CHAPTER IV

RESULTS AND DICUSSION

4.1 Properties of Commercial Products

Table 4.1 Mechanical and thermal properties of commercial products.

Commercial Products	Tensile strength(Kg/cm^2)	Tear strength(Kg/cm)	Izod impact strength(Kg/cm)	Shrinkage (%)	HDT (°C)
Box use	> 420	35	> 1.38	< +3,-3	> 65
Stationary	> 420	35	> 1.36	< +3,-3	> 65
Vacuum	> 450	32	> 1.36	< +3,-3	> 67
Sample (non-filler)	468	43	1.64	1.78	68.3

Table 4.1 shows mechanical and thermal properties of R-PVCOPS, which were acceptable as commercial products that were used in box use, stationary and vacuum grade product compared with those of R-PVCOPS having no filler. It was found that R-PVCOPS in the absence of filler still yield the acceptable mechanical and thermal properties, namely, tensile strength, tear strength, Izod impact strength, HDT and % shrinkage.

This research studied the effect of fillers on the mechanical properties of R-PVCOPS. Since the rigid PVC had a high production cost, its cost of production should be then reduced by adding fillers. $CaCO_3$, talcum and kaolin fillers were used. The ratio and the content added were varied to determine the optimum value for R-PVCOPS production by calendering process.

4.2 Effect of Filler Content on Mechanical Properties of R-PVCOPS

4.2.1 Tensile Properties

When the material or polymer was forced by external force, there would be internal stress, which was thoroughly dispersed on the matrix of the material. When the external force increased, the vibrated molecules would rearrange. The molecules, which had a closed structure and size would rearrange to each other to obtain the most stable state. Thus the dispersion was not good for the closed particle sized fillers. It would be agglomerated. By following Tjong et al. [12] observations, it was that the filler particles tend to link together to form larger aggregrates when the $CaCO_3$ content was increased.

On the other hand, the small particle sized filler would thoroughly and evenly disperse into the polymer matrix so that the polymer was reinforced. In contrast, the large particle sized filler would hardly disperse into the polymer matrix resulting in voids or spaces in the polymer. Thus the mechanical properties decreased. The dispersion of fillers into the polymer matrix depends on shape and particle size of fillers if more than two types of filler were mixed. One of these fillers should have the smaller particle size to disperse between the interstitial space of the molecules of the larger particle sized filler and polymer.

Tables 4.2 – 4.4 and Figures 4.1 – 4.3 show tensile strength of R-PVCOPS. The results were indicated that tensile strength increased when the content of filler increased as shown in Figure 4.1 and Table 4.2. By following the work of Mishara et al.[13], the inherent properties of filled PVC/EVA blends depend on the concentration of the filler and strength of polymer-filler interface. Talcum gave the highest tensile strength, followed by kaolin and $CaCO_3$. Both talcum and kaolin contain the silicate group. Its molecular structure is plate like or lamellar, which is hexagonal and provides the higher intermolecular force than that of the cubic $CaCO_3$.

When two-fillers were mixed (Figure 4.2 and Table 4.3), tensile strength increased compared with those of the R-PVCOPS containing only one filler. (Table 4.2 and Figure 4.1) The results indicated that tensile strength sharply increased when the filler content increased. Very importantly, two-filler mixture gave even higher tensile strength as follows: $CaCO_3$/talcum, followed by $CaCO_3$/ kaolin and talcum/kaolin. The particle size and shape of $CaCO_3$ and talc were different, the particle size of $CaCO_3$ is less than 2 micrometer and that of talcum is larger than 10 micrometer. The larger the difference of particle size, the better the dispersion of the mixed fillers. For the mixture of $CaCO_3$/talcum, talcum could disperse between the chains of R-PVCOPS. Then $CaCO_3$ with the smaller particle size disperses in between the spaces of talcum and R-PVCOPS/talcum. The same reason is applied for the mixture of kaolin/$CaCO_3$.

Nonetheless, the mixture of talcum/kaolin yield the lower tensile strength, because the shape and particle size of both fillers are similar. Therefore, the placement of these two fillers in the void structure of R-PVCOPS is dominated by the filler packing density.

Table 4.2 Tensile strength of one-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Tensile strength (Kg/cm^2)
	$CaCO_3$	Talcum	Kaolin		
S_1	5.0	-	-	5	476
S_2	10.0	-	-	10	482
S_3	20.0	-	-	20	533
S_4	-	5.0	-	5	534
S_5	-	10.0	-	10	551
S_6	-	20.0	-	20	579
S_7	-	-	5.0	5	512
S_8	-	-	10.0	10	525
S_9	-	-	20.0	20	565

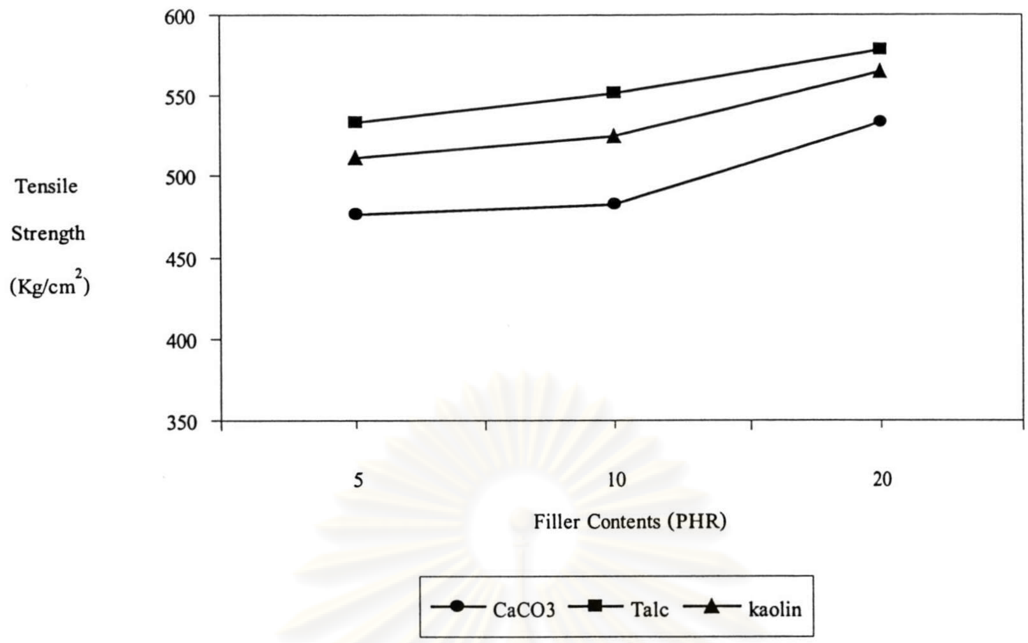

Figure 4.1 Effect of one-filler concentration on tensile strength of R-PVCOPS.

Table 4.3 Tensile strength of two-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Tensile strength (Kg/cm^2)
	$CaCO_3$	Talcum	Kaolin		
S_{10}	2.5	2.5	-	5	575
S_{11}	5.0	5.0	-	10	609
S_{12}	10.0	10.0	-	20	611
S_{13}	2.5	-	2.5	5	557
S_{14}	5.0	-	5.0	10	564
S_{15}	10.0	-	10.0	20	577
S_{16}	-	2.5	2.5	5	517
S_{17}	-	5.0	5.0	10	520
S_{18}	-	10.0	10.0	20	527

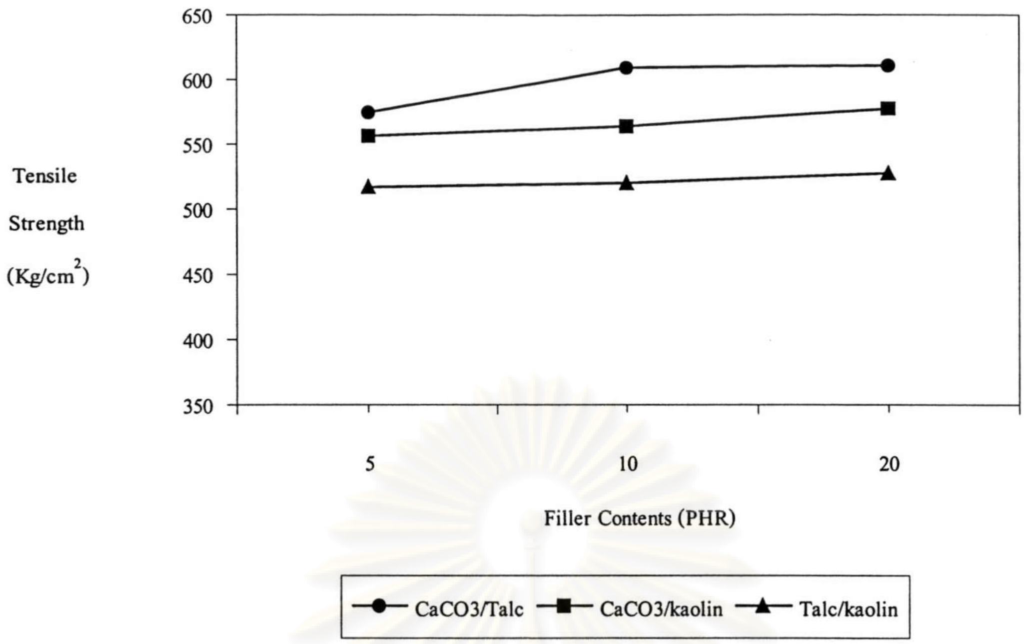

Figure 4.2 Effect of two-filler concentration on tensile strength of R- PVCOPS.

When three-fillers were mixed at various ratios and contents (Figure 4.3 and Table 4.4), tensile strength of the mixture was higher than that of the two-filler filled R-PVCOPS. (Tables 4.3) At afixed filler concentration, the mixture of $CaCO_3$/ talcum/kaolin at the ratio of 1.5 :1 :2.5 giving a total filler concentration of 5 phr gave the lower tensile strength. However, the mixture of $CaCO_3$ /talcum /kaolin at the ratio of 1 :2.5 :1.5 at 10 phr gave the highest tensile strength, followed by the mixture of $CaCO_3$/talcum/kaolin at the ratio of 2.5 :1.5 :1.

The particular ratio of these three fillers gave very interesting mechanical properties. Because of their different shapes and sizes the filler placement in the voids or spaces among the polymer chains is the control factor. It does not need to have a high total filler concentration, such as 20 phr, the tensile strength, for example, at 20 phr, is significantly lower than those at 10 phr. As described above, the samples S_{20}, S_{23} and S_{26} containing 2, 3 and 5 phr of kaolin, respectively (large particle size), have more free spaces after filler occupation, contributing to the higher tensile strength.

Table 4.4 Tensile strength of three-filler filled R-PVCOPS.

Sample No.	**Type of filler (phr)**			**Total (phr)**	**Tensile strength (Kg/cm^2)**
	$CaCO_3$	**Talcum**	**Kaolin**		
S_{19}	2.5	1.5	1.0	5	552
S_{20}	5.0	3.0	2.0	10	575
S_{21}	10.0	6.0	4.0	20	565
S_{22}	1.0	2.5	1.5	5	598
S_{23}	2.0	5.0	3.0	10	643
S_{24}	4.0	10.0	6.0	20	611
S_{25}	1.5	1.0	2.5	5	542
S_{26}	3.0	2.0	5.0	10	539
S_{27}	6.0	4.0	10.0	20	528

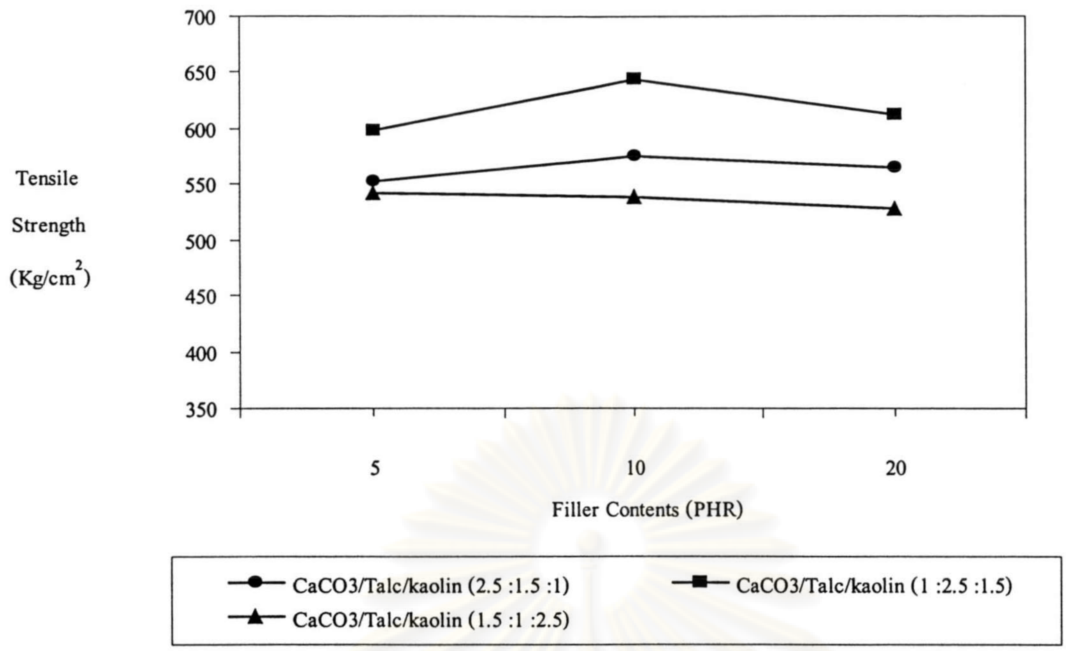

Figure 4.3 Effect of three-filler concentration on tensile strength of R-PVCOPS.

4.2.2 Tear Properties

The filler with the small particle size can thoroughly disperse into interchain free volume the polymer. The polymer can thus be more reinforced. If the particle size of filler is large, it is hardly dispersed into the free space of chains. The mechanical properties are therefore decreased.

Tables 4.5 – 4.7 and Figures 4.4 – 4.6 show tear strength of R-PVOPS. The results show that at 10 phr, the tear strength increased when the filler content increased, but at 20 phr, the tear strength decreased when the filler content increased. These results indicate that the excess amount of the fillers cannot be filled in the free space of the polymer chain, but they reside outside the space. Thus the intermolecular force of the polymer decreased so that tear strength of the polymer could then be decreased. Figure 4.4 shows that tear strength of R-PVCOPS incorporating talcum and $CaCO_3$ as fillers were silmilar but those containing kaolin was much lower, since the particle size of kaolin was larger than that of talcum and $CaCO_3$.

Figure 4.5 shows the tear strength of two-filler filled R-PVCOPS. It shows that the tear strength was higher than that of one-filler filled sheets. Two-filler filled systems, which gave the highest tear strength was found in $CaCO_3$/talcum followed by $CaCO_3$/kaolin, and talcum/kaolin. Similarly, we found that at the total concentration of two-filler filled R-PVCOPS one-filler filled sheet of 10 phr, the tear strengths of S_2, S_5 and S_3 are at miximum.

Table 4.5 Tear strength of one-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Tear strength (Kg/cm^2)
	$CaCO_3$	Talcum	Kaolin		
S_1	5.0	-	-	5	40.5
S_2	10.0	-	-	10	43.3
S_3	20.0	-	-	20	37.2
S_4	-	5.0	-	5	50.8
S_5	-	10.0	-	10	57.5
S_6	-	20.0	-	20	55.1
S_7	-	-	5.0	5	47.8
S_8	-	-	10.0	10	55.4
S_9	-	-	20.0	20	56.5

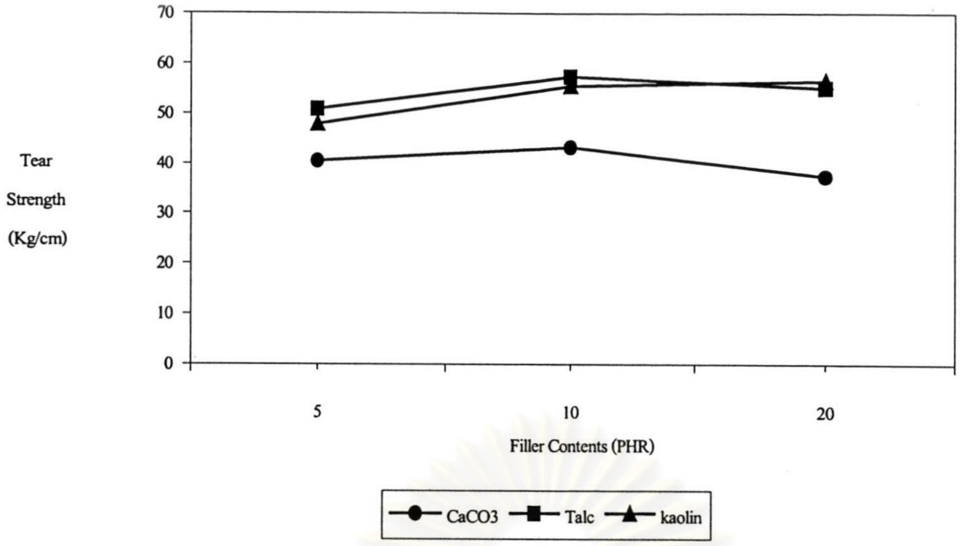

Figure 4.4 Effect of one-filler concentration on tear strength of R-PVCOPS.

Table 4.6 Tear strength of two-filler filled R-PVCOPS.

Sample No.	**Type of filler (phr)**			**Total (phr)**	**Tear strength (Kg/cm^2)**
	$CaCO_3$	**Talcum**	**Kaolin**		
S_{10}	2.5	2.5	-	5	63.5
S_{11}	5.0	5.0	-	10	67.3
S_{12}	10.0	10.0	-	20	64.1
S_{13}	2.5	-	2.5	5	58.3
S_{14}	5.0	-	5.0	10	63.6
S_{15}	10.0	-	10.0	20	60.5
S_{16}	-	2.5	2.5	5	51.5
S_{17}	-	5.0	5.0	10	54.2
S_{18}	-	10.0	10.0	20	50.5

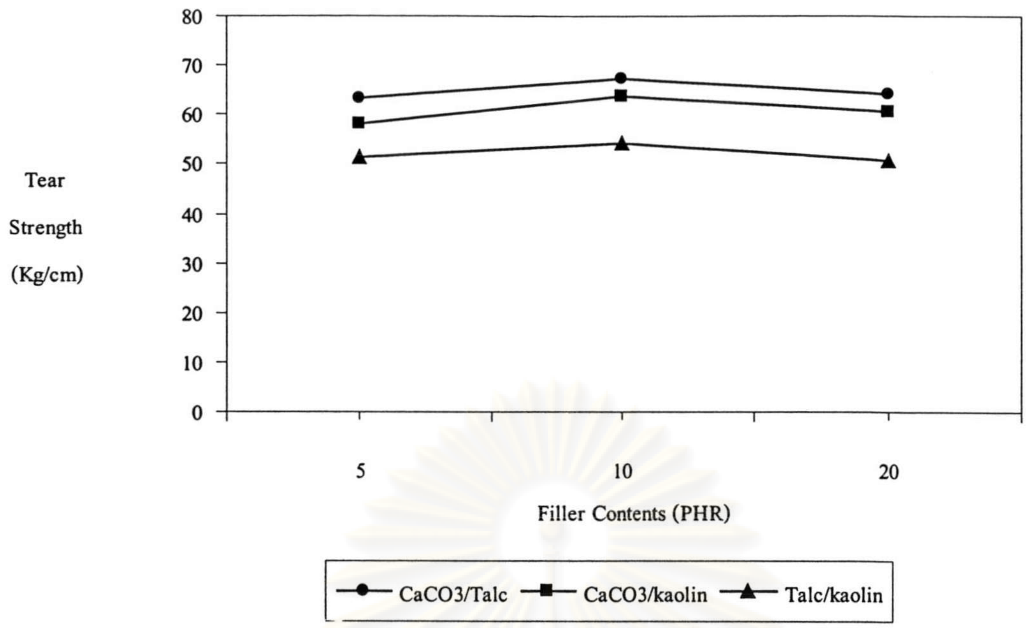

Figure 4.5 Effect of two-filler concentration on tear strength of R-PVCOPS.

Table 4.7 shows tear strength of three-filler filled R-PVCOPS. The tear strength of this system was found somewhat higher than those of two-filler filled system (Figure 4.6). However, we still found that at the total filler concentration of 10 phr, the order of tear strength is as follows: s_{26} (57.5 kg/cm) < s_{20}(65.5 kg/cm) < s_{23} (68.7 kg/cm). The tear results are in good agreement with those of tensile strength.

Table 4.7 Tear strength of three-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Tear strength (Kg/cm^2)
	$CaCO_3$	Talcum	Kaolin		
S_{19}	2.5	1.5	1.0	5	60.1
S_{20}	5.0	3.0	2.0	10	65.5
S_{21}	10.0	6.0	4.0	20	56.9
S_{22}	1.0	2.5	1.5	5	63.9
S_{23}	2.0	5.0	3.0	10	68.7
S_{24}	4.0	10.0	6.0	20	60.0
S_{25}	1.5	1.0	2.5	5	53.3
S_{26}	3.0	2.0	5.0	10	57.5
S_{27}	6.0	4.0	10.0	20	51.2

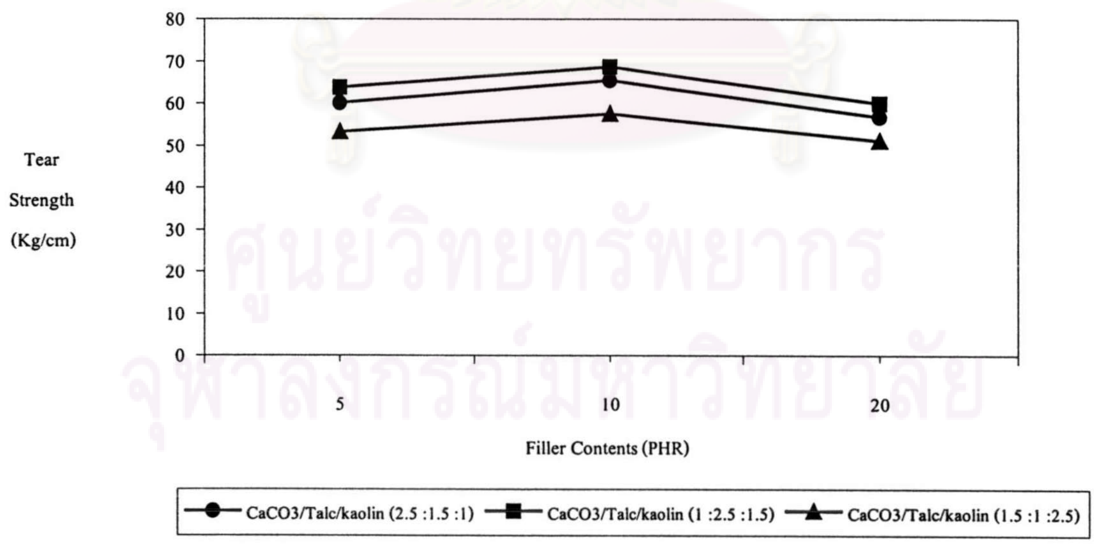

Figure 4.6 Effect of three-filler concentration on tear strength of R-PVCOPS.

4.2.3 Impact Properties

Impact strength is one of the mechanical property which reports the ability of energy absorption before breaking. If the polymer absorbs high energy, it is highly flexible, behaving like a rubber[25]. The rubber has much higher impact strength than plastic. Nevertheless, if a plastic in reinforced properly, the impact strength will, of course be, higher.

Tables 4.8– 4.10 and Figures 4.7 – 4.9 show Izod impact strength of R-PVCOPS. When the content of filler increased, impact strength increases until 10 phr. Impact strength decreased at 20 phr. Very interestingly, when the content of kaolin increased, impact strength also increased. This may suggest that kaolin is rather flexible, and R-PVCOPS containing $CaCO_3$ and talcum gave the lower impact strength than that filled only with kaolin.

Table 4.8 Izod impact strength of one-filler filled R-PVCOPS.

Sample	**Type of filler (phr)**			**Total**	**Impact strength**
No.	**$CaCO_3$**	**Talcum**	**Kaolin**	**(phr)**	**(Kg/cm)**
S_1	5.0	-	-	5	3.7
S_2	10.0	-	-	10	4.1
S_3	20.0	-	-	20	2.2
S_4	-	5.0	-	5	3.5
S_5	-	10.0	-	10	4.3
S_6	-	20.0	-	20	2.9
S_7	-	-	5.0	5	1.5
S_8	-	-	10.0	10	2.6
S_9	-	-	20.0	20	3.6

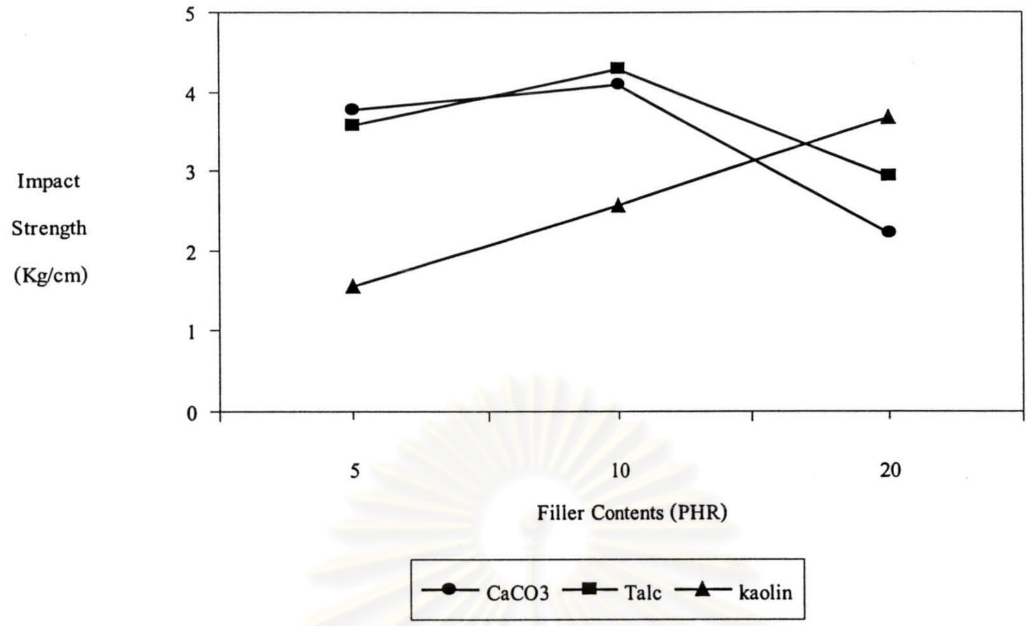

Figure 4.7 Effect of one-filler concentration on impact strength of R-PVCOPS.

Similarly, when the two fillers were mixed and added into the R-PVCOPS, impact strength of two-filler filled R-PVCOPS was higher than that of one-filler filled sheets (Table 4.9 and Figure 4.8). The highest impact strength is found at 10 phr filled sheets. Any second filler (talcum or kaolin) added with $CaCO_3$ at 10 phr could better disperse into the space of the molecule chains of R-PVCOPS than those at 20 phr.

Impact strength decreased markedly when mixing kaolin with talcum, because the particle sizes of kaolin and talcum are similar. Therefore, the probability of the dispersion of kaolin/talcum into the interchain space of R-PVCOPS would be less than that of talcum/$CaCO_3$ or kaolin/$CaCO_3$. The particle size of $CaCO_3$ is smaller than that of kaolin or talcum. Thus, the polymer chains would absorb a large amount of energy to deform or break down, when it is loaded. So, the impact strength of R-PVCOPS filling with $CaCO_3$ as a filler is higher than of containing kaolin or talcum as the filler.

Table 4.9 Izod impact strength of two-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Impact strength (Kg/cm)
	$CaCO_3$	Talcum	Kaolin		
S_{10}	2.5	2.5	-	5	4.1
S_{11}	5.0	5.0	-	10	7.6
S_{12}	10.0	10.0	-	20	2.8
S_{13}	2.5	-	2.5	5	4.4
S_{14}	5.0	-	5.0	10	7.5
S_{15}	10.0	-	10.0	20	3.4
S_{16}	-	2.5	2.5	5	1.9
S_{17}	-	5.0	5.0	10	4.1
S_{18}	-	10.0	10.0	20	1.5

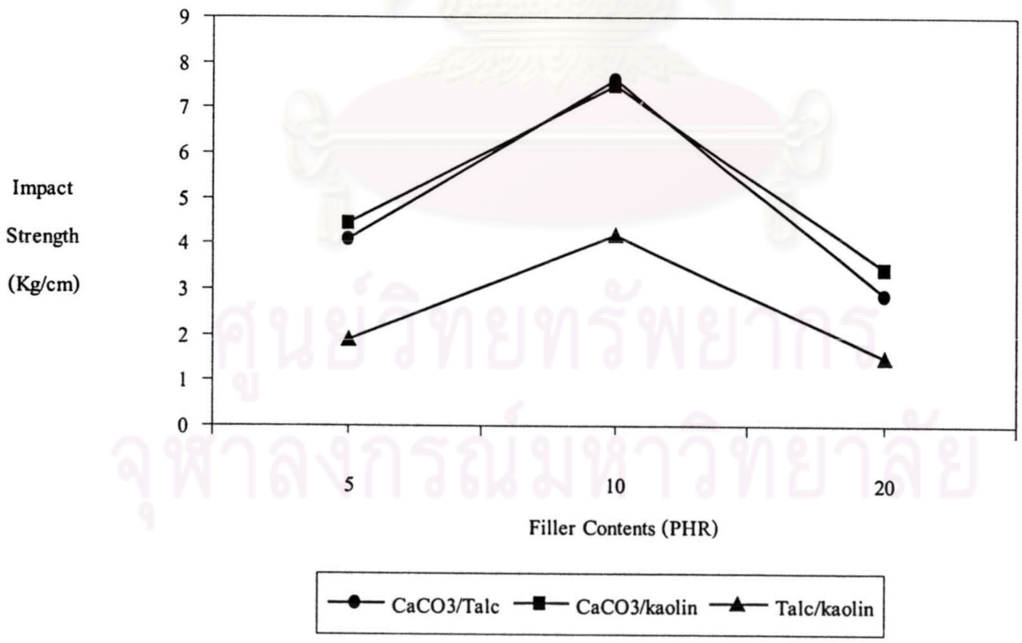

Figure 4.8 Effect of two-filler concentration on impact strength of R-PVCOPS.

When three fillers were mixed with R-PVCOPS at various ratios, the resulting impact strength of R-PVCOPS was slightly lower than that of two-filler filled sheets (Table 4.10 and Figure 4.9). The mixture of $CaCO_3$/talcum/kaolin at the ratio of 1 :2.5 :1.5 gave the highest impact strength followed by the ratio of 2.5 :1.5 :1 and 1.5 :1 :2.5. The dispersion of the two fillers into the intermolecular chains of R-PVCOPS, which act as the matrix depends on the shape and particle size of the filler. One of the two fillers should have a smaller particle size so that it could thoroughly disperse into the interchains of polymer. Following Yanagase et al.[16] and Maiti et al.[17] work who studied tensile and impact behavior of the $CaCO_3$ filled polypropylene in the composition range 0-60 wt% filler. The impact strength increased while tensile strength decreased.

Table 4.10 Izod impact strength of three-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Impact strength (Kg/cm)
	$CaCO_3$	Talcum	Kaolin		
S_{19}	2.5	1.5	1.0	5	3.3
S_{20}	5.0	3.0	2.0	10	5.3
S_{21}	10.0	6.0	4.0	20	2.2
S_{22}	1.0	2.5	1.5	5	3.8
S_{23}	2.0	5.0	3.0	10	5.7
S_{24}	4.0	10.0	6.0	20	2.0
S_{25}	1.5	1.0	2.5	5	1.7
S_{26}	3.0	2.0	5.0	10	2.8
S_{27}	6.0	4.0	10.0	20	1.8

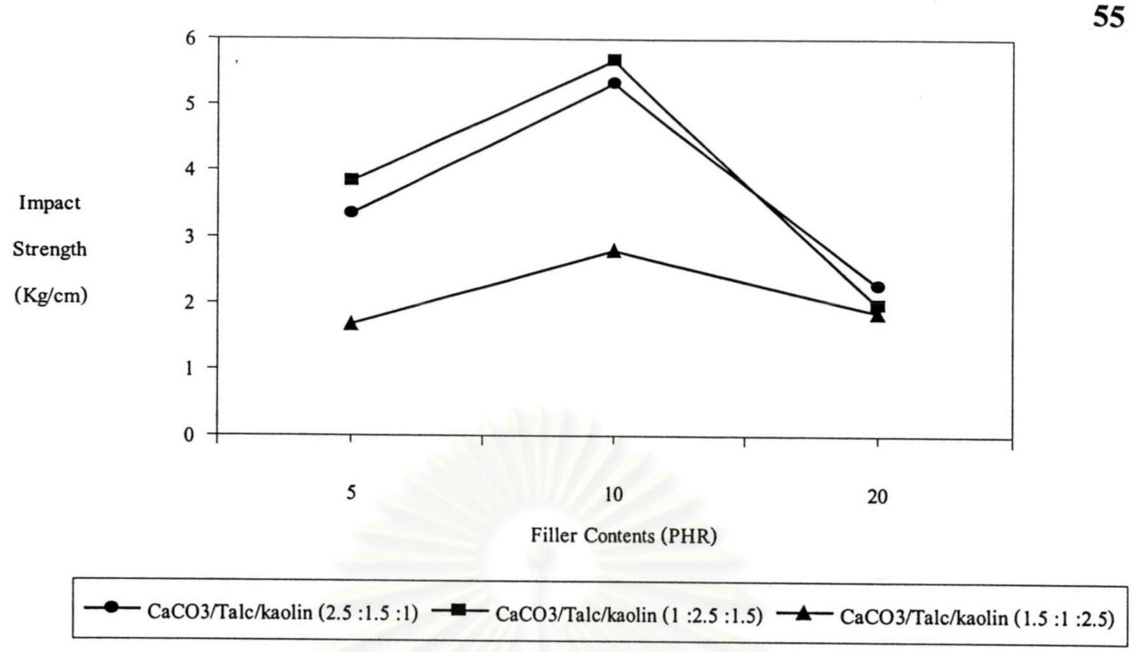

Figure 4.9 Effect of three-filler concentration on impact strength of R-PVCOPS.

4.3 Effect of Filler Content on Thermal Properties of R-PVCOPS

4.3.1 Heat Deflection Temperature (HDT)

HDT is the primary temperature that material or polymer begins to deflect, which can occur from loading or forcing on the material or polymer. So the temperature limit in applications can be known by HDT [24]. It can be determined by thermal analysis including differential thermal analysis (DTA), differential scanning calorimetry (DSC) and thermal mechanical analysis (DMA). HDT can be compared with glass transition temperature (Tg) of the polymer.

Tables 4.11–4.13 and Figures 4.10 – 4.12 show the HDT of R-PVCOPS, in which different filler types and contents are added. The results show that the talc gave the highest HDT, followed by $CaCO_3$, and kaolin. (Table 4.11 and Figure 4.10). These results were different from the hardness measurement, which was measured in Mohr's scale of hardness. Talcum is used as a standard mineral. The hardness of talcum is one. This implies that talcum has low hardness at its surface. When it was mixed in R-PVCOPS, the R-PVCOPS sheets would be soften and have high stiffness.

Table 4.11 Heat deflection temperature of one-filler filled R-PVCOPS.

Sample No.	**Type of filler (phr)**			**Total (phr)**	**HDT (°C)**
	$CaCO_3$	**Talcum**	**Kaolin**		
S_1	5.0	-	-	5	69.2
S_2	10.0	-	-	10	69.4
S_3	20.0	-	-	20	69.3
S_4	-	5.0	-	5	71.3
S_5	-	10.0	-	10	72.7
S_6	-	20.0	-	20	72.1
S_7	-	-	5.0	5	70.2
S_8	-	-	10.0	10	68.6
S_9	-	-	20.0	20	68.0

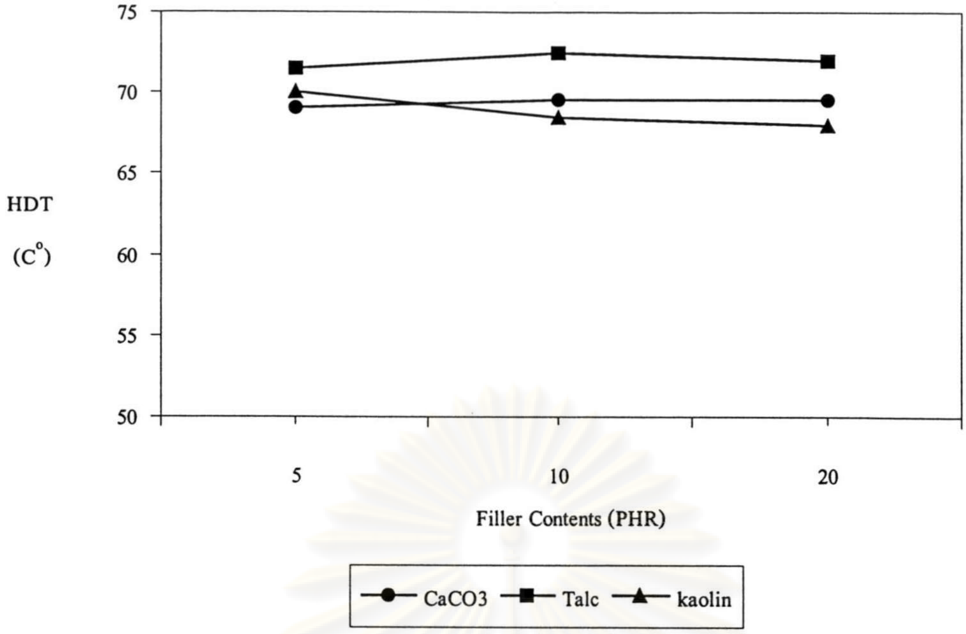

Figure 4.10 Effect of one-filler concentration on Heat deflection temperature of R- PVCOPS.

When two-fillers were mixed (Table 4.12 and Figure 4.11), HDT of R-PVCOPS containing $CaCO_3$/kaolin or talcum/kaolin had a lower HDT than those containing $CaCO_3$/talcum. Since the hardness of kaolin is two, which is higher than that of talcum (with one). When kaolin was dispersed into the intermolecular chains of R-PVCOPS, more spaces could result in; the molecules of PVC could rearrange their chains as an influence from the addition of large particle sized kaolin. When the polymer was loaded, the molecular chain movement of R-PVCOPS containing $CaCO_3$/kaolin and talcum/kaolin changed much faster than those of R-PVCOPS having $CaCO_3$/talcum as filler. Therefore, the HDT of R-PVCOPS would then decrease.

Table 4.12 Heat deflection temperature of two-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	HDT (°C)
	$CaCO_3$	Talcum	Kaolin		
S_{10}	2.5	2.5	-	5	72.0
S_{11}	5.0	5.0	-	10	72.7
S_{12}	10.0	10.0	-	20	72.5
S_{13}	2.5	-	2.5	5	69.8
S_{14}	5.0	-	5.0	10	70.6
S_{15}	10.0	-	10.0	20	70.9
S_{16}	-	2.5	2.5	5	69.7
S_{17}	-	5.0	5.0	10	69.2
S_{18}	-	10.0	10.0	20	68.2

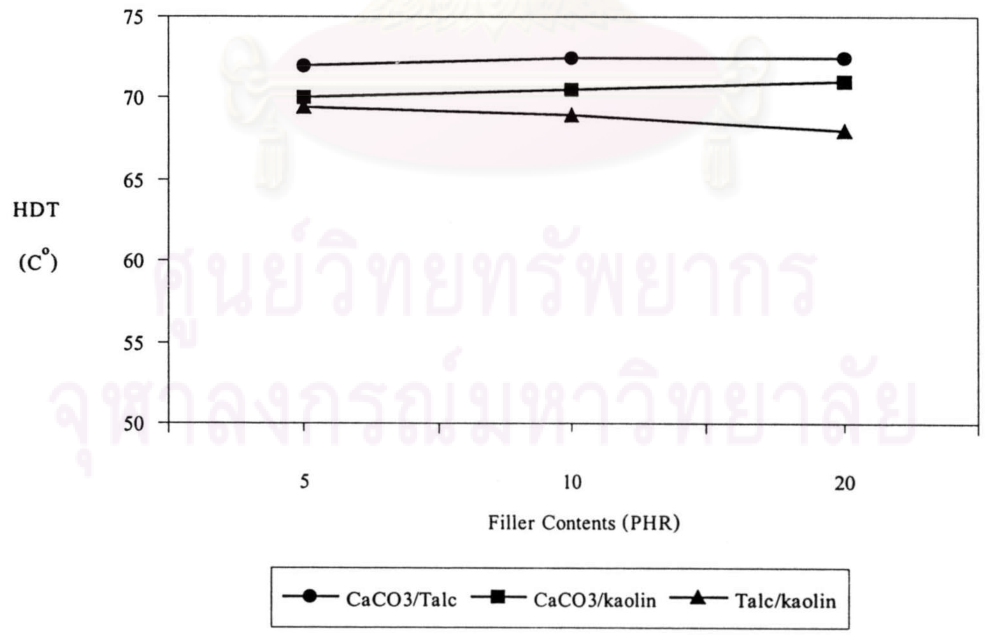

Figure 4.11 Effect of two-filler concentration on heat deflection temperature of R- PVCOPS

When three fillers were mixed as shown in Table 4.13, the results show that the mixture of $CaCO_3$/talcum/kaolin at 2.5 :1.5 :1 gave the highest HDT, followed by the ratio of 1 :2.5 :1.5 and 1.5 :1.5 :2.5, respectively. If the content of kaolin was excess, the HDT would decrease. The mixture of $CaCO_3$/talcum/kaolin at 2.5 :1.5 :1 gave higher HDT than the ratio of 1 :2.5 :1.5. Since Mohr's scale of hardness of $CaCO_3$ was three, which was much higher than kaolin and talcum, resulting in the highest hardness at the PVCOPS surface. Additionally, $CaCO_3$ in the PVCOPS could better disperse into the intermolecular chains of R-PVCOPS than talc and kaolin because of its small particle size ($CaCO_3$). Therefore, the ratio of $CaCO_3$/talcum/kaolin at 2.5 :1.5 :1 gave the highest HDT. The HDT of the R-PVCOPS therefore increased when $CaCO_3$ in the mixture was increased.

Table 4.13 Heat deflection temperature of three-filler filled R-PVCOPS.

Sample	Type of filler (phr)			Total	HDT
No.	$CaCO_3$	Talcum	Kaolin	(phr)	(°C)
S_{19}	2.5	1.5	1.0	5	73.0
S_{20}	5.0	3.0	2.0	10	73.9
S_{21}	10.0	6.0	4.0	20	73.3
S_{22}	1.0	2.5	1.5	5	71.9
S_{23}	2.0	5.0	3.0	10	73.0
S_{24}	4.0	10.0	6.0	20	71.8
S_{25}	1.5	1.0	2.5	5	70.6
S_{26}	3.0	2.0	5.0	10	69.7
S_{27}	6.0	4.0	10.0	20	69.2

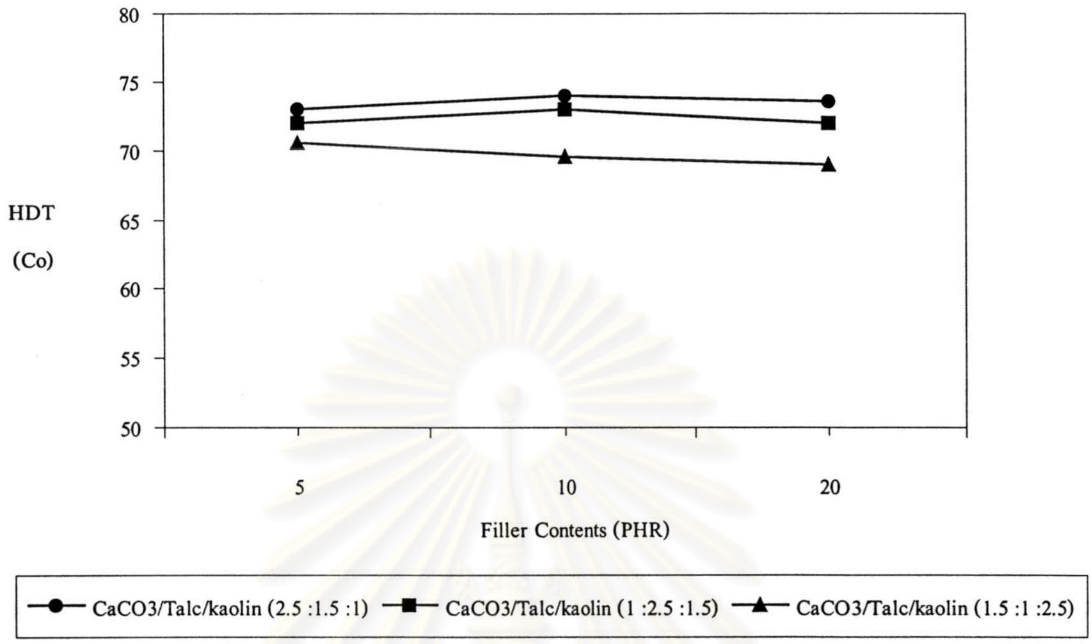

Figure 4.12 Effect of three-filler concentration on heat deflection temperature of R- PVCOPS.

4.3.2 Shrinkage Properties

Shrinkage is the percentage measurement of the plastic when it was shrinked after exposure to heat by a static heat stability method. When the material or polymer was heated, molecules of the polymer would be stimulated and rearranged into the proper direction. Thus, after the arrangement at ambient temperature, the specific volume of the polymer would be lower than the volume at processing temperature. The shrink would then take place. After processing, density of the polymer also decreased, resulting in internal stress or residual stress[25]. The polymer would be bent or twisted after a calendering process. Thus surface of the product would not be smooth.

Tables 4.14 – 4.16 and Figures 4.13 – 4.15 show % shrinkage of R-PVCOPS when the filler was added by varying both the content and ratio of fillers. When the content of filler decreased, % shrinkage of PVCOPS also increased. Therefore, % shrinkage depended on the content of filler. From Figure 4.13, kaolin had the highest % shrinkage, followed by $CaCO_3$ and talcum, When two fillers were mixed and added into R-PVCOPS, % shrinkage of R-PVCOPS decreased compared with % shrinkage of R-PVCOPS having only one filler (Table 4.15 and Figure 4.14). Since the rearrangements of the two fillers reduced the spaces between the polymer chains, thus % shrinkage would then decrease. Figure 4.14 shows that R-PVCOPS containing the talcum/kaolin as fillers had the highest % shrinkage, followed by $CaCO_3$/talcum, and $CaCO_3$/kaolin.

Table 4.14 % Shrinkage of one-filler filled R-PVCOPS.

Sample	Type of filler (phr)			Total	Shrinkage
No.	$CaCO_3$	Talcum	Kaolin	(phr)	(%)
S_1	5.0	-	-	5	0.89
S_2	10.0	-	-	10	0.85
S_3	20.0	-	-	20	0.80
S_4	-	5.0	-	5	0.81
S_5	-	10.0	-	10	0.76
S_6	-	20.0	-	20	0.70
S_7	-	-	5.0	5	1.00
S_8	-	-	10.0	10	0.95
S_9	-	-	20.0	20	0.90

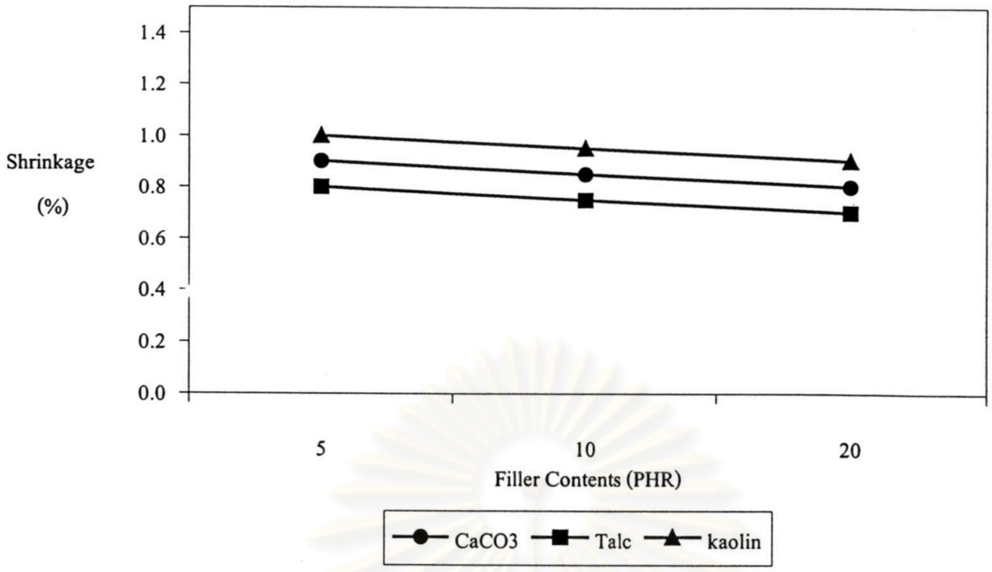

Figure 4.13 Effect of one-filler concentration on % shrinkage of R-PVCOPS.

Table 4.15 % Shrinkage of two-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Shrinkage (%)
	$CaCO_3$	Talcum	Kaolin		
S_{10}	2.5	2.5	-	5	0.80
S_{11}	5.0	5.0	-	10	0.80
S_{12}	10.0	10.0	-	20	0.75
S_{13}	2.5	-	2.5	5	0.80
S_{14}	5.0	-	5.0	10	0.70
S_{15}	10.0	-	10.0	20	0.65
S_{16}	-	2.5	2.5	5	0.95
S_{17}	-	5.0	5.0	10	0.90
S_{18}	-	10.0	10.0	20	0.85

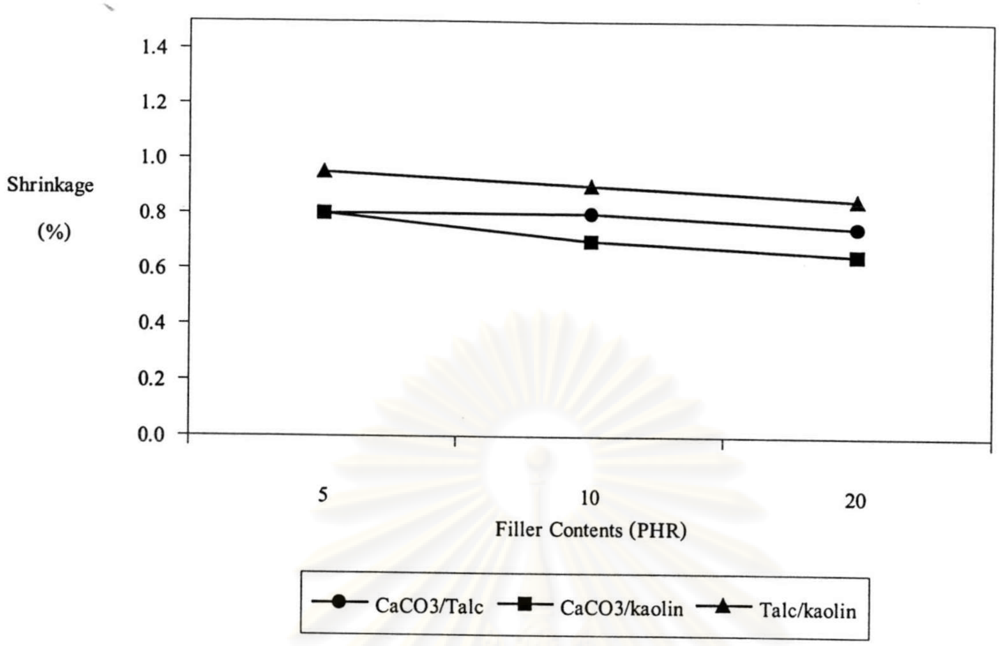

Figure 4.14 Effect of two-filler concentration on % shrinkage of R-PVCOPS.

When three fillers were mixed at various ratios and contents (Table 4.16 and Figure 4.15), the resulting % shrinkage was lower than that those using two types of fillers. The mixture of $CaCO_3$/talcum/kaolin at the ratio of 1.5 : 1 : 2.5 gave the higher % shrinkage. Since the particle size of kaolin is larger than any other fillers and there was a much higher kaolin content than the other ratios. Thus the rearrangement of these fillers increased the spaces of the intermolecule chains after processing, resulting in a higher % shrinkage.

Table 4.16 % Shrinkage of three-filler filled R-PVCOPS.

Sample No.	Type of filler (phr)			Total (phr)	Shrinkage (%)
	$CaCO_3$	Talcum	Kaolin		
S_{19}	2.5	1.5	1.0	5	0.80
S_{20}	5.0	3.0	2.0	10	0.75
S_{21}	10.0	6.0	4.0	20	0.70
S_{22}	1.0	2.5	1.5	5	0.75
S_{23}	2.0	5.0	3.0	10	0.75
S_{24}	4.0	10.0	6.0	20	0.65
S_{25}	1.5	1.0	2.5	5	1.24
S_{26}	3.0	2.0	5.0	10	1.20
S_{27}	6.0	4.0	10.0	20	1.00

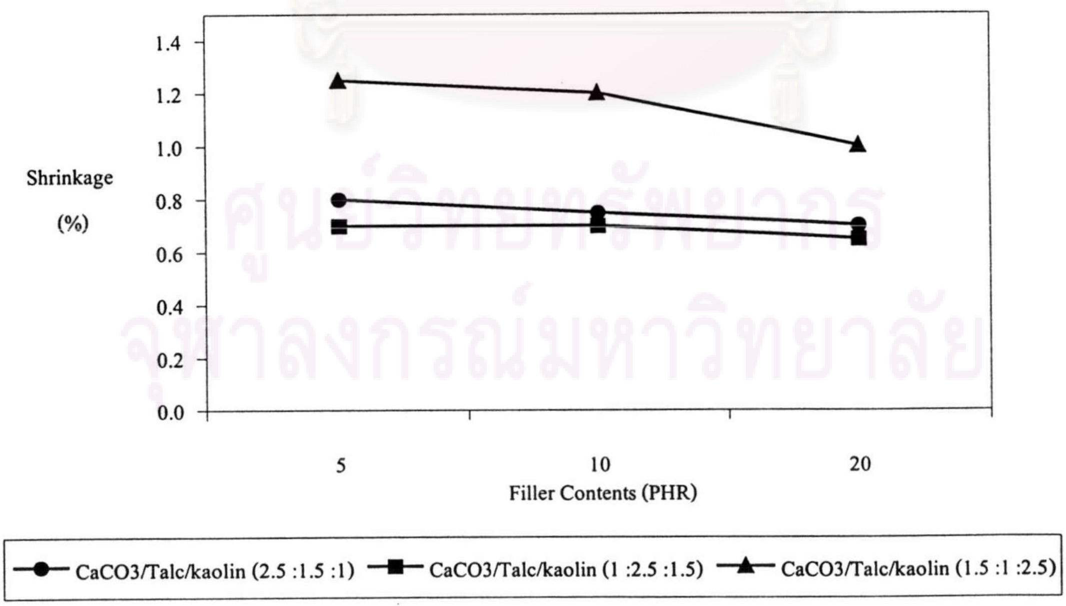

Figure 4.15 Effect of three-filler concentration on % shrinkage of R-PVCOPS

4.4 Effect of Fiiler Content on Morphological Characteristics of R-PVCOPS

4.4.1 Scanning Electron Micrcscopy (SEM)

The morphological properties of adding the filler into R-PVCOPS by varying the content and the ratio of the three fillers were be studied by two-phased dispersion theory: A matrix phase and a dispersed phase were shown in Figures 4.16 – 4.43.

Figure 4.16 shows the SEM micrograph of a smooth surface of R-PVCOPS without any added filler. Figures 4.17 – 4.19 show SEM micrographs of R-PVCOPS in which $CaCO_3$ was added at 5, 10, 20 phr, respectively. When $CaCO_3$ concentration was increased, the dispersion of $CaCO_3$ in the polymer matrix was better than those of talcum and kaolin as shown in Figures 4.20 – 4.22 and Figures 4.23 – 4.25, respectively. $CaCO_3$ powder would be thoroughly dispersed into the spaces of the intermolecular chains resulting in the rearrangement of the filler into the proper direction. The SEM micrographs of R-PVCOPS (Figures 4.26 – 4.34) show that talcum and kaolin were better dispersed than $CaCO_3$ when two of these fillers were mixed. Thus the mixture of talcum/$CaCO_3$ was better dispersed than the mixture of talcum/kaolin and $CaCO_3$/kaolin. The talcum/$CaCO_3$ which acts as a disperse phase would disperse into R-PVCOPS which acts as a matrix phase. We found that the content of talcum/$CaCO_3$ at 10 phr was an optimum, They would disperse better than the content of the mixture of 20 phr $CaCO_3$/talcum/kaolin at 1 :2.5 :1.5, but the dispersion of dispersed phase into the matrix phase would not be much better at 20 phr. The phase in the SEM micrographs agreed with the results obtained from tensile strength testing (Tables 4.2 – 4.4). Figures 4.35 – 4.43 show the SEM micrographs of R-PVCOPS containing the mixture of three fillers. It was found that at 10 phr the fillers would disperse better than those at 5 phr and 20 phr. The best dispersion is the PVCOPS containing the mixture of $CaCO_3$/talcum/kaolin at 1 :2.5 :1.5, followed by the ratios of 2.5 :1.5 :1 and 1.5 :1 :2.5, respectively.

The dispersion of two types of fillers into the R-PVCOPS depends directly on the shape and particle size of the fillers. The small particle sized filler disperse better into the void volumes of the another bigger filler and intermolecular chains of R-PVCOPS. The particle size of $CaCO_3$ was the smallest. The particle sizes of talcum and kaolin are similar. At 10 phr, the mixed filler can better disperse with R-PVCOPS than those at 5 phr and 20 phr. These results are in good agreement with those obtained from the tensile strength testing as shown in Tables 4.8 – 4.10 and Figure 4.3.

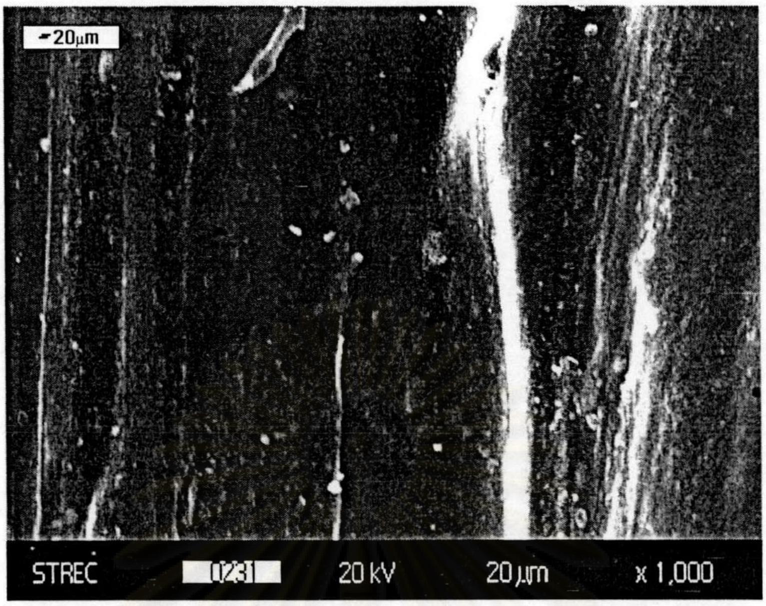

Figure 4.16 SEM micrograph of R-PVCOPS Virgin (no-filler) at 1,000X magnification

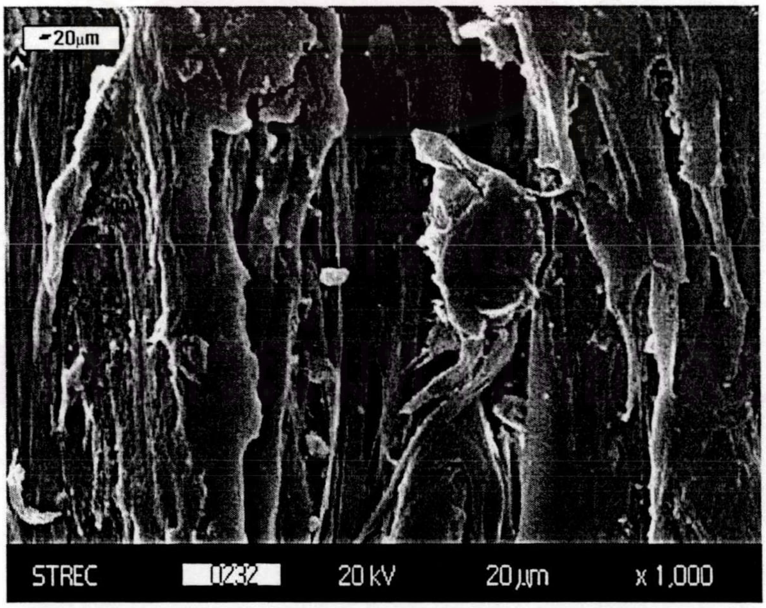

Figure 4.17 SEM micrograph of R-PVCOPS with $CaCO_3$ 5 phr at 1,000X magnification

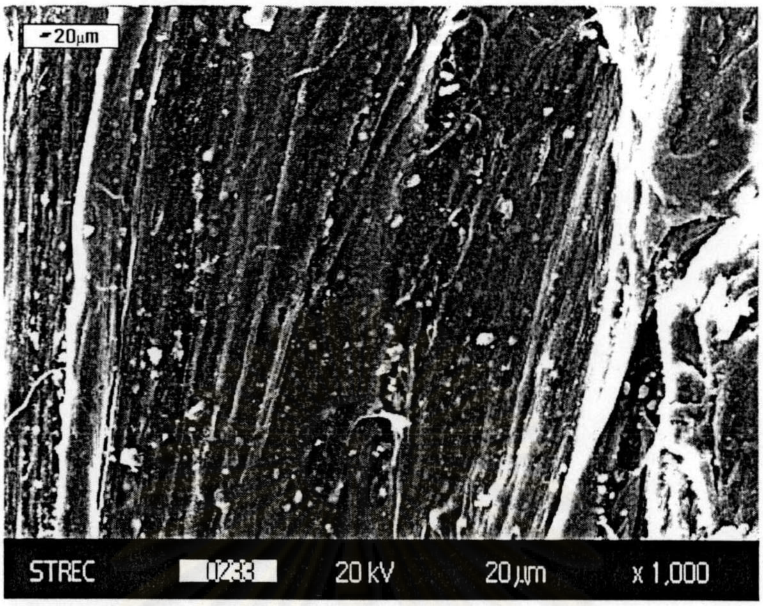

Figure 4.18 SEM micrograph of R-PVCOPS with $CaCO_3$ 10 phr at 1,000X magnification

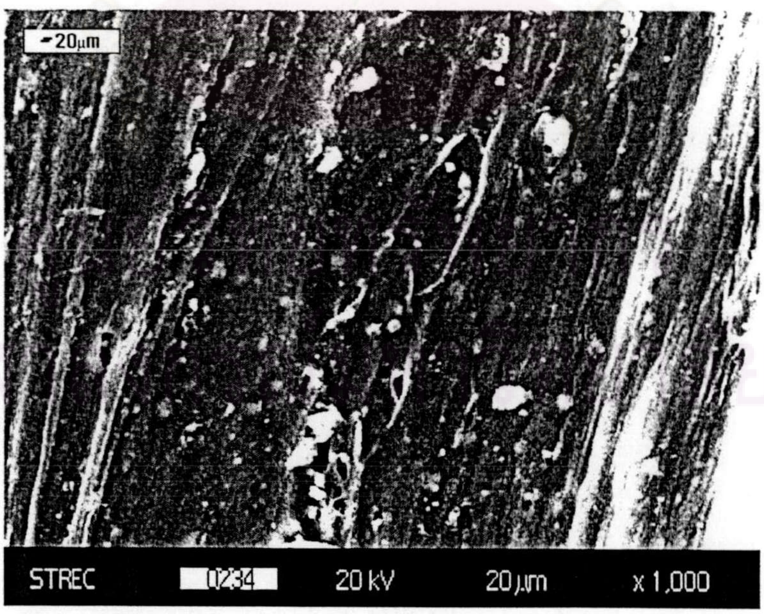

Figure 4.19 SEM micrograph of R-PVCOPS with $CaCO_3$ 20 phr at 1,000X magnification

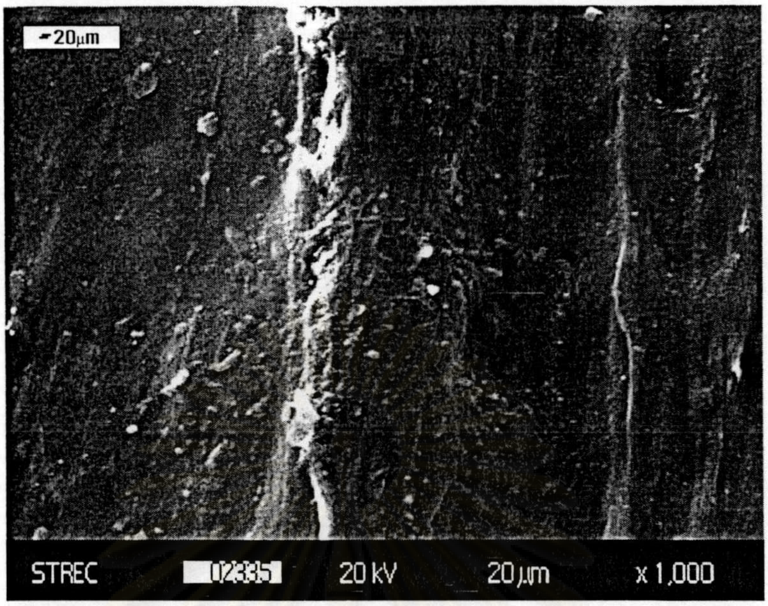

Figure 4.20 SEM micrograph of R-PVCOPS with talc 5 phr at 1,000X magnification

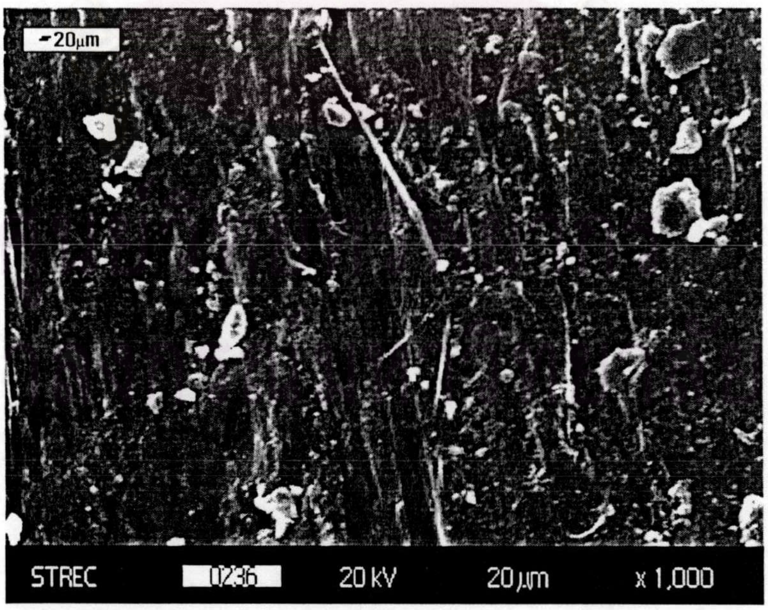

Figure 4.21 SEM micrograph of R-PVCOPS with talc 10 phr at 1,000X magnification

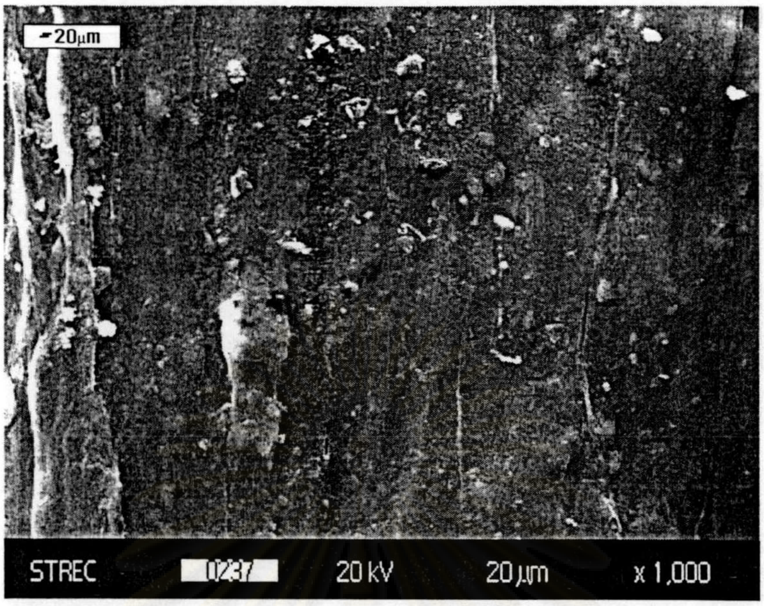

Figure 4.22 SEM micrograph of R-PVCOPS with talc 20 phr at 1,000X magnification

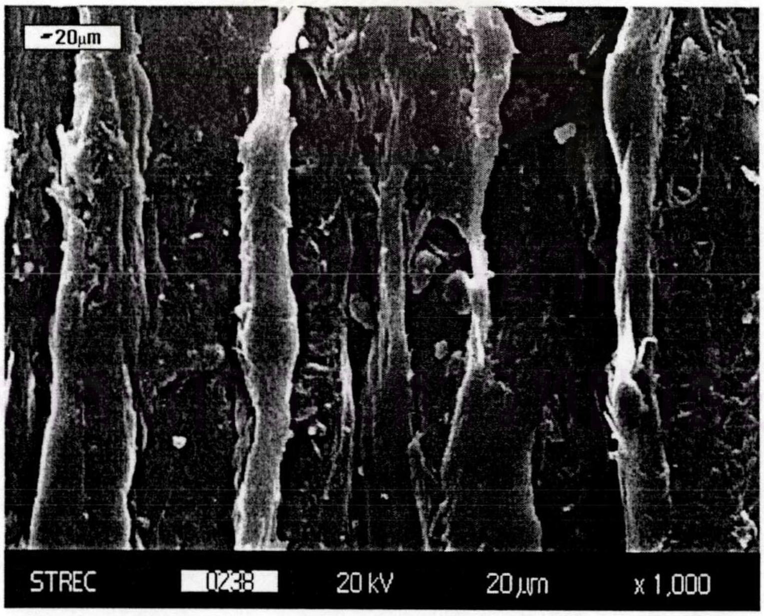

Figure 4.23 SEM micrograph of R-PVCOPS with kaolin 5 phr at 1,000X magnification

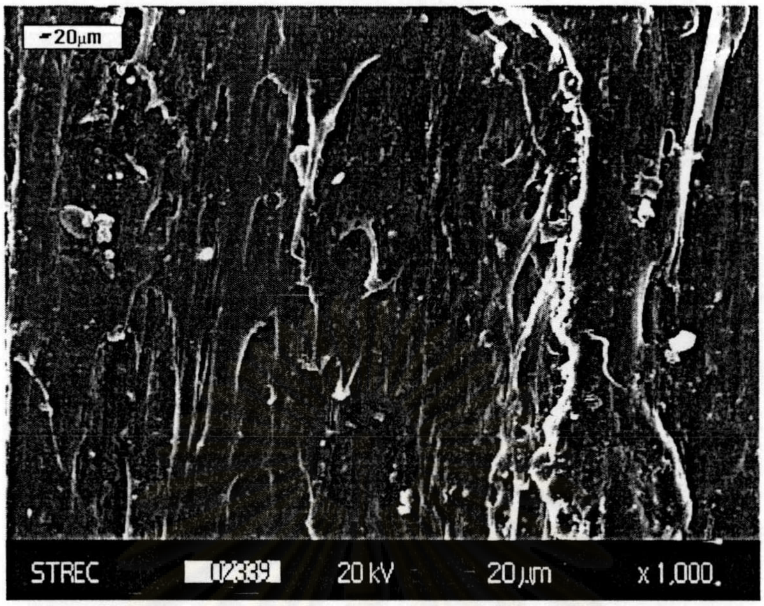

Figure 4.24 SEM micrograph of R-PVCOPS with kaolin 10 phr at 1,000X magnification

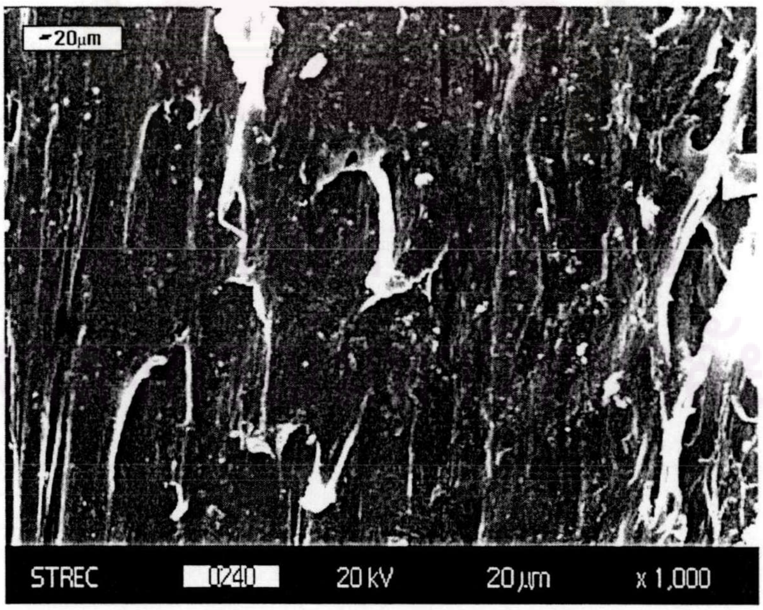

Figure 4.25 SEM micrograph of R-PVCOPS with kaolin 20 phr at 1,000X magnification

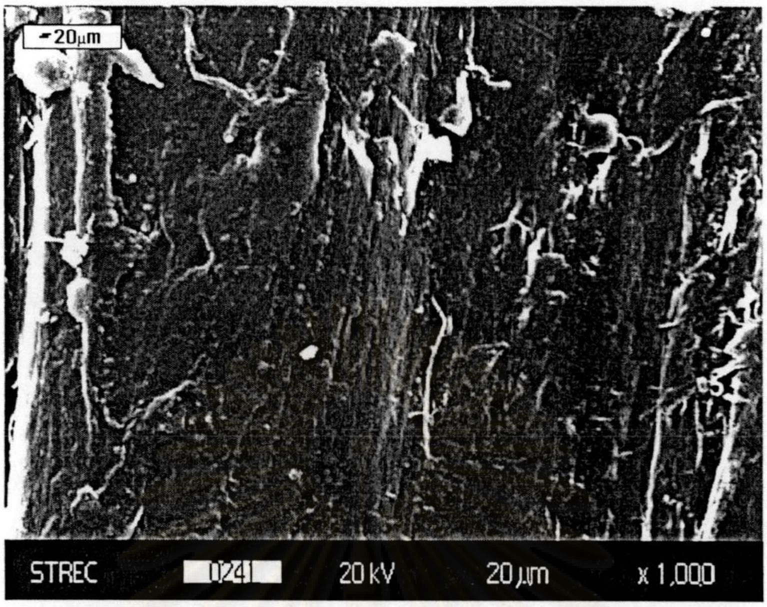

Figure 4.26 SEM micrograph of R-PVCOPS with $CaCO_3$/talc 5 phr at 1,000X magnification

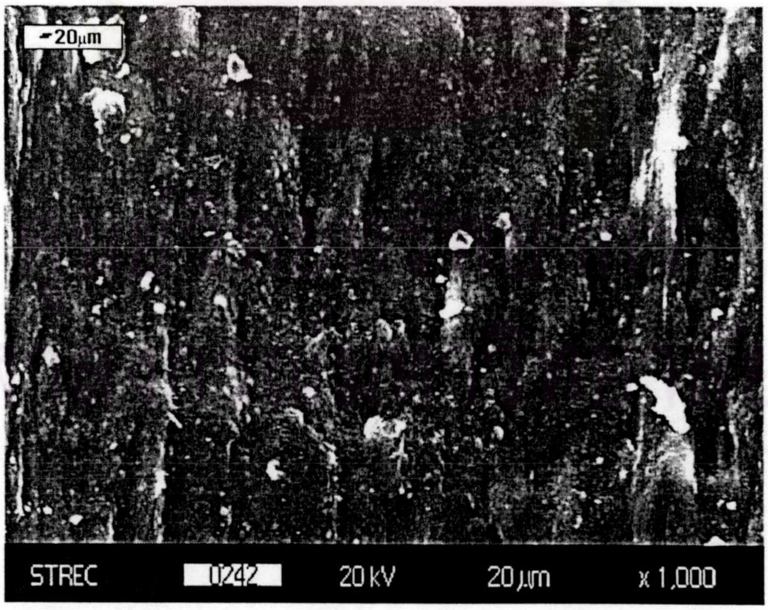

Figure 4.27 SEM micrograph of R-PVCOPS with $CaCO_3$/talc 10 phr at 1,000X magnification

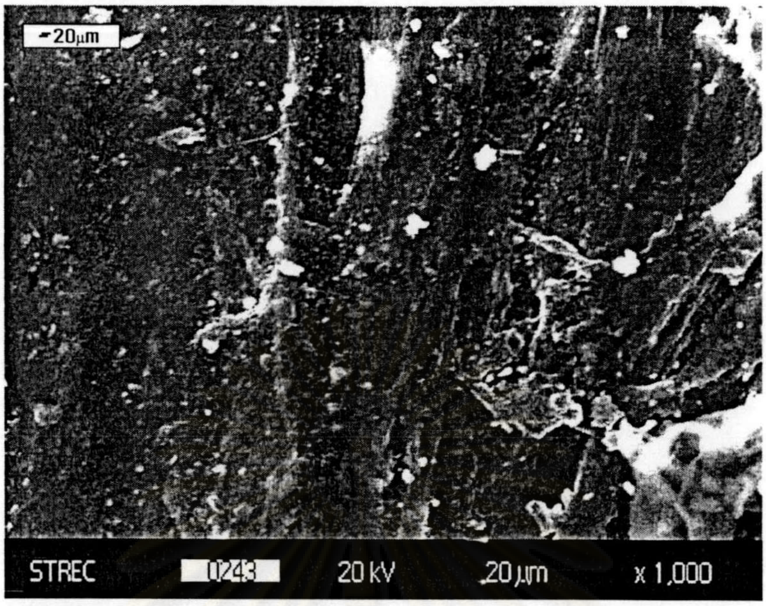

Figure 4.28 SEM micrograph of R-PVCOPS with $CaCO_3$/talc 20 phr at 1,000X magnification

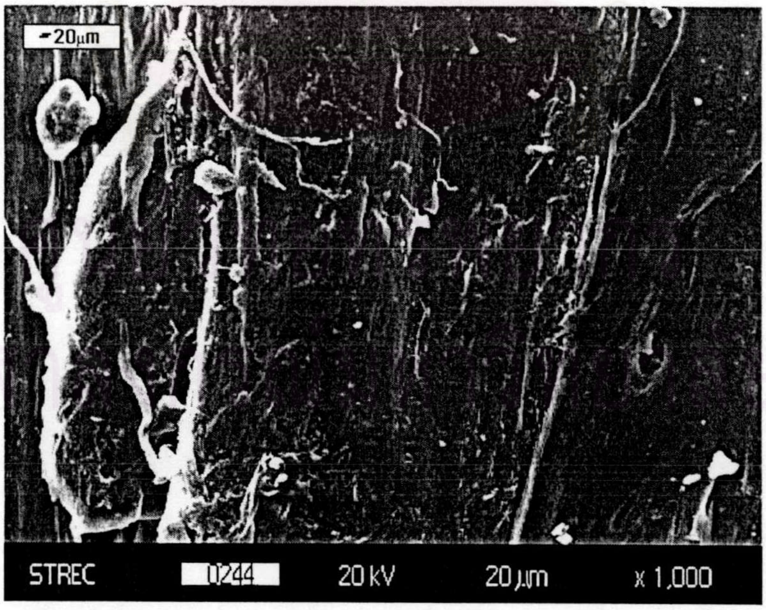

Figure 4.29 SEM micrograph of R-PVCOPS with $CaCO_3$/kaolin 5 phr at 1,000X magnification

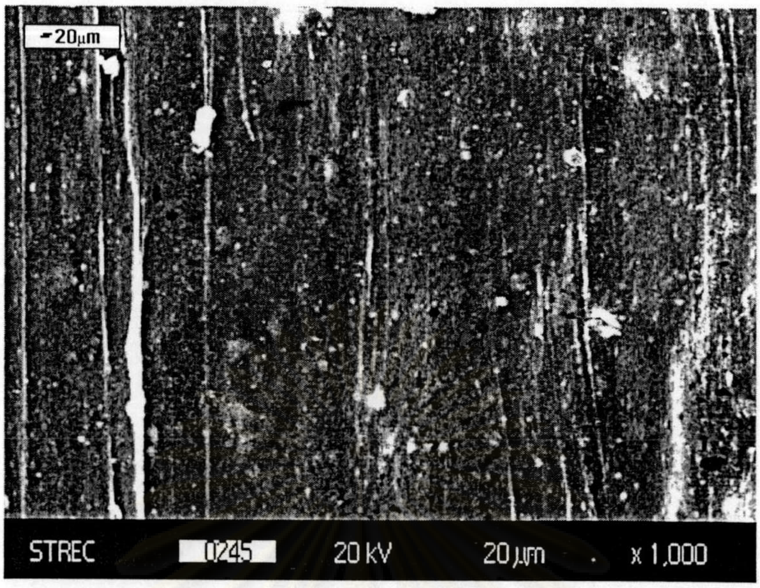

Figure 4.30 SEM micrograph of R-PVCOPS with $CaCO_3$/kaolin 10 phr at 1,000X magnification

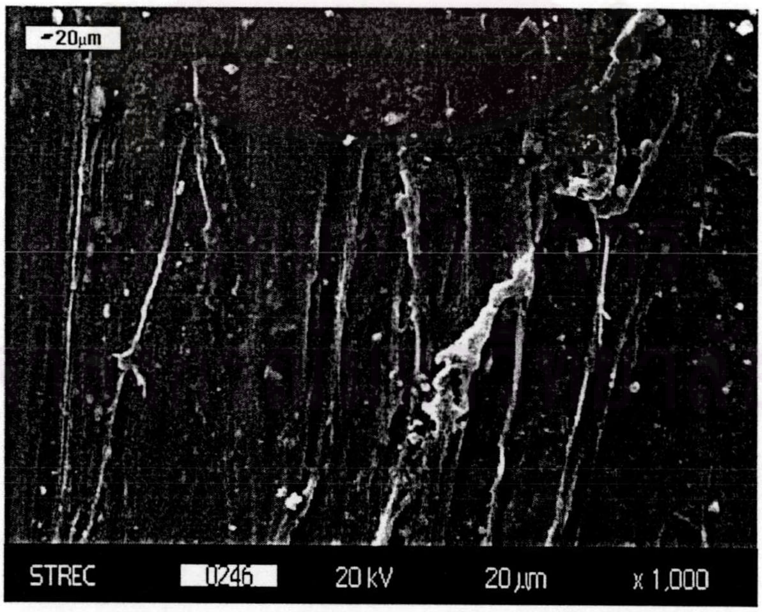

Figure 4.31 SEM micrograph of R-PVCOPS with $CaCO_3$/kaolin 20 phr at 1,000X magnification

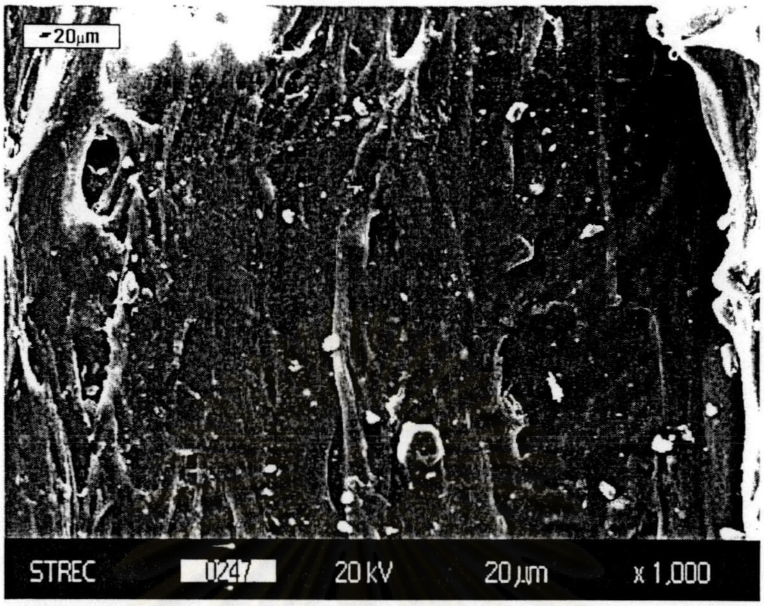

Figure 4.32 SEM micrograph of R-PVCOPS with talc/kaolin 5 phr at 1,000X magnification

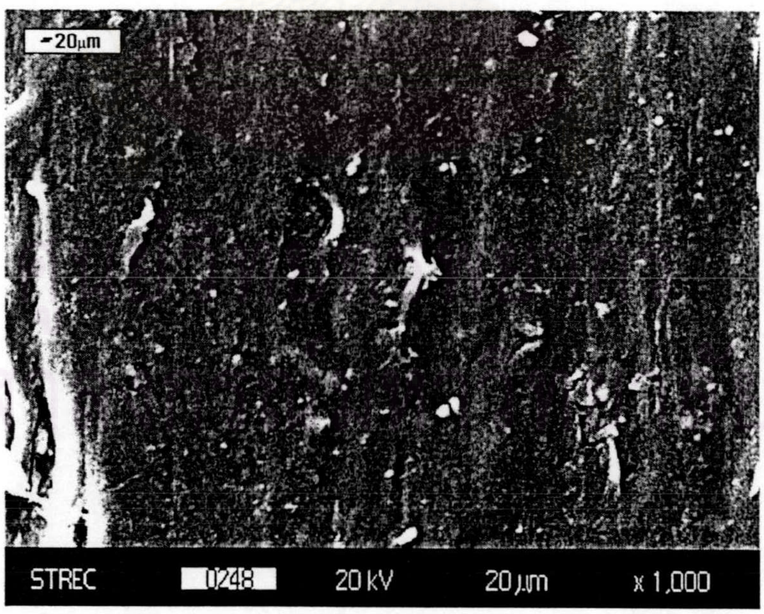

Figure 4.33 SEM micrograph of R-PVCOPS with talc/kaolin 10 phr at 1,000X magnification

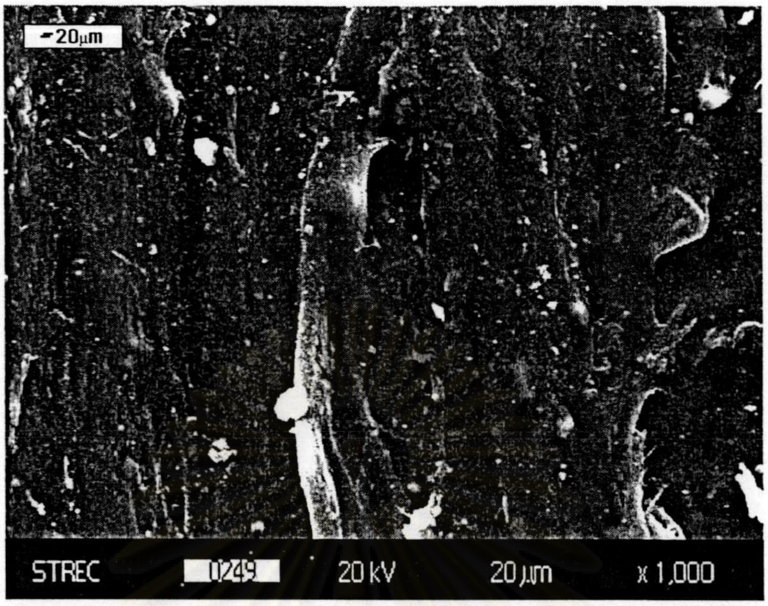

Figure 4.34 SEM micrograph of R-PVCOPS with talc/kaolin 20 phr at 1,000X magnification

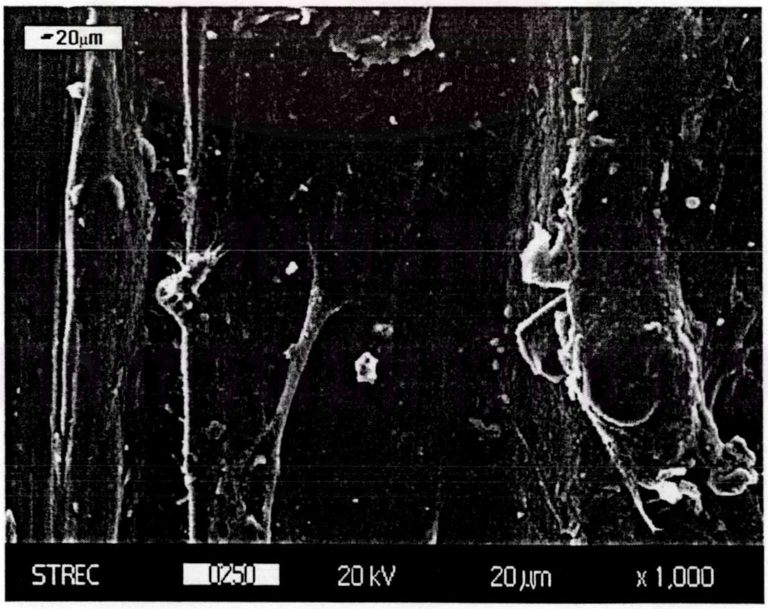

Figure 4.35 SEM micrograph of R-PVCOPS with $CaCO_3$/talc /kaolin (2.5: 1.5: 1) 5 phr at 1,000X magnification

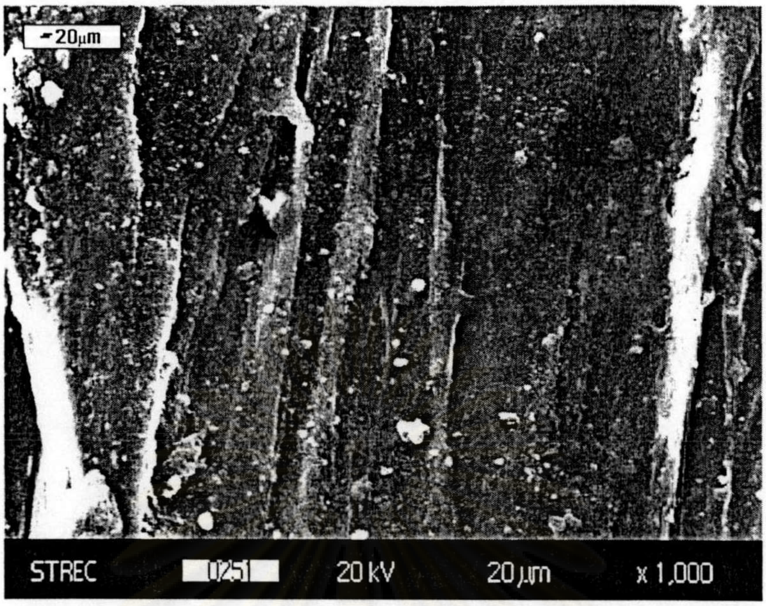

Figure 4.36 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (2.5: 1.5: 1) 10 phr at 1,000X magnification

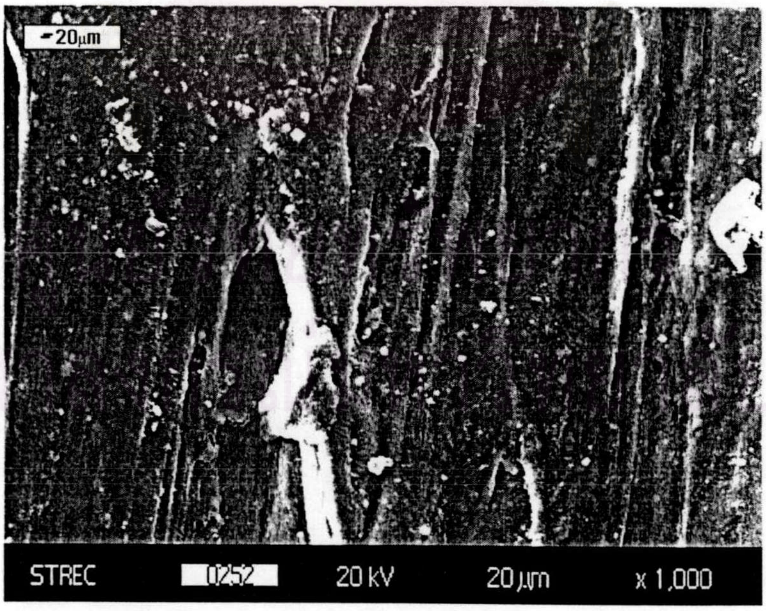

Figure 4.37 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (2.5: 1.5: 1) 20 phr at 1,000X magnification

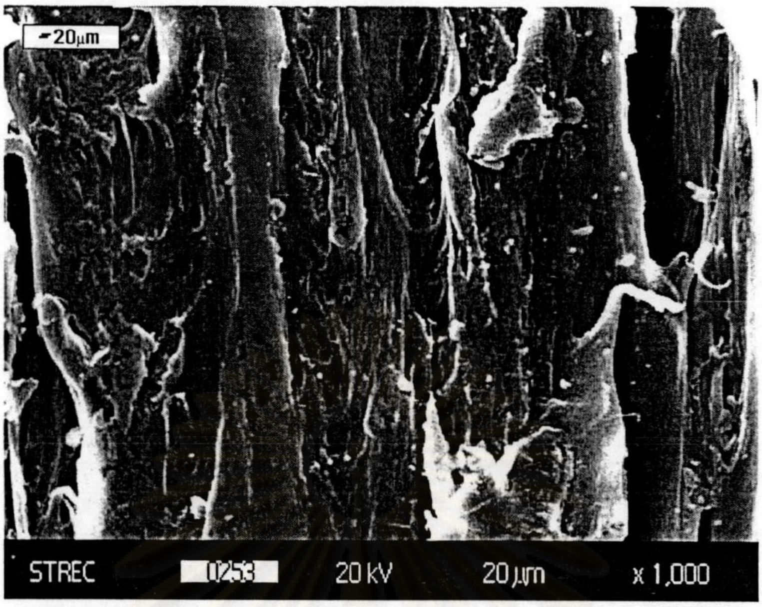

Figure 4.38 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (1: 2.5: 1.5) 5 phr at 1,000X magnification

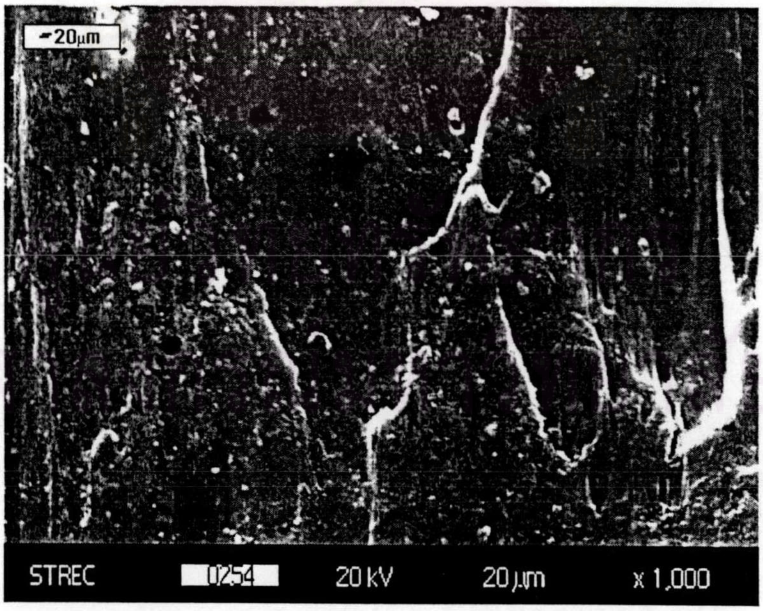

Figure 4.39 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (1: 2.5: 1.5) 10 phr at 1,000X magnification

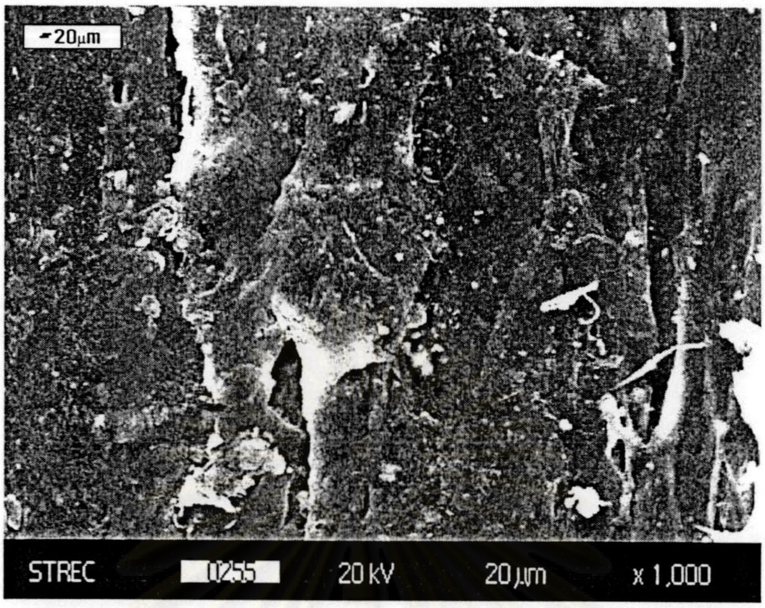

Figure 4.40 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (1: 2.5: 1.5) 20 phr at 1,000X magnification

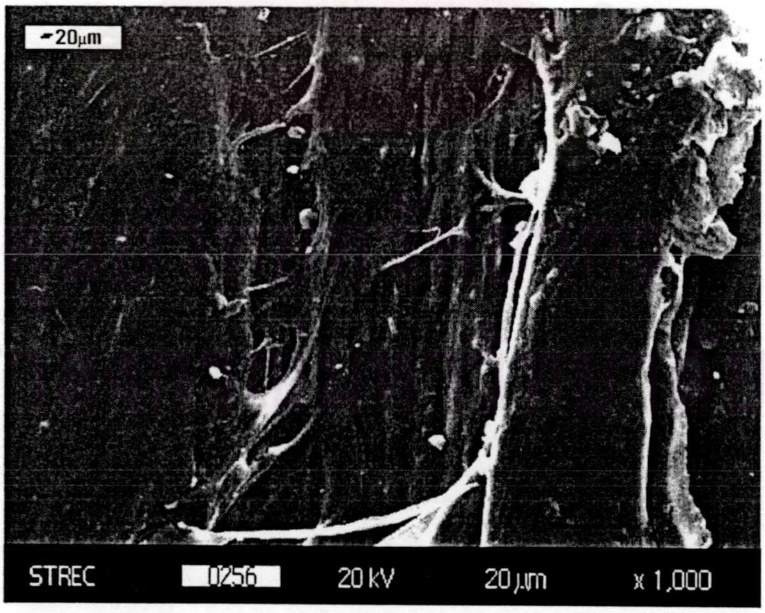

Figure 4.41 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (1.5: 1: 2.5) 5 phr at 1,000X magnification

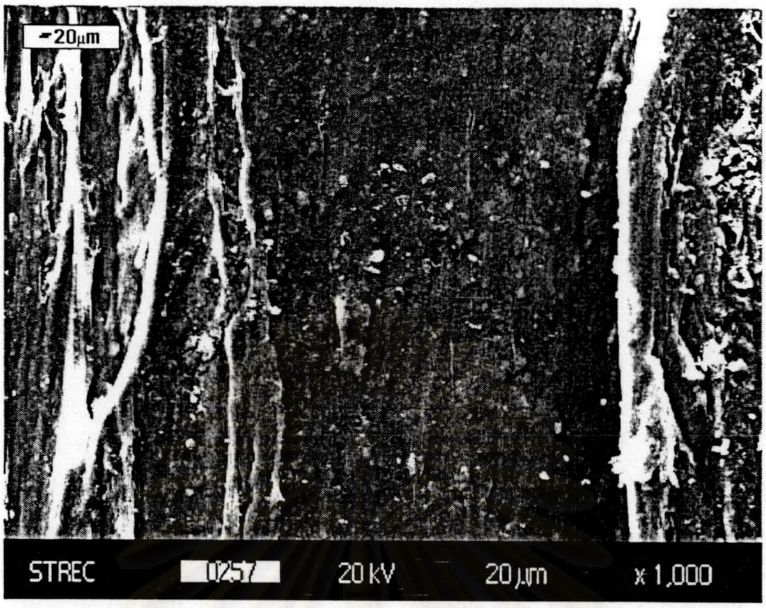

Figure 4.42 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (1.5: 1: 2.5) 10 phr at 1,000X magnification

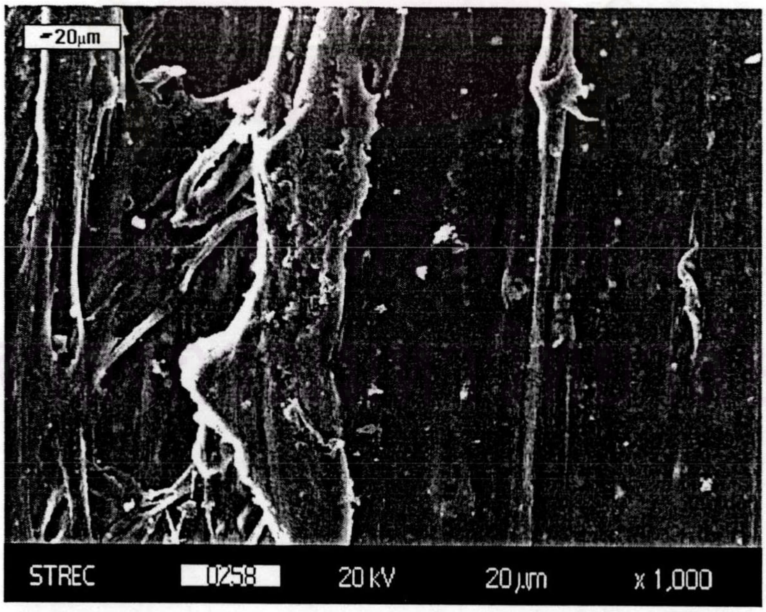

Figure 4.43 SEM micrograph of R-PVCOPS with $CaCO_3$ /talc /kaolin (1.5: 1: 2.5) 20 phr at 1,000X magnification

4.5 Comparison of Properties of New Products with Commercial Available Materials

Table A.2 in Appendix 1 shows the result of the mechanical properties and thermal properties of R-PVCOPS under the effect of fillers. The highest tensile strength, tear strength and HDT are contributed by the R-PVCOPS containing the filler ratio of $CaCO_3$/talcum/kaolin at 1 :2.5 :1.5 to make a total filler content of 10 phr. The mixture of $CaCO_3$/talcum at 1:1 at 10 phr gave the highest impact strength and % shrinkage. The mixted filler of $CaCO_3$/talcum at 10 phr is the best ratio since it has a low production cost and gave the proper property for the applications as shown in Table 4.17. Following Robert et al. [14] reported that a floor mat was produced from a mixture of PVC, plasticizer, stabilizer and $CaCO_3$ as filler in order to reduce cost.

4.6 Economic Consideration

Table 4.17 shows the cost comparison between the PVC new product incorporating talcum and $CaCO_3$ fillers at the ratio of 1:1 to a total concentration of 10 phr based on 100 phr of PVC, and the commercial product without filler. The result shows that the new PVC production costs 2.6 Baht/kg lower than the commercial one.

Table 4.17 Cost analysis between the PVC new product and the PVC commercial product

Particulate	Ingredient (phr)									Total cost (฿)
	PVC (SG 610)	Stabilizer (JF-50R)	Impact modifier (ABS)	Processing aid	Internal lubricant (G-161)	External lubricant (G-70S)	Type of filler (phr)			
							$CaCO_3$	Talc	Kaolin	
Price (฿/Kg)	30	185	70	100	83	175	3.2	8	19	643.2
Industrial formulation (phr)	100	1.8	7	2	0.55	0.65	-	-	-	112.00
Total cost (฿)	3,000	333	490	200	45.65	113.75	-	-	-	4,182.40
										37.34
Thesis formulation (phr)	100	1.8	7	2	0.55	0.65	5	5	-	122
Total cost (฿)	3,000	333	490	200	45.65	113.75	16	40	-	4,238.40
										34.74
									Diff.	2.60