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## APPENDICES

## APPENDIX A

**Table A-1** Material Specification of Calcium Carbonate Omyacarb 2.

Properties	Specification
Specific gravity	2.7
Particle size (avg), $\mu\text{m}$	2.9
Moisture content, %wt	< 0.2
CaCO <sub>3</sub> , %wt	$\geq 98.5$
MgO, %wt	< 1.5
Iron oxide, %wt	< 0.03
Acid insoluble, % wt	< 0.2
Surface modification	-

**Table A-2** Material Specification of Silica Tokusil UR-T.

Properties	Specification
Bulk density, g/ml	0.20-0.24
BET surface area, m <sup>2</sup> /g	150-180
Moisture content, %wt	< 8
SiO <sub>2</sub> , %wt	$\geq 97$
Na <sub>2</sub> SO <sub>4</sub> , %wt	< 1.8
Fe <sub>2</sub> O <sub>3</sub> , %wt	< 0.1
Loss on ignition, % wt	< 14
PH (5% suspension)	6.70-7.30
Whiteness	96

**Table A-3** Material Specification of Carbon Black Thaiblack N330.

Properties	Test Result
Iodine no., mg/g	81.1
DBP, cc/100g	103.00
24M4 DBP, cc/100g	84.5
Tint strength, %IRB#3	104.1
Heating loss, % max	0.5
Ash content, %max	0.21
Pour density, kg/m <sup>3</sup>	368.8
Fine content, %max	4.0
P. hardness, g	16.2
Sieve residue #325, % max	0.0105
Sieve residue #35, % max	0.0000

## APPENDIX B

### Mechanical Properties of Natural Rubber Composites.

**Table B-1** Tensile Strength of Compound according to ASTM D412-98a.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Tensile strength (MPa)	23.61	23.17	27.48	27.98	29.32	24.47	24.21	26.08	24.38	25.27	22.32	12.83	25.12	28.78	26.40	18.44	28.73
	24.40	23.65	27.49	32.25	24.57	24.71	23.50	22.78	27.50	25.57	22.82	16.03	25.95	25.20	25.03	18.43	27.31
Mean	23.89	25.70	26.20	27.47	28.18	24.99	24.52	26.37	24.31	25.55	22.34	15.70	23.68	26.51	21.47	11.89	29.44
SD.	23.97	24.17	27.06	29.23	27.36	24.72	24.08	25.08	25.40	25.46	22.49	14.85	24.92	26.83	24.30	16.25	28.49
	0.40	1.34	0.74	2.62	2.48	0.26	0.52	1.99	1.82	0.17	0.28	1.76	1.15	1.81	2.54	3.78	1.08

**Table B-2** Ultimate Elongation of Compound according to ASTM D412-98a.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Ultimate elongation (%)	775.2	654.4	705.6	738.7	873.0	778.7	654.6	691.6	624.9	749.3	724.6	752.5	658.0	553.6	718.2	634.7	435.0
	679.5	689.3	722.7	775.0	757.0	655.1	697.3	614.2	666.7	818.7	766.9	641.8	646.4	699.6	659.6	633.8	476.0
Mean	720.9	600.0	666.7	734.2	669.3	702.4	653.1	668.4	696.8	612.0	732.0	618.3	702.9	705.6	686.7	574.0	420.0
SD.	725.2	647.9	698.3	749.3	766.4	712.1	668.3	658.1	662.8	726.7	741.2	670.9	669.1	652.9	688.2	614.2	443.7
	48	45	29	22	52	62	25	40	36	65	23	72	30	86	29	35	29

**Table B-3** 100% Modulus of Compound according to ASTM D412-98a.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Modulus	1.03	1.27	1.34	1.36	1.45	1.29	1.23	1.34	1.44	1.41	1.30	0.89	1.14	1.16	1.26	1.27	3.01
100 %	1.08	1.31	1.28	1.33	1.40	1.40	1.05	1.29	1.38	1.23	1.29	1.06	1.29	1.28	1.25	1.23	3.62
( MPa)	1.07	1.43	1.32	1.25	1.48	1.49	1.29	1.39	1.28	1.44	1.23	1.00	1.08	1.23	1.29	1.13	3.28
Mean	1.06	1.33	1.31	1.31	1.44	1.39	1.19	1.34	1.37	1.36	1.27	0.98	1.17	1.22	1.27	1.21	3.31
SD.	0.03	0.08	0.03	0.06	0.04	0.10	0.12	0.05	0.08	0.11	0.04	0.09	0.11	0.06	0.02	0.07	0.31

**Table B-4** 300% Modulus of Compound according to ASTM D412-98a.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Modulus	2.58	3.35	3.84	3.69	3.32	3.90	3.78	3.70	4.11	3.57	3.61	2.16	3.04	2.98	3.87	3.66	13.92
300 %	2.91	3.49	3.82	4.03	4.21	3.11	3.46	3.47	4.00	2.96	3.44	2.64	3.67	3.39	3.24	3.58	13.29
( MPa)	2.98	4.04	3.83	3.79	4.48	3.38	3.93	3.95	3.70	3.94	3.38	2.57	2.93	3.36	3.10	3.14	14.87
Mean	2.82	3.63	3.83	3.84	4.00	3.46	3.72	3.71	3.94	3.49	3.48	2.46	3.21	3.24	3.41	3.46	14.03
SD.	0.21	0.36	0.01	0.17	0.61	0.40	0.24	0.24	0.21	0.49	0.12	0.26	0.40	0.23	0.41	0.28	0.80

**Table B-5** Tear Strength of Compound according to ASTM D624.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Maximum strength	44.08	42.38	45.95	45.47	44.20	38.99	46.38	47.61	42.44	43.23	51.16	40.16	43.24	39.53	44.23	39.16	97.21
( N/mm )	43.98	44.81	46.96	46.01	46.22	37.64	46.45	46.59	42.90	42.63	49.25	38.93	42.24	41.85	41.09	39.62	71.84
Mean	46.21	44.81	43.15	47.04	45.00	35.27	44.38	46.49	42.83	44.88	52.22	39.17	43.35	40.65	43.86	39.10	84.23
SD.	44.76	44.00	45.35	46.17	45.14	37.30	45.74	46.90	42.72	43.58	50.88	39.42	42.94	40.68	43.06	39.29	84.43
	1.26	1.40	1.97	0.80	1.02	1.88	1.18	0.62	0.25	1.17	1.51	0.65	0.61	1.16	1.72	0.28	12.69



**Table B-6** Hardness (shore A) of Compound according to ASTM D2240-97.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Hardness (Shore A)	50.00	50.00	53.50	52.00	51.00	53.00	49.50	51.00	51.50	50.50	55.00	49.00	51.50	51.00	54.00	54.00	55.00
	49.50	50.00	52.50	52.00	51.00	53.00	49.00	52.00	51.00	50.00	55.00	49.50	51.00	50.00	54.50	54.00	55.50
	49.50	50.50	52.00	51.00	51.00	52.50	50.00	52.50	52.00	51.00	54.00	49.00	51.50	50.00	55.00	54.00	55.50
Mean	49.67	50.17	52.67	51.67	51.00	52.83	49.50	51.83	51.50	50.50	54.67	49.17	51.33	50.33	54.50	54.00	55.33
SD.	0.29	0.29	0.76	0.58	0.00	0.29	0.50	0.76	0.50	0.50	0.58	0.29	0.29	0.58	0.50	0.00	0.29

**Table B-7** Specific Gravity of Compound.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Specific gravity	0.975	1.054	1.073	1.117	1.160	1.215	1.028	1.069	1.117	1.158	1.208	1.032	1.086	1.136	1.171	1.240	1.107
	0.973	1.062	1.076	1.122	1.161	1.216	1.023	1.077	1.126	1.156	1.213	1.034	1.083	1.137	1.166	1.243	1.105
Mean	0.974	1.058	1.075	1.120	1.161	1.216	1.026	1.073	1.122	1.157	1.211	1.033	1.085	1.137	1.169	1.242	1.106

**Table B-8** Original and Swollen Polymer Weight for Crosslinking Density Calculation.

	Natural rubber	Nanocalcium carbonate					Uncoated nanocalcium carbonate					2 $\mu$ -calcium carbonate					Carbon black
	0	10	20	30	40	50	10	20	30	40	50	10	20	30	40	50	40
Initial weight (g)	0.0890	0.0837	0.0818	0.0854	0.0696	0.0950	0.0657	0.0714	0.0824	0.1030	0.0998	0.0768	0.0991	0.1054	0.1010	0.1032	0.0765
Swollen weight (g)	0.3155	0.2801	0.2676	0.2656	0.2133	0.2702	0.2200	0.2342	0.2575	0.3255	0.3034	0.2639	0.3266	0.3340	0.3218	0.3034	0.2130

## APPENDIX C

The crosslinking density of natural rubber composites was calculated according to Flory-Huggins Theory [4]. Swelling can be determined gravimetrically, by weighing the polymer sample before the experiment ( $w_0$ ) and subtracting this value from the solvent swollen polymer weight ( $w_s$ ) as in Eq. C.1

$$V_{equil} = \frac{w_0}{\rho_2} + \frac{w_s - w_0}{\rho_1} \quad (C.1)$$

and

$$V_{2m} = \frac{w_0}{v_{equil} \times \rho_2} \quad (C.2)$$

where	$\rho_2$	= polymer density	= 0.974 g/cm <sup>3</sup> (Table B-7)
	$\rho_1$	= solvent density (toluene)	= 0.870 g/cm <sup>3</sup>
	$w_0$	= original polymer weight	= 0.0890 g (Table B-8)
	$w_s$	= swollen polymer weight	= 0.3155 g (Table B-8)

$$V_{equil} = \frac{0.0890}{0.974} + \frac{0.3155 - 0.0890}{0.870} = 0.3517$$

Substituting  $V_{equil} = 0.3517$  in Eq. C.2

$$V_{2m} = \frac{0.0890}{0.3517 \times 0.974} = 0.2598$$

The molecular weight per crosslinking unit,  $M_c$  is calculated using Eq. C.3

$$M_c = \frac{V_1 \rho_2 \left( V_{2m}^{1/3} - \frac{V_{2m}}{2} \right)}{-[\ln(1 - V_{2m}) + V_{2m} + \chi_1 V_{2m}^2]} \quad (C.3)$$

where  $V_1$  is molar volume of solvent and  $\chi_1$  is polymer-solvent interaction parameter.

In chemistry, the molar volume of a substance is the volume of one mole of that substance. It can be computed as the substance's atomic or molecular weight, divided by its density.

Hence,

$$V_1 = 107.10 \text{ cm}^3/\text{mol}$$

Substituting the known value  $V_1$ ,  $\rho_2$ ,  $V_{2m}$  and  $\chi_1 = 0.393$  [12] for rubber/toluene in Eq. C.3

$$M_c = 3623.15 \text{ g/mol}$$

Thus, the crosslinking density of natural rubber composites is,

$$\begin{aligned} n_c &= \frac{\rho_2}{3623.15} \\ &= 2.688 \times 10^{-4} \text{ mol/cm}^3 \end{aligned}$$

APPENDIX D

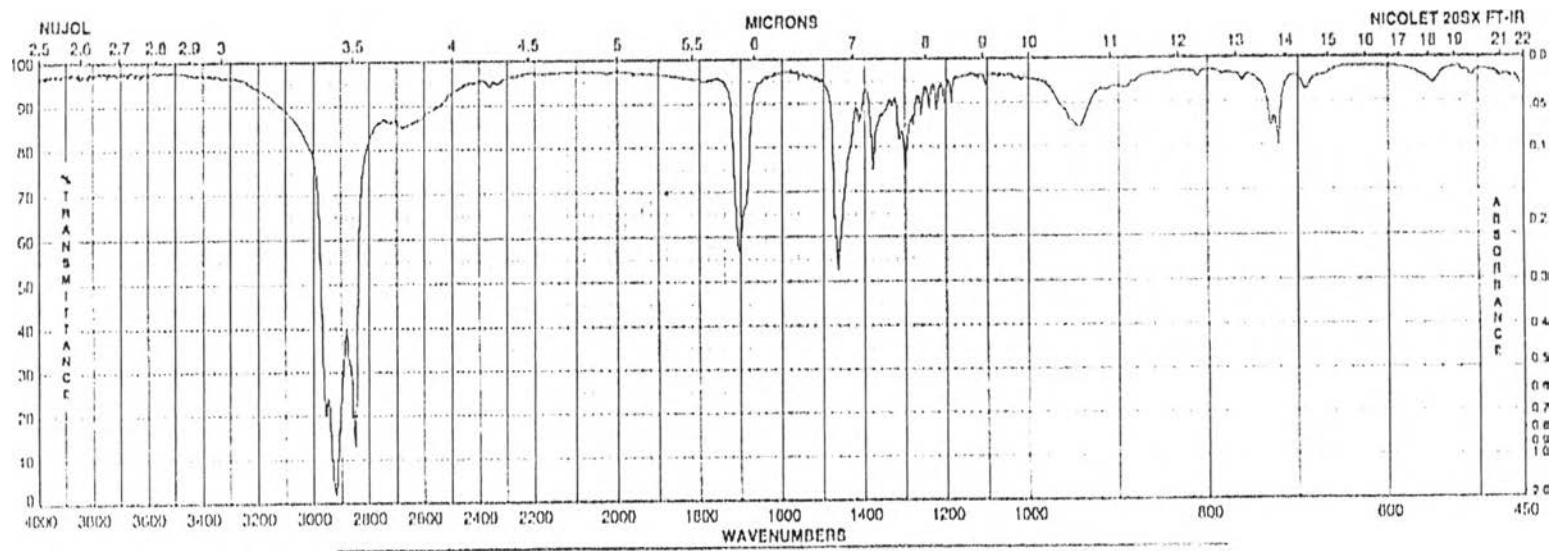


Figure D-1 IR Spectrum of Stearic Acid [30]

## VITAE

Miss. Wilairat Chuafak was born on April 20, 1977, in Bangkok, Thailand. She received her Bachelor's degree in Industrial Chemistry, from the Faculty of Science, King Mongkut's Institute of Technology Ladkrabang in 1999. She has pursued Master's Degree in Petrochemistry and Polymer Science, Program of Petrochemistry and Polymer Science, Faculty of Science, Chulalongkorn University since 2002 and finished her study in 2005.

