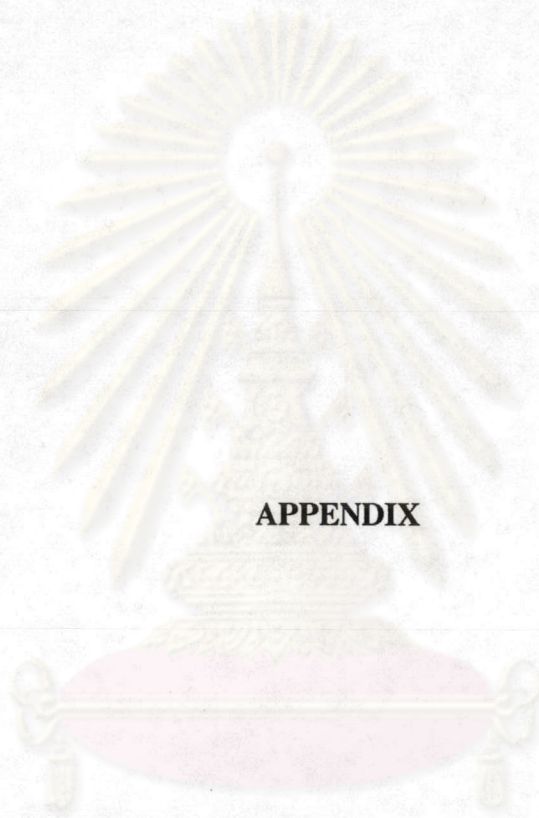
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APPENDIX

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## APPENDIX A

### 1. Determination the percentage of graft copolymer (or grafting efficiency) [36,37]

The graft copolymer are characterized by extraction with solvents. The product contains three components in quantities a, b, and c.

a is the weight of free rubber determined by Soxhlet extraction for 24 h with 60-80 °C petroleum ether.

b is the weight of graft copolymer determined from the residual weight after extraction of free homopolymers.

c is the weight of free PMMA removed after the extraction of free rubber by Soxhlet extraction with acetone for 24 h.

These quantities combined into a single expression which is the measure of the grafting efficiency or % graft copolymer.

$$\text{Grafting efficiency} = \frac{b}{a + b + c} \times 100$$

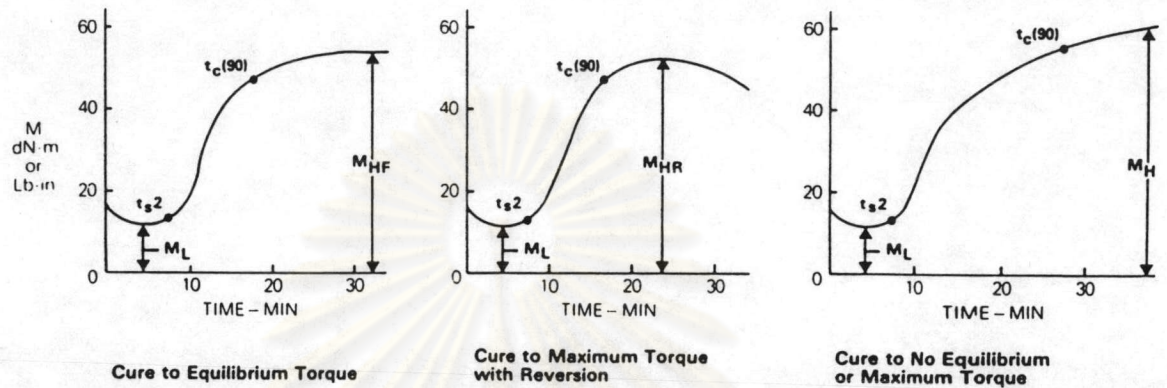
### 2. Determination the conversion of graft coplomerization

The graft reactions and resulting grafted samples are characterized according to the following parameter:

$$\text{Total Conversion (\%)} = \frac{\text{Total weight of polymer formed}}{\text{Weight of monomer charged}} \times 100$$

## APPENDIX B

### 1. Cure characteristics of rubber compounds



**Figure B1** Types of Cure Curve [40]

### 2. Cure Characteristic interpretation [40]

The following measurements, as defined by ASTM D-2084, may be taken from a Monsanto rheograph.

2.1 Minimum Torque,  $M_L$ , (dN.m or lbf.in) - A measure of the flow characteristic/viscosity of unvulcanized compound.

2.2 Maximum Torque - A measure of shear modulus or stiffness of the fully cured compound.

$M_{HF}$  = maximum torque where curve plateaus, (dN.m or lbf.in)

$M_{HR}$  = maximum torque of reverting curve, (dN.m or lbf.in)

$M_H$  = highest torque attained during specified period of time when no plateau or maximum torque is obtained, (dN.m or lbf.in).



### 2.3 Scorch time:

$ts_1$  = minutes to 1 (dN.m or lbf.in) rise above  $M_L$ , usually used with  $1^\circ$  arc.

$ts_2$  = minutes to 2 (dN.m or lbf.in) rise above  $M_L$ , usually used with  $3^\circ$  and  $5^\circ$  arc.

2.4 Cure time: (Time to a percentage of full Cure - An inverse measure of cure rate, based on time to develop some percentage of the highest torque.

$t_x$  = minutes to  $x\%$  of maximum torque,  $t_x = \text{minutes to } XM_x/100$ .

$t'_x$  = minutes to  $x\%$  of torque increase,  $t'_x = \text{minutes to } M_L + x(M_H - M_L)/100$  torque.

2.5 CRI, Cure Rate Index - A measure of cure rate based on the linear slope the rising curve,  $CRI = 100/(\text{cure time} - \text{scorch time})$ .

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## APPENDIX C

## 1. Physical Properties of GNR/PVC Vulcanizates

Table C1 The summary of 300% Modulus (MPa) of GNR/PVC blends.

GNR/PVC ratio	Grafted NR type			
	NR	GNR-20	GNR-40	GNR-60
<b>1) PVC-P00</b>				
-100:00	2.11 (0.93)	4.43 (1.81)	16.00(10.72)	18.87 (9.83)
-90:10	2.13 (2.67)	2.00 (1.42)	14.11(11.31)	13.42 (9.12)
-80:20	1.52 (0.90)	2.28 (0.89)	-	-
-60:40	-	3.49 (0.33)	-	-
-40:60	-	-	-	-
-00:100	-	-	-	-
<b>2) PVC-P20</b>				
-100:00	2.11 (0.93)	4.43 (1.18)	16.00(10.73)	18.87 (9.83)
-90:10	1.93 (2.01)	5.61 (4.08)	14.86 (6.40)	18.98(17.27)
-80:20	3.03 (0.77)	9.94 (4.96)	20.73(11.61)	20.88 (7.23)
-60:40	3.73 (1.31)	16.59 (7.33)	-	-
-40:60	-	-	-	-
-00:100	-	-	-	-
<b>3) PVC-P40</b>				
-100:00	2.11 (0.93)	4.43 (1.18)	16.00(10.73)	18.87 (9.83)
-90:10	2.11 (0.77)	6.63 (3.27)	17.24 (8.08)	20.00 (9.81)
-80:20	2.69 (2.78)	7.62 (1.95)	20.98 (7.08)	20.00 (5.00)
-60:40	-	13.60 (4.61)	-	-
-40:60	3.32 (0.81)	-	-	-
-00:100	23.11 (5.01)	23.11 (5.01)	23.11 (5.01)	23.11 (5.01)

**Table C2** The summary of Tensile Strength (MPa) of GNR/PVC blends.

GNR/PVC ratio	Grafted NR type			
	NR	GNR-20	GNR-40	GNR-60
<b>1) PVC-P00</b>				
-100:00	24.86 (0.13)	27.68 (0.34)	31.37 (1.29)	27.68 (0.71)
-90:10	10.95 (0.66)	7.82 (0.08)	16.14 (0.59)	14.01 (0.69)
-80:20	6.81 (0.37)	7.15 (0.23)	11.68 (0.73)	16.82 (0.56)
-60:40	-	5.59 (0.24)	9.80 (0.23)	15.75 (0.54)
-40:60	-	-	9.23 (0.51)	14.66 (0.63)
-00:100	-	-	-	-
<b>2) PVC-P20</b>				
-100:00	24.86 (0.13)	27.68 (0.34)	31.37 (1.29)	27.68 (0.71)
-90:10	16.12 (0.92)	20.08 (2.09)	22.51 (1.21)	21.80 (0.07)
-80:20	15.86 (1.57)	22.63 (0.39)	22.60 (0.40)	22.00 (0.34)
-60:40	11.41 (0.88)	16.74 (0.85)	17.37 (0.26)	19.15 (1.05)
-40:60	4.04 (0.59)	12.51 (0.26)	16.81 (0.73)	20.54 (0.32)
-00:100	31.34 (0.37)	31.34 (0.37)	31.34 (0.37)	31.34 (0.37)
<b>3) PVC-P40</b>				
-100:00	24.86 (0.13)	27.68 (0.34)	31.37 (1.29)	27.68 (0.71)
-90:10	17.40 (1.89)	20.92 (0.99)	23.79 (1.62)	25.37 (0.38)
-80:20	17.42 (1.46)	20.74 (0.58)	22.17 (0.90)	21.36 (0.49)
-60:40	7.18 (0.35)	18.15 (1.15)	18.66 (0.32)	16.95 (0.28)
-40:60	4.72 (0.02)	13.51 (0.37)	15.73 (0.35)	17.69 (0.28)
-00:100	23.32 (5.24)	23.32 (5.24)	23.32 (5.24)	23.32 (0.52)



**Table C3** The summary of Elongation at break (%) of GNR/PVC blends.

GNR/PVC ratio	Grafted NR type			
	NR	GNR-20	GNP-40	GNR-60
<b>1) PVC-P00</b>				
-100:00	780 (28.58)	680 (17.68)	530 (22.08)	329 (14.35)
-90:10	628 (23.50)	651 (30.38)	448 (33.00)	322 (9.36)
-80:20	520 (16.05)	635 (9.75)	225 (13.83)	178 (8.81)
-60:40	-	490 (5.74)	101 (2.17)	74 (9.90)
-40:60	-	-	28 (2.24)	31 (2.24)
-00:100	-	-	-	-
<b>2) PVC-P20</b>				
-100:00	780 (28.58)	680 (17.68)	530 (22.08)	329 (14.35)
-90:10	820 (8.16)	618 (34.37)	453 (30.52)	311 (6.85)
-80:20	711 (14.43)	583 (30.09)	322 (13.91)	323 (14.23)
-60:40	589 (25.02)	304 (2.49)	177 (11.09)	182 (8.04)
-40:60	53 (2.59)	154 (2.24)	80 (8.44)	109 (2.16)
-00:100	172 (7.46)	172 (7.46)	172 (7.46)	172 (7.46)
<b>3) PVC-P40</b>				
-100:00	780 (28.58)	680 (17.68)	530 (22.08)	329 (14.35)
-90:10	827 (12.47)	680 (25.50)	537 (36.82)	364 (17.68)
-80:20	797 (2.78)	563 (26.56)	313 (7.05)	324 (10.74)
-60:40	1088 (24.78)	388 (12.36)	242 (1.09)	222 (7.56)
-40:60	352 (0.61)	227 (12.93)	168 (3.70)	210 (1.25)
-00:100	309 (11.36)	309 (11.36)	309 (11.36)	309 (11.36)

**Table C4** The summary of Tear Strength (N/mm) of GNR/PVC blends.

GNR/PVC ratio	Grafted NR type			
	NR	GNR-20	GNR-40	GNR-60
<b>1) PVC-P00</b>				
-100:00	33.51 (1.20)	41.43 (3.14)	60.37 (2.29)	77.71 (0.70)
-90:10	28.84 (0.71)	41.12 (3.88)	44.29 (0.59)	52.11 (4.15)
-80:20	25.26 (0.79)	39.40 (2.18)	38.86 (1.53)	56.09 (6.97)
-60:40	-	32.39 (1.54)	42.60 (3.44)	47.44 (0.45)
-40:60	-	-	38.23 (3.24)	47.73 (0.88)
-00:100	-	-	-	-
<b>2) PVC-P20</b>				
-100:00	33.51 (1.20)	41.43 (3.14)	60.37 (2.29)	77.71 (0.70)
-90:10	30.00 (0.87)	38.69 (4.37)	44.15 (2.56)	62.70 (5.02)
-80:20	28.84 (1.22)	47.10 (3.23)	48.12 (2.47)	59.70 (1.47)
-60:40	28.21 (1.39)	35.05 (2.82)	32.13 (2.06)	36.56 (1.63)
-40:60	34.15 (0.63)	30.49 (0.80)	27.57 (0.92)	62.13 (3.25)
-00:100	174.84(1.95)	174.84(1.95)	174.84(1.95)	174.84(1.95)
<b>3) PVC-P40</b>				
-100:00	33.51 (1.20)	41.43 (3.14)	60.37 (2.29)	77.71 (0.70)
-90:10	30.58 (3.02)	35.22 (3.30)	42.78 (2.57)	63.20 (5.30)
-80:20	32.77 (0.79)	38.12 (1.27)	45.86 (2.75)	49.05 (6.44)
-60:40	31.32 (2.63)	38.97 (0.43)	41.98 (1.90)	45.59 (4.35)
-40:60	33.32 (0.29)	32.44 (1.71)	38.42 (1.81)	51.25 (5.31)
-00:100	94.12 (2.95)	94.12 (2.95)	94.12 (2.95)	94.12 (2.95)



**Table C5** The summary of Hardness (IRHD) of GNR/PVC blends.

GNR/PVC ratio	Grafted NR type			
	NR	GNR-20	GNR-40	GNR-60
<b>1) PVC-P00</b>				
-100:00	27.00 (0.08)	31.60 (0.22)	72.17 (0.39)	95.83 (0.21)
-90:10	39.92 (0.18)	47.84 (0.21)	62.26 (1.18)	95.14 (0.14)
-80:20	43.40 (1.26)	50.90 (0.64)	65.88 (0.12)	96.02 (0.23)
-60:40	-	67.48 (1.13)	82.92 (0.86)	97.58 (0.38)
-40:60	-	-	98.04 (0.23)	99.54 (0.05)
-00:100	-	-	-	-
<b>2) PVC-P20</b>				
-100:00	27.00 (0.08)	31.60 (0.22)	72.17 (0.39)	95.83 (0.21)
-90:10	37.36 (0.48)	44.62 (0.12)	60.28 (0.37)	92.60 (0.23)
-80:20	44.86 (0.08)	49.88 (0.32)	65.30 (0.55)	94.68 (0.66)
-60:40	65.20 (0.58)	67.28 (1.41)	75.28 (0.56)	95.42 (0.40)
-40:60	97.06 (0.50)	83.02 (0.27)	95.60 (0.24)	99.52 (0.07)
-00:100	-	-	-	-
<b>3) PVC-P40</b>				
-100:00	27.00 (0.08)	31.60 (0.22)	72.17 (0.39)	95.83 (0.21)
-90:10	37.12 (0.32)	45.48 (0.37)	59.20 (0.54)	91.72 (0.41)
-80:20	41.96 (0.61)	49.28 (0.17)	63.28 (0.23)	94.70 (0.28)
-60:40	59.30 (2.41)	62.44 (0.34)	73.52 (0.35)	93.60 (0.55)
-40:60	68.25 (1.25)	74.58 (0.42)	87.26 (4.09)	97.30 (0.57)
-00:100	-	-	-	-

2. Abrasion resistance of PVC/GNR vulcanizates

**Table C6** The summary of Abrasion resistance, Taber abraser type  
(Volume loss, cm<sup>3</sup> / 2000 cycles) of GNR/PVC blends.

GNR/PVC ratio	Grafted NR type			
	NR	GNR-20	GNR-40	GNR-60
<b>1) PVC-P00</b>				
-100:00	0.0163(0.010)	0.0122(0.001)	0.0139(0.001)	0.1049(0.029)
-90:10	-	-	0.0048( - )	0.1617(0.003)
-80:20	-	0.3078(0.001)	0.0251(0.000)	0.2105(0.017)
-60:40	-	0.3169(0.046)	0.2335(0.000)	0.2722(0.035)
-40:60	-	-	0.2762(0.016)	0.2766(0.019)
-00:100	-	-	-	-
<b>2) PVC-P20</b>				
-100:00	0.0163(0.010)	0.0122(0.001)	0.0139(0.001)	0.1049(0.029)
-90:10	-	-	0.0089(0.003)	0.2895(0.003)
-80:20	0.9356(0.147)	0.2171(0.056)	0.0262(0.004)	0.2368(0.009)
-60:40	1.4811( - )	0.2658(0.003)	0.3991(0.042)	0.4338(0.029)
-40:60	0.7656(0.070)	0.5136(0.096)	0.4252(0.034)	0.5370(0.068)
-00:100	-	-	-	-
<b>3) PVC-P40</b>				
-100:00	0.0163(0.010)	0.0122(0.001)	0.0139(0.001)	0.1049(0.029)
-90:10	-	-	0.0152(0.001)	0.2405(0.017)
-80:20	0.6641(0.404)	0.0556(0.013)	0.1278(0.031)	0.3755(0.019)
-60:40	0.9325(0.046)	0.6117(0.010)	0.3827(0.006)	0.5541(0.002)
-40:60	0.7648(0.025)	0.7546(0.093)	0.4829(0.037)	0.5523(0.005)
-00:100	-	-	-	-



### 3. Solvent resistance of NR and GNR/PVC vulcanizates

**Table C7** The summary of % Solvent Swelling of modified NR vulcanizates.

Rubber compounds	Change in mass, %
NR	308.04 (1.36)
GNR-20	242.97 (1.79)
GNR-40	212.70 (3.62)
GNR-60	190.82 (1.28)

**Table C8** The summary of % Solvent Swelling of GNR/PVC-P40 blends (60/40, 40/60)

GNR/PVC-P40 blends	Change in mass, %	
	( 60/40 )	( 40/60 )
NR	137.50 (2.04)	82.33 (0.72)
GNR-20	123.72 (0.98)	71.34 (2.02)
GNR-40	113.44 (0.51)	64.10 (0.26)
GNR-60	101.25 (2.28)	49.99 (0.24)

**Table C9** The summary of % Solvent Swelling of GNR-40/PVC blends (60/40 ratio)

GNR-40/PVC blends	Change in mass, %
PVC-P00	157.14 (0.25)
PVC-P20	123.83 (3.38)
PVC-P40	113.44 (0.51)

**Table C10** The summary of % Solvent Swelling of GNR40/PVC-P40 blends.

GNR40/PVC-P40 ratio	Change in mass, %
100 : 00	212.70 (3.62)
90 : 10	206.80 (5.43)
80 : 20	174.87 (0.99)
60 : 40	113.44 (0.51)
40 : 60	64.10 (0.26)

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