CHAPTER IV

RESULTS AND DISCUSSIONS

The effect of silane coupling agent, glass fiber loading and the PVC/SAN composition on mechanical properties of glass fiber reinforced of PVC/SAN composites were studied. In this work, the composites were prepared by a two roll mill and then were pressed for molding in a compression machine. The properties such as tensile strength, tensile modulus, elongation at break, flexural strength, flexural modulus, hardness and heat distortion temperature were tested. The microstructure of tensile fracture were observed by means of scanning electron microscope (SEM).

4.1 Effect of Drying Temperature on Tensile Strength of Glass Fiber Reinforced PVC/SAN Composites

Table 4.1 shows the influence of the drying temperature on the tensile strength of glass fiber-reinforced composites. Generally speaking, silane coupling agents are often applied to substrate surface. Intermediate silanetriols form hydrogen bonds to the surface but ultimately condense to oxane bonds across the interface. This reaction may be driven to completion by drying at higher temperature[13]. Using the aminosilane and mercaptosilane coupling agents, the tensile strength increased with drying at higher temperature. The tensile strength reached a maximum value at drying condition of 170°C and 7 min. It can be inferred that this condition gave a maximum formation of oxane bond (MO-Si). This optimum drying condition was chosen for the following experiments.

Table 4.1 Effect of Drying Temperature on Tensile Strength

Drying condition	Tensile strength (MPa)	
	aminosilane	mercaptosilane
24 hr / room temperature	54.68±1.86	47.52±3.63
7 min. / 110 °C	49.06±0.95	46.83±0.97
7 min/ 130 °C	48.50±3.35	47.49±2.66
7min / 150 °C	52.56±2.75	44.00±2.09
7min / 170 °C	55.94±2.38	49.10±2.16

4.2 Effect of Silane Coupling Agent Concentration

Compatibility between glass fiber and PVC/SAN matrix is enhanced by using appropriate silane coupling agent. The heat-cleaned glass fiber was treated by the silane coupling agent. The treated fiber was dried at 170 °C for 7 min. Then the composites were fabricated by compression molding.

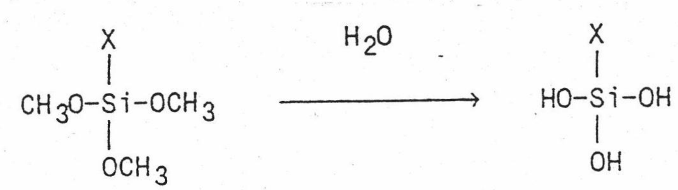
Table 4.2 and Figures 4.1-4.3 illustrate the effect of concentration of aminosilane coupling agent on tensile properties of composites. The aminosilane coupling agent improved the tensile strength of the PVC/SAN composites containing 10%, 20% and 30% glass fiber. Figures 4.1-4.3 show that the composites containing aminosilane coupling agent treated glass fiber had a higher tensile strength than did the untreated-glass fiber composites. The tensile strength reached a maximum value at 0.5% aminosilane concentration. Further increase in aminosilane coupling agent (1%

and 1.5%) produced the decrease in tensile strength. Therefore, the optimum aminosilane concentration was 0.5%.

Figures 4.4-4.6 illustrate the effect of concentration of mercaptosilane coupling agent on tensile strength of the composites. The mercaptosilane coupling agent could improve the tensile strength of the composites containing 10%, 20% and 30% glass fiber. Figures 4.4-4.6 illustrate that the composites containing mercaptosilane coupling agent treated glass fiber had a higher tensile strength than did the untreated glass fiber composites. The tensile strength reached a maximum value at 2% mercaptosilane concentration. Thus, the optimum mercaptosilane concentration was 2%.

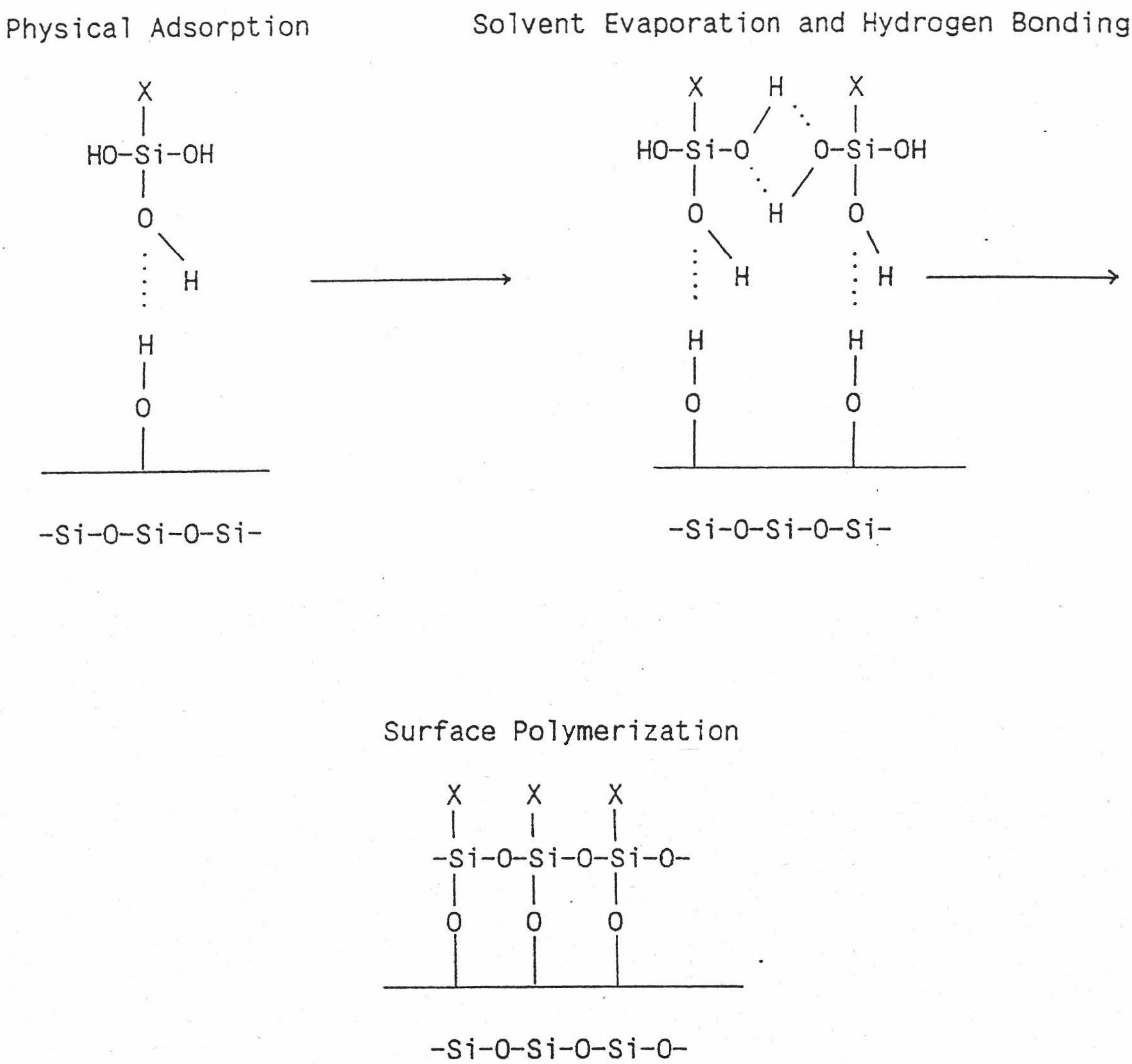
According to the results, it can be seen that there is an interfacial adhesion induced by any silane coupling agent between the fiber and the matrix. Indeed, in the absence of such adhesion, the fiber would act as a void and therefore stress concentration exists, thereby it reduces the tensile strength of the filler/polymer matrix composites. [21]

Aminosilane and mercaptosilane are organofunctional silane generally recommended for coupling reaction which occurs in the interface between PVC/SAN and glass fiber. Firstly, silane coupling agent was prehydrolyzed and applied to the fibers through a dilute aqueous solution. Secondly, upon drying, silanetriols of the coupling agent condense with silanetriols of the fibers to form covalent siloxane bond with the surface. Finally, it reacts with the polymer. The coupling reactions can be shown as follows:



Trialkoxy silane X = $HS(CH_2)_3Si$

$NH_2(CH_2)_3Si$



The silanes readily form three-dimensional polysiloxane networks through hydrolysis and condensation of the alkoxy groups[13,14]. Then, the polymeric siloxane segments may interdiffuse among PVC/SAN chains with cross-linked structure in PVC.

For the formation of cross-linked structure in PVC, it could be occurred by the reaction of PVC with mercaptosilane coupling agent to yield the silane-grafted PVC that was cross-linked by the hydrolytic mechanism. The grafting of the silanes on PVC was carried out at 180°C during processing in the presence of tribasic leadsulfate.

Table 4.2 Effect of Concentration of Aminosilane and Mercaptosilane Coupling Agent on Tensile Strength.

Composites	Tensile Strength (MPa)	Composites	Tensile Strength (MPa)
B60/40-G10	43.37±2.08		
B60/40-G20	41.56±6.30		
B60/40-G30	30.58±1.23		
B70/30-G10	49.83±6.13		
B70/30-G20	54.29±1.06		
B70/30-G30	48.17±3.47		
B80/20-G10	50.26±0.99		
B80/20-G20	38.34±0.97		
B80/20-G30	31.07±0.94		
B60/40-G10/A0.5	55.94±2.38	B60/40-G10/M0.5	49.10±0.97
B60/40-G20/A0.5	63.83±3.36	B60/40-G20/M0.5	53.50±2.23
B60/40-G30/A0.5	69.90±1.44	B60/40-G30/M0.5	62.64±2.10
B60/40-G10/A1.0	50.46±4.39	B60/40-G10/M1.0	57.13±1.83
B60/40-G20/A1.0	59.26±5.86	B60/40-G20/M1.0	60.26±1.56
B60/40-G30/A1.0	61.68±1.68	B60/40-G30/M1.0	60.13±2.57
B60/40-G10/A1.5	39.33±3.80	B60/40-G10/M1.5	58.82±3.80
B60/40-G20/A1.5	54.57±4.48	B60/40-G20/M1.5	53.72±3.73
B60/40-G30/A1.5	64.61±1.37	B60/40-G30/M1.5	65.66±2.36
		B60/40-G10/M2.0	62.92±6.70
		B60/40-G20/M2.0	65.18±4.66
		B60/40-G30/M2.0	73.59±3.50

Table 4.2 (continued)

Composites	Tensile Strength (MPa)	Composites	Tensile Strength (MPa)
B70/30-G10/A0.5	59.07±2.45	B70/30-G10/M0.5	61.79±1.37
B70/30-G20/A0.5	62.50±1.47	B70/30-G20/M0.5	61.56±1.13
B70/30-G30/A0.5	65.66±1.89	B70/30-G30/M0.5	64.02±2.08
B70/30-G10/A1.0	57.04±2.66	B70/30-G10/M1.0	55.78±1.36
B70/30-G20/A1.0	61.02±1.63	B70/30-G20/M1.0	58.21±1.73
B70/30-G30/A1.0	65.51±1.39	B70/30-G30/M1.0	61.58±1.68
B70/30-G10/A1.5	54.94±4.33	B70/30-G10/M1.5	59.04±0.53
B70/30-G20/A1.5	59.67±5.04	B70/30-G20/M1.5	55.81±3.48
B70/30-G30/A1.5	59.47±2.12	B70/30-G30/M1.5	66.59±0.84
		B70/30-G10/M2.0	63.09±1.19
		B70/30-G20/M2.0	63.96±2.81
		B70/30-G30/M2.0	78.91±0.80
B80/20-G10/A0.5	60.62±0.87	B80/20-G10/M0.5	60.60±2.92
B80/20-G20/A0.5	64.90±2.01	B80/20-G20/M0.5	67.62±3.14
B80/20-G30/A0.5	68.93±2.47	B80/20-G30/M0.5	66.62±7.91
B80/20-G10/A1.0	58.09±2.85	B80/20-G10/M1.0	51.67±5.16
B80/20-G20/A1.0	64.40±1.19	B80/20-G20/M1.0	60.29±6.50
B80/20-G30/A1.0	64.46±1.01	B80/20-G30/M1.0	45.93±1.19
B80/20-G10/A1.5	56.68±0.69	B80/20-G10/M1.5	63.44±1.08
B80/20-G20/A1.5	61.23±0.58	B80/20-G20/M1.5	69.55±1.31
B80/20-G30/A1.5	60.93±1.33	B80/20-G30/M1.5	83.26±7.59
		B80/20-G10/M2.0	65.69±1.66
		B80/20-G20/M2.0	78.53±4.55
		B80/20-G30/M2.0	88.56±2.67

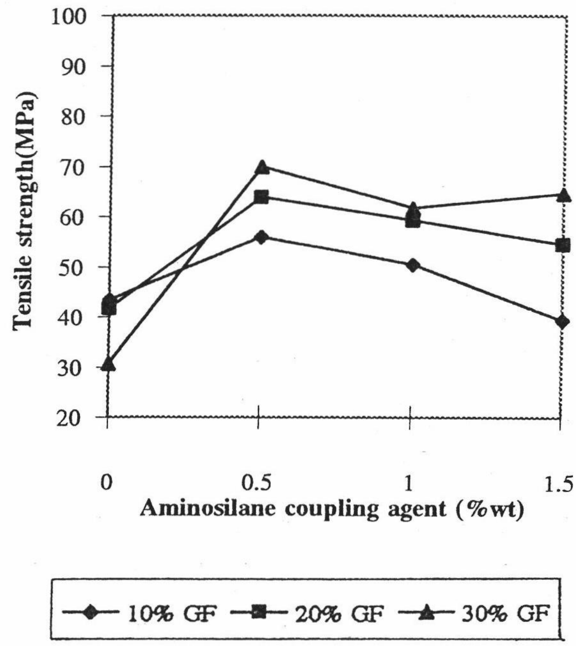


Figure 4.1 Effect of aminosilane coupling agent concentration on tensile strength of PVC 60/SAN 40 composites.

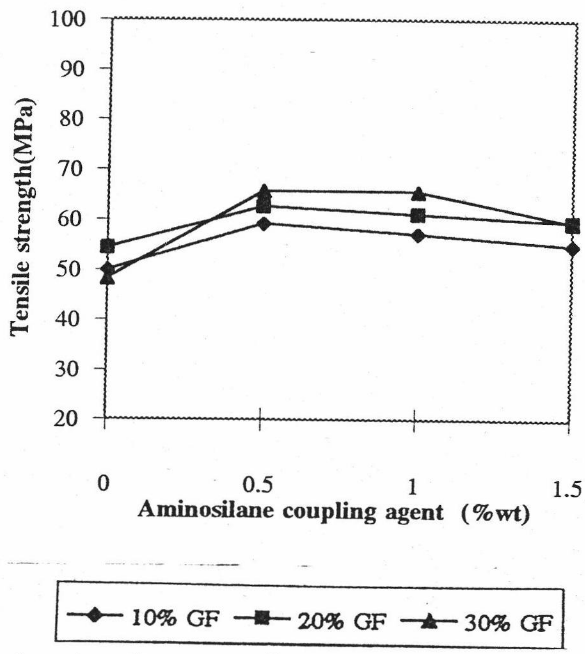


Figure 4.2 Effect of aminosilane coupling agent concentration on tensile strength of PVC 70/SAN 30 composites.

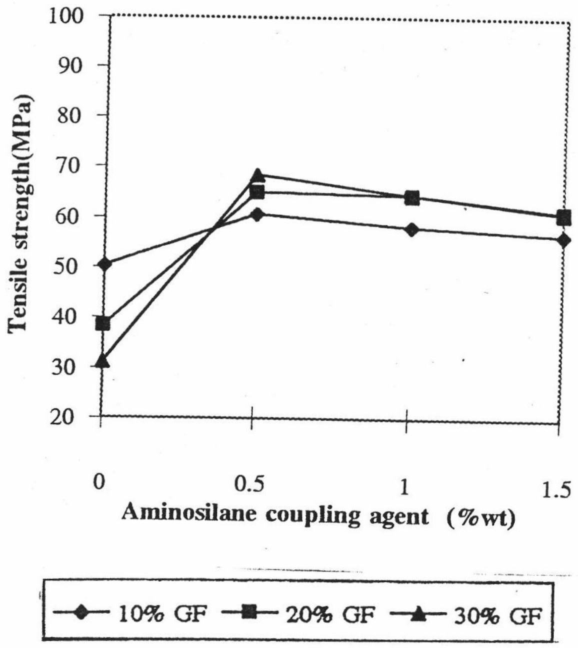


Figure 4.3 Effect of aminosilane coupling agent concentration on tensile strength of PVC 80/SAN 20 composites.

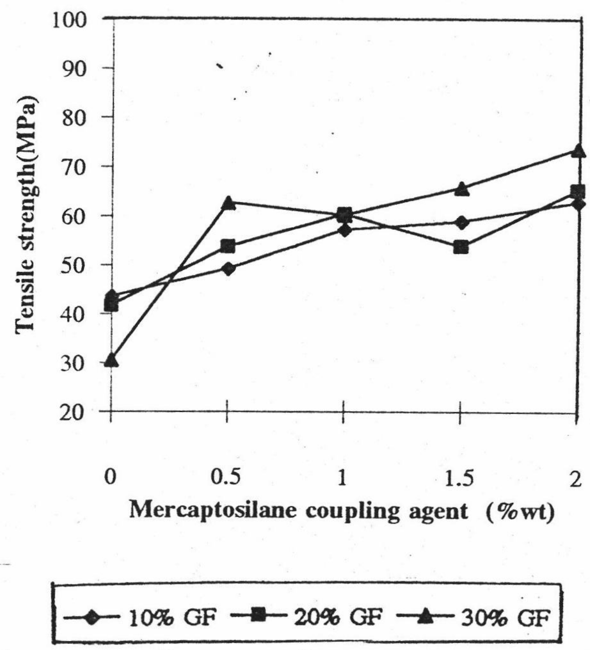


Figure 4.4 Effect of mercaptosilane coupling agent concentration on tensile strength of PVC 60/SAN 40 composites.

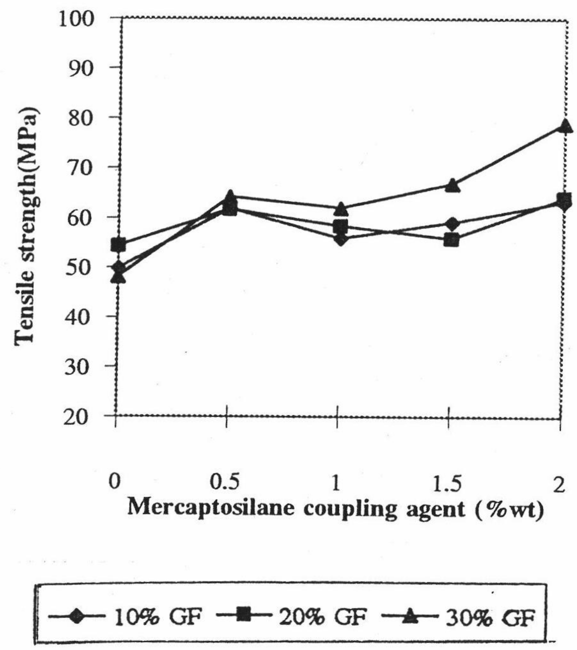


Figure 4.5 Effect of mercaptosilane coupling agent concentration on tensile strength of PVC 70/SAN 30 composites.

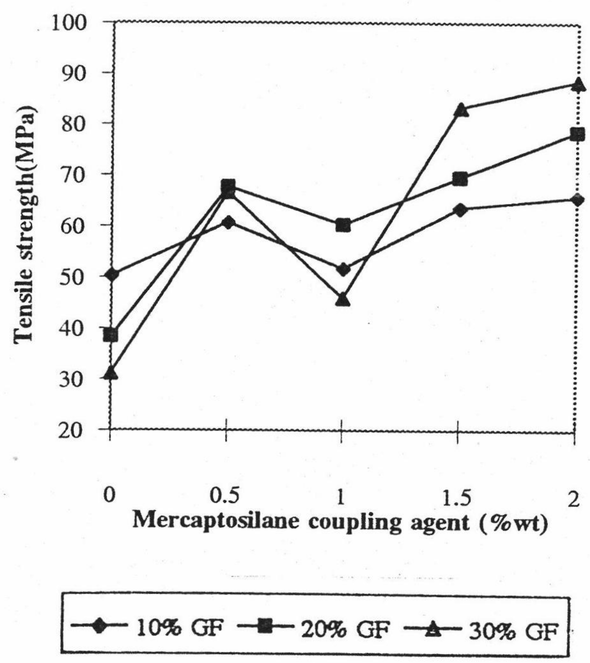


Figure 4.6 Effect of mercaptosilane coupling agent concentration on tensile strength of PVC 80/SAN 20 composites.

4.3 Mechanical Properties of the Composites

Mechanical properties of the glass fiber-PVC/SAN composites can indicate the performance behavior of the interfacial adhesion between the glass fiber and the matrix. The greater the interfacial adhesion, the better the mechanical properties. In this work, the mechanical properties tested were the tensile properties, flexural properties, hardness and heat distortion temperature. To select materials for engineering design so as to fabricate any products, one should know the proper properties for the respective functions and performance applications. Table 4.4 exhibits the tensile, flexural properties, hardness and heat distortion temperature of the glass fiber-PVC/SAN composites at various PVC/SAN ratios and glass fiber loadings. The mechanical properties of composites treated with aminosilane and mercaptosilane coupling agent were compared.

Table 4.3 Effect of Different Coupling Agents on Mechanical Properties of the Composites at Various PVC/SAN Compositions and Percents of Glass Fiber.

Composite	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at Break (%)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Hardness (M-Scale)	HDT (oC)	Glass Fiber Content (%wt)	Void Content (%v)
B60/40	32.17±2.72	52.66±5.56	1.03±0.06	32.35±4.81	3.61±0.74				
B60/40-G10	43.37±2.08	31.73±13.35	1.76±0.26	43.79±10.91	4.15±0.12				
B60/40-G20	41.65±6.30	14.35±7.26	1.73±0.44	38.94±3.04	3.18±0.30				
B60/40-G30	30.58±1.23	11.77±1.59	178±0.17	61.70±3.89	5.50±0.50			29.24	4.09
B60/40-G10/A0.5	55.94±2.38	70.70±58.42	1.79±0.80	86.25±12.15	4.83±0.22	13.0		10.17	0.90
B60/40-G20/A0.5	63.83±3.36	18.85±7.91	2.23±0.29	66.38±4.51	4.68±0.34	18.5		21.16	1.21
B60/40-G30/A0.5	69.90±1.44	18.92±8.63	2.02±0.18	102.68±7.50	7.38±0.56	27.7	83.8	28.10	1.85
B60/40-G10/M2.0	62.92±6.70	20.83±5.01	2.19±0.45	83.33±5.55	5.11±0.33	29.8		10.17	1.12
B60/40-G20/M2.0	65.18±4.66	24.26±22.52	2.06±0.34	85.89±2.95	6.15±0.42	30.7		19.32	1.22
B60/40-G30/M2.0	73.59±3.50	26.27±10.19	2.16±0.19	101.89±8.83	6.64±0.70	46.0	83.2	28.60	3.00
B70/30	32.77±6.19	30.63±2.49	1.49±0.43	44.18±3.71	4.08±0.22				
B70/30-G10	49.83±6.13	7.05±2.56	2.98±0.58	65.16±4.56	3.44±0.24				
B70/30-G20	54.29±1.06	12.26±1.82	3.34±0.23	62.02±2.34	4.16±0.34				
B70/30-G30	48.16±3.47	17.83±13.41	2.45±0.25	67.04±3.40	4.67±0.52	31.3		27.48	1.48
B70/30-G10/A0.5	59.07±2.45	9.62±9.44	3.49±0.45	89.15±1.72	5.76±0.19	32.0	77.5	10.00	2.07

Table 4.3 (continued)

Composite	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at Break (%)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Hardness (M-Scale)	HDT (oC)	Glass Fiber Content (%wt)	Void Content (%v)
B70/30-G20/A0.5	62.49±1.47	14.84±15.87	2.83±0.54	97.68±2.72	5.97±0.19	46.3	78.5	19.46	1.58
B70/30-G30/A0.5	65.66±1.89	26.96±15.89	2.61±0.15	100.86±2.21	6.63±0.19	45.9	80.1	28.90	1.48
B70/30-G10/M2.0	63.09±1.19	19.32±4.74	2.70±0.40	99.34±5.82	4.69±0.45	38.8	77.9	9.38	1.23
B70/30-G20/M2.0	63.96±2.81	31.81±12.67	1.65±0.31	112.24±2.61	6.32±0.16	58.5	80.9	20.36	2.15
B70/30-G30/M2.0	78.91±0.80	32.69±27.29	2.62±0.17	110.33±2.42	6.97±0.32	72.1	81.8	30.21	1.41
B80/20	50.64±2.13	17.87±5.63	6.93±4.09	60.87±9.66	4.58±0.37				
B80/20-G10	50.26±0.99	7.89±3.48	3.53±0.12	50.05±1.17	3.24±0.12		72.8	11.12	1.01
B80/20-G20	38.34±0.97	8.25±3.50	3.18±0.23	73.62±3.28	4.68±0.45		75.8	20.99	1.46
B80/20-G30	31.07±0.94	8.62±3.34	3.05±0.05	76.05±2.79	5.66±0.35	37.3	77.9	28.87	2.23
B80/20-G10/A0.5	60.62±0.87	17.72±10.73	3.08±0.27	91.16±8.45	4.40±0.61	57.2	77.5	9.87	3.96
B80/20-G20/A0.5	64.90±2.01	27.20±17.91	2.45±0.41	97.80±2.97	5.72±0.38	68.5	78.8	19.14	1.02
B80/20-G30/A0.5	68.39±2.47	32.08±9.76	1.64±0.27	103.30±2.49	6.12±0.48	68.4	80.7	28.58	1.12
B80/20-G10/M2.0	65.69±1.66	17.20±8.08	3.39±0.21	95.93±11.20	4.05±0.64	58.9	76.7	10.16	3.20
B80/20-G20/M2.0	78.53±4.55	27.19±8.05	2.78±0.21	109.07±7.24	5.69±0.41	67.6	79.3	19.45	1.59
B80/20-G30/M2.0	88.56±2.67	29.02±4.31	2.61±0.08	121.99±7.74	7.12±1.04	77.7	81.1	29.26	2.16

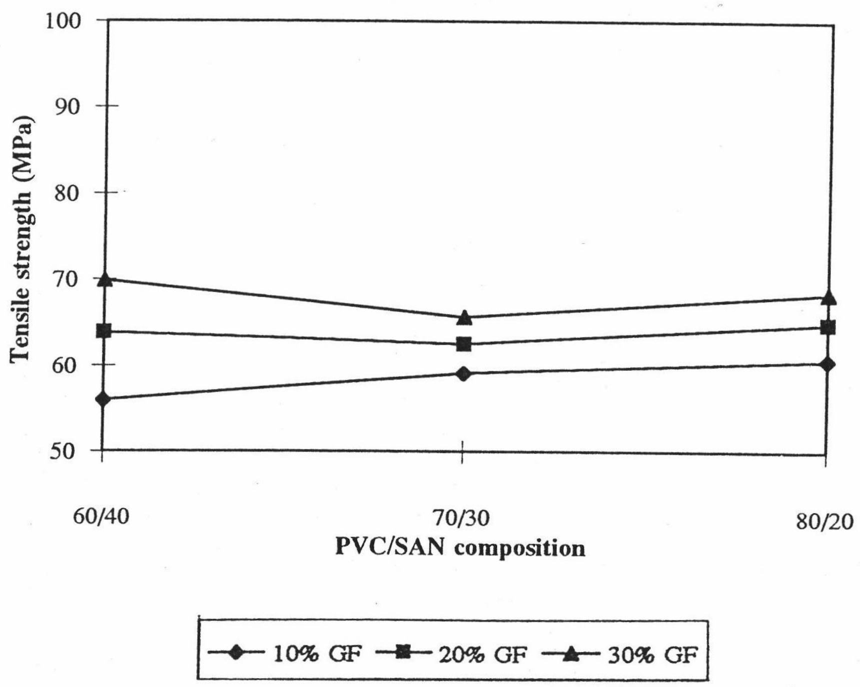
4.4 Effect of PVC/SAN Composition

The effect of PVC/SAN composition on mechanical properties of the GF-reinforced PVC/SAN composites is shown in Figures 4.7-4.10. From Figures 4.7-4.8, the tensile strength and flexural strength increased with increasing PVC/SAN ratio (60/40, 70/30 and 80/20). Tensile strength and flexural strength of composites containing aminosilane were improved slightly. Tensile strength and flexural strength of composites containing mercaptosilane were improved tremendously. The glass fiber-reinforced composite at PVC/SAN ratio of 80:20 had specially provided the highest strength.

The hardness of the GF-reinforced composites at various PVC/SAN compositions are presented in Figure 4.9. It indicated that the hardness of the composites increased with PVC/SAN ratio. The hardness of the composite at PVC/SAN ratio of 80:20 reached the highest value.

Figure 4.10 illustrates the effect of PVC/SAN composition on the heat distortion temperature (HDT). The heat distortion temperature decreased with increasing PVC/SAN ratio (or SAN content reduction).

In this work, the chosen PVC/SAN compositions used were 60/40, 70/30 and 80/20. It can be seen that the increase of PVC content resulted in a formation of more cross-linked structure in PVC especially at PVC/SAN ratio of 80:20. This is the explanation of the higher tensile strength, flexural strength and hardness of the GF-reinforced PVC 80/SAN 20 composites.



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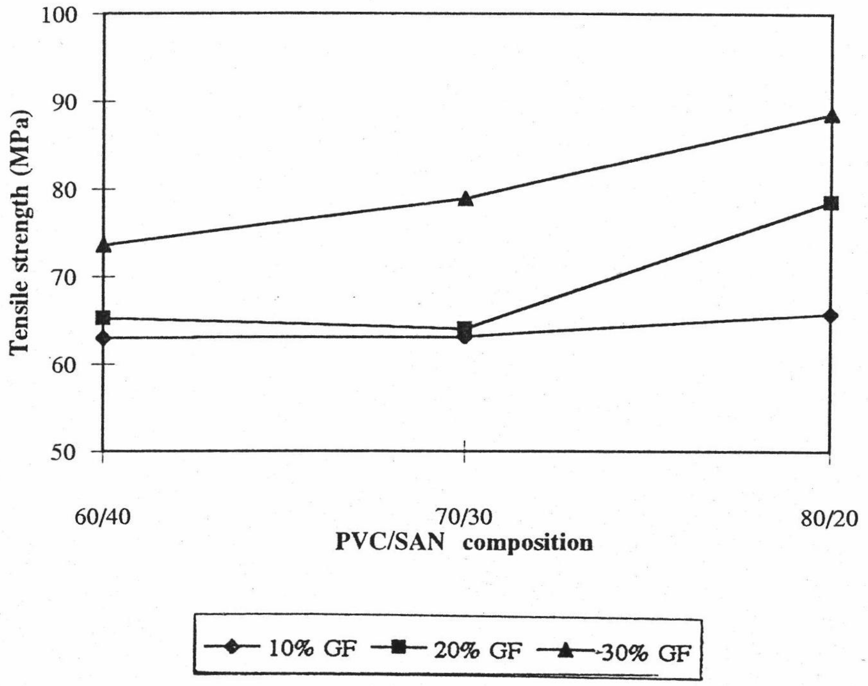
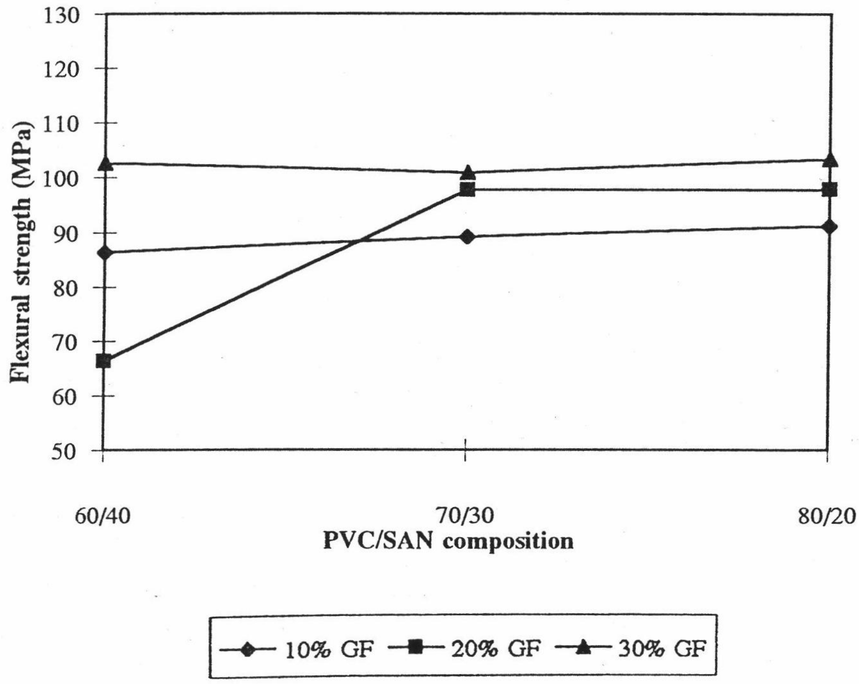


b)

Figure 4.7 Effect of PVC/SAN composition on tensile strength of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



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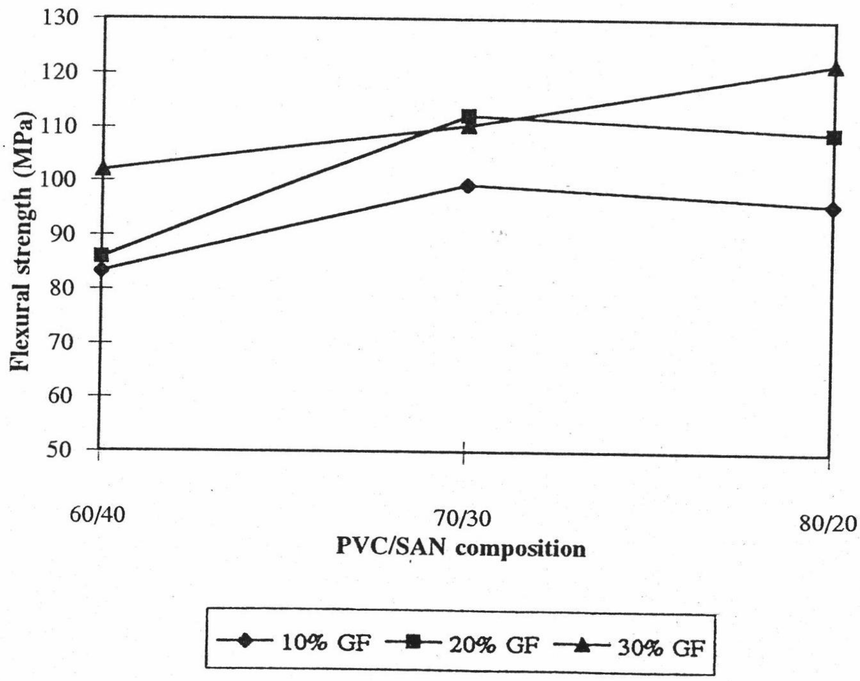
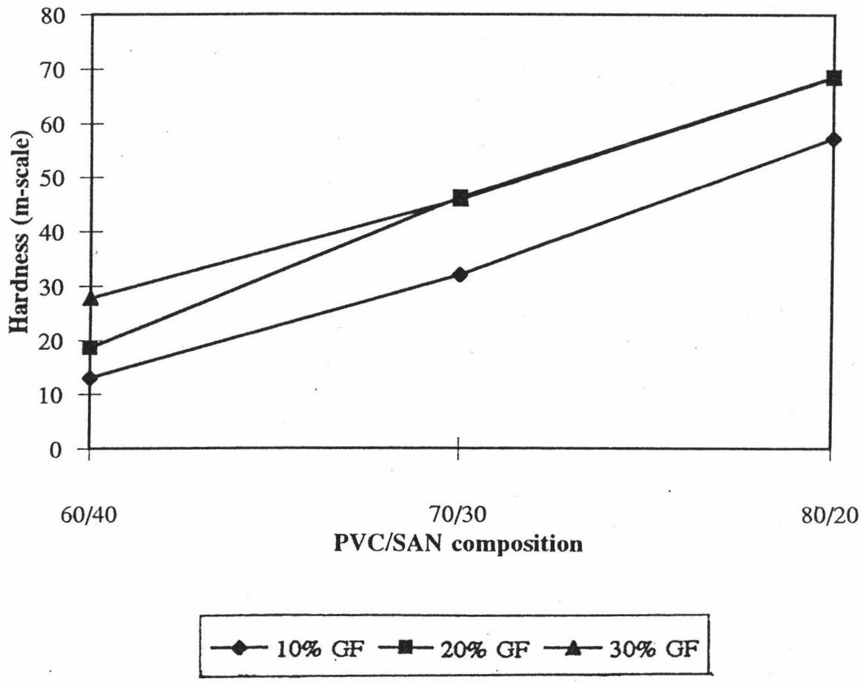


b)

Figure 4.8 Effect of PVC/SAN composition on flexural strength of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



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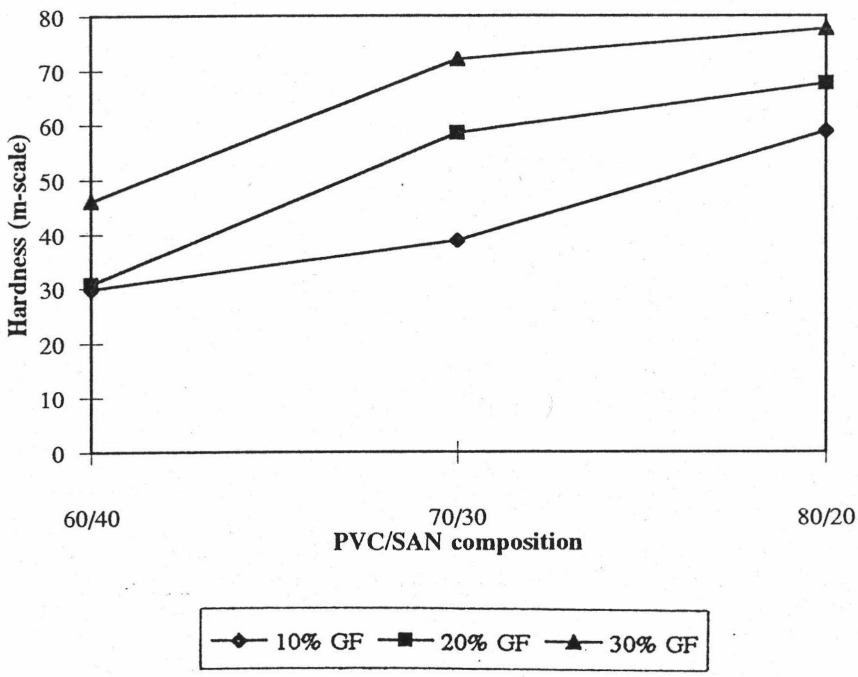
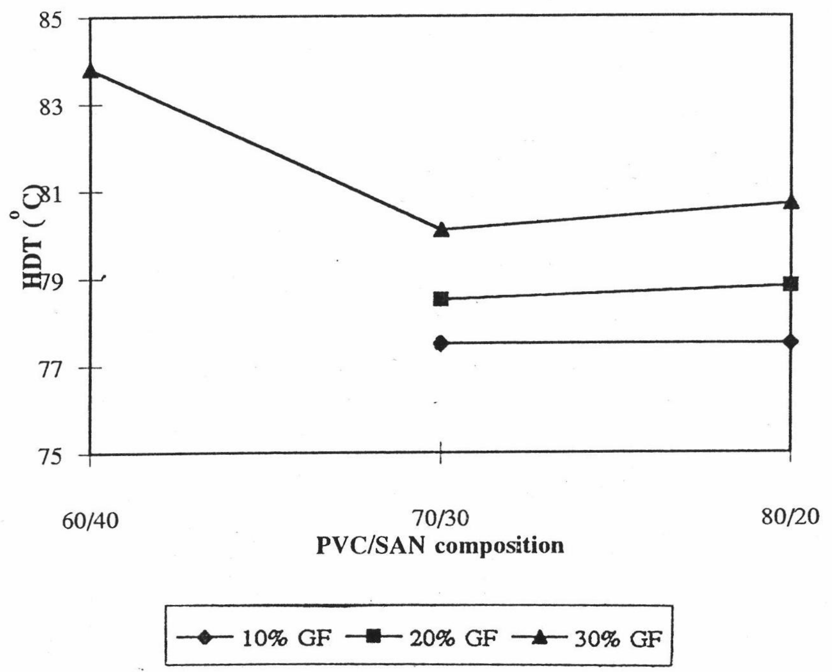


b)

Figure 4.9 Effect of PVC /SAN composition on hardness of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



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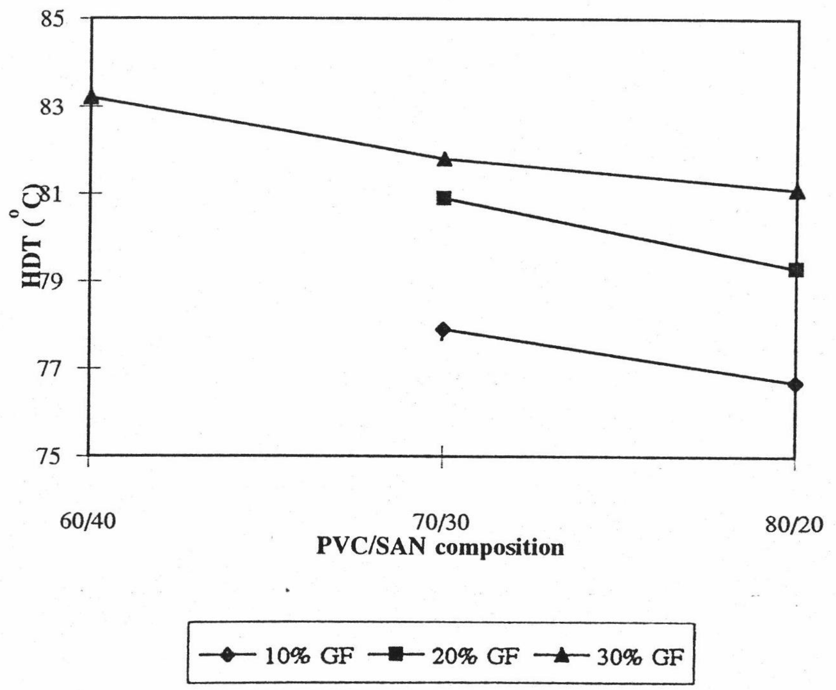


b)

Figure 4.10 Effect of PVC /SAN composition on HDT of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%

4.5 Effect of Glass Fiber Loading

The glass fiber loading is an important variable of mechanical properties of the composites. The enhancement of the mechanical properties of composites was obtained by the increase of glass fiber content. Figures 4.11-4.17 show the effect of glass fiber loading on mechanical properties of the GF-reinforced PVC/SAN composites. The variation of properties with the addition of glass fiber to PVC/SAN composites is discussed as follows.

From Figure 4.11, the tensile strength of the composites increased with increasing glass fiber loading. This effect was attributed to the coupling interaction between the treated glass fiber and the PVC/SAN matrix, which yielded the good interfacial adhesion. The PVC 80/SAN 20 composite containing 30% glass fiber treated with mercaptosilane had the highest tensile strength.

The tensile modulus of the composites increased with increasing glass fiber content as shown in Figure 4.12 (except the PVC 60/SAN 40 composite containing aminosilane coupling agent). From Figure 4.13, the elongation at break decreased gradually with increasing glass fiber loading.

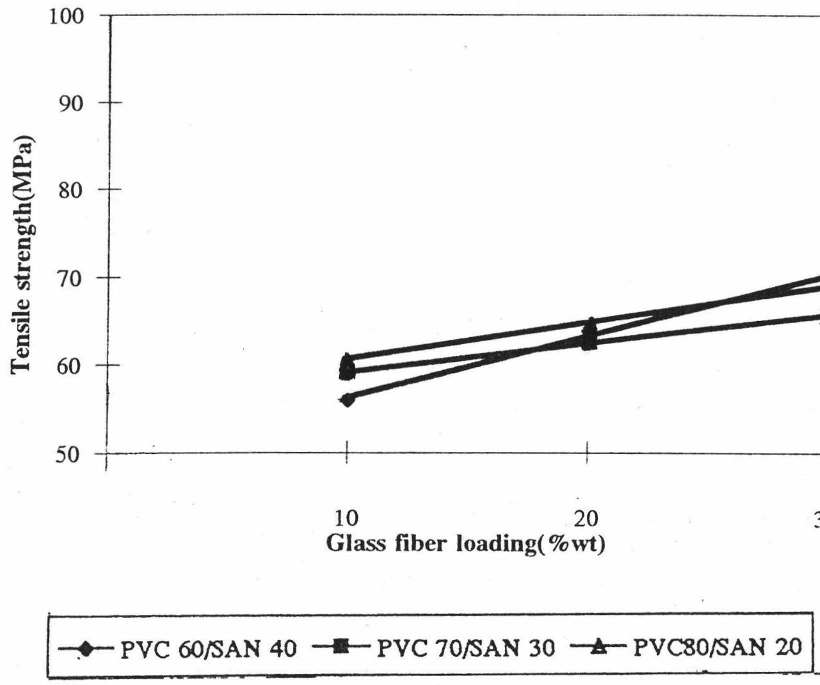
The flexural strength of the composites increased with increasing glass fiber loading as shown in Figure 4.14. It may be noted that the chemical adhesion between the treated glass fiber and the PVC/SAN matrix induced significantly better flexural properties. From Figure 4.15, the flexural modulus of the composites increased with glass fiber content.

Therefore, an increase in the glass fiber loading increased the tensile strength and modulus and also the flexural strength and modulus for the range of 10-30% glass fiber.

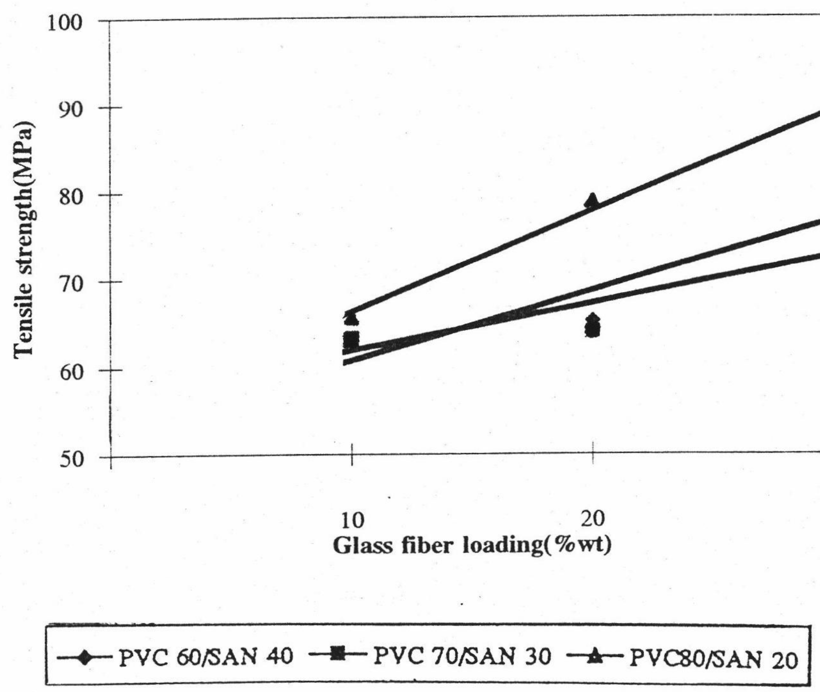
As can be seen from Figures 4.14 and 4.15, the glass fiber loading and silane coupling agent increased the flexural strength and modulus. But the flexural properties of PVC 60/SAN 40 composite containing 10% glass fiber treated with aminosilane decreased dramatically. This may be related to the breaking of the fibers during the processing of the composite.

The hardness of the composites increased with increasing glass fiber loading as shown in Figure 4.16. Both silane coupling agents improved the hardness of the composites. From Figure 4.17, the heat distortion temperature of the composites increased steadily with increasing glass fiber conent.

The mathematical relations between various mechanical properties and glass fiber loading were established in the form of empirical equations by using the regression analysis. The equations and coefficient of determination (R^2) are presented in Table 4.5. Most of the equations are in the form of linear equation, $Y = aX + b$ where Y is the mechanical properties and X is the glass fiber content. The constant a and b are presented in Table 4.5. These equations could be used to roughly predict the mechanical properties of PVC/SAN composites in the range of 10-30% glass fiber.



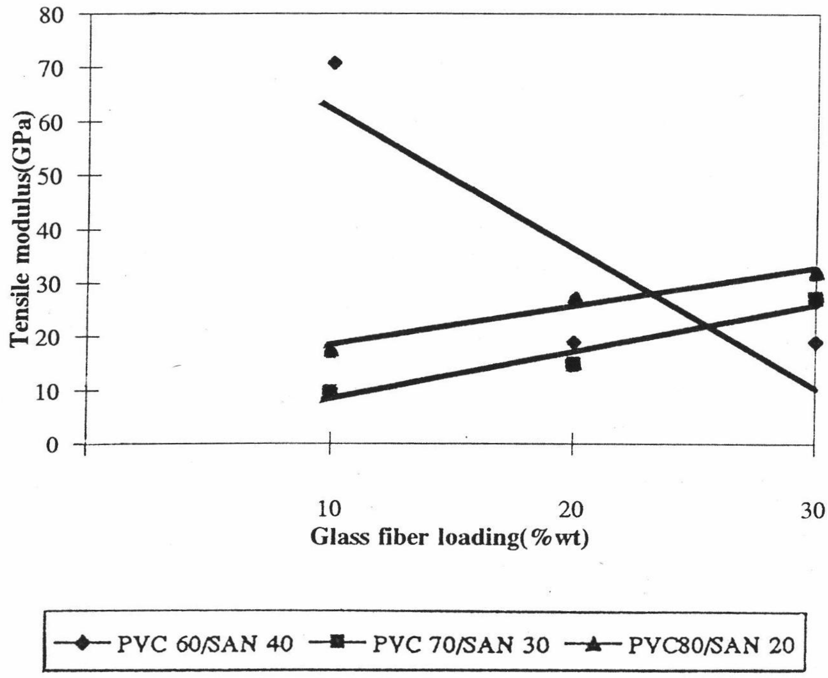
a)



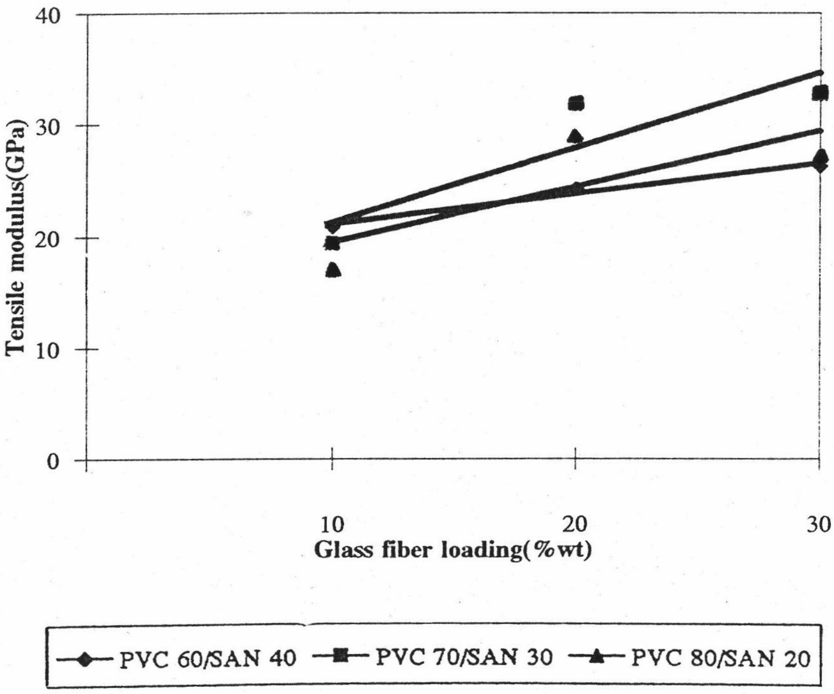
b)

Figure 4.11 Effect of glass fiber loading on tensile strength of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



a)



b)

Figure 4.12 Effect of glass fiber loading on tensile modulus of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%

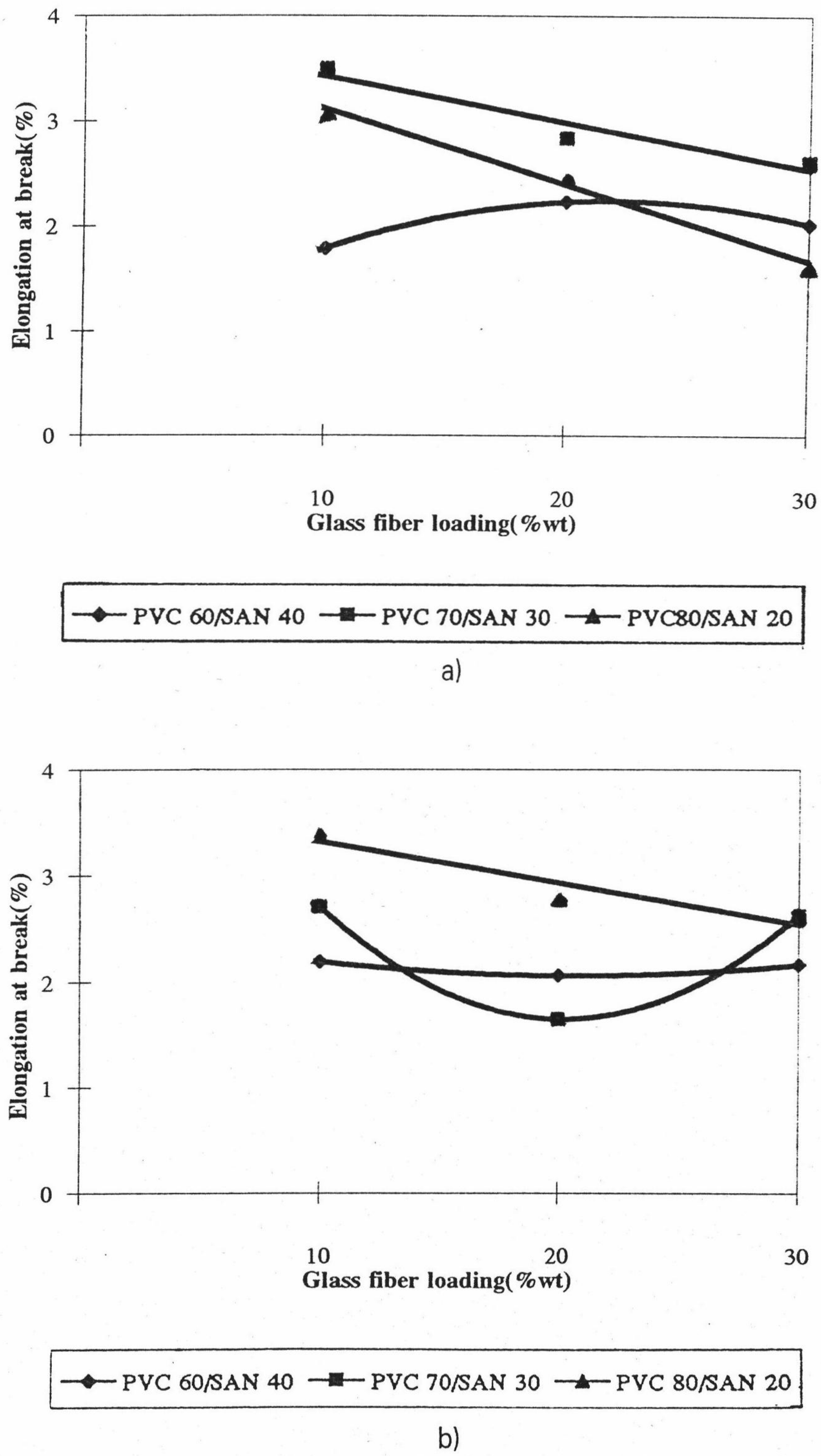
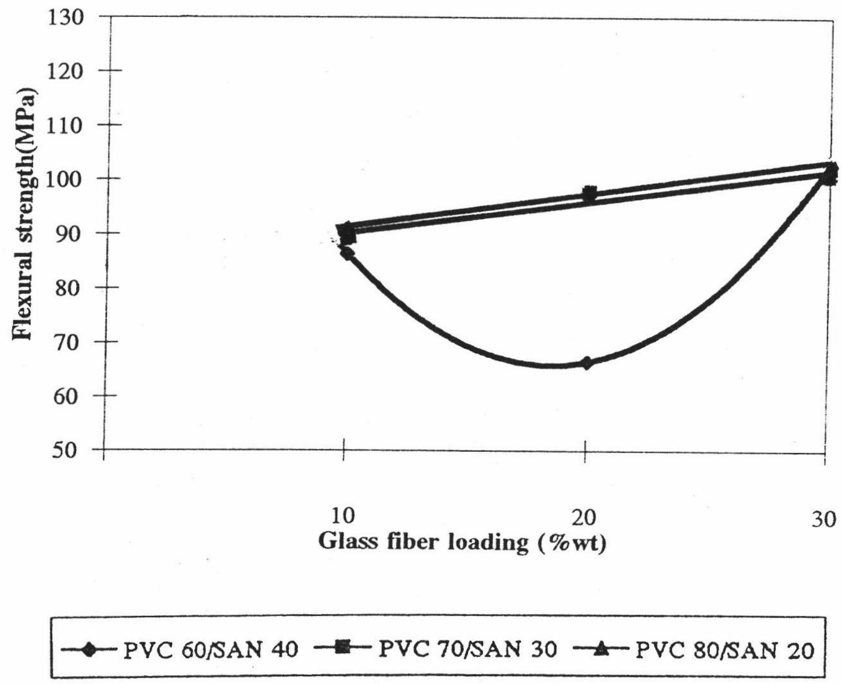


Figure 4.13 Effect of glass fiber loading on elongation at break of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



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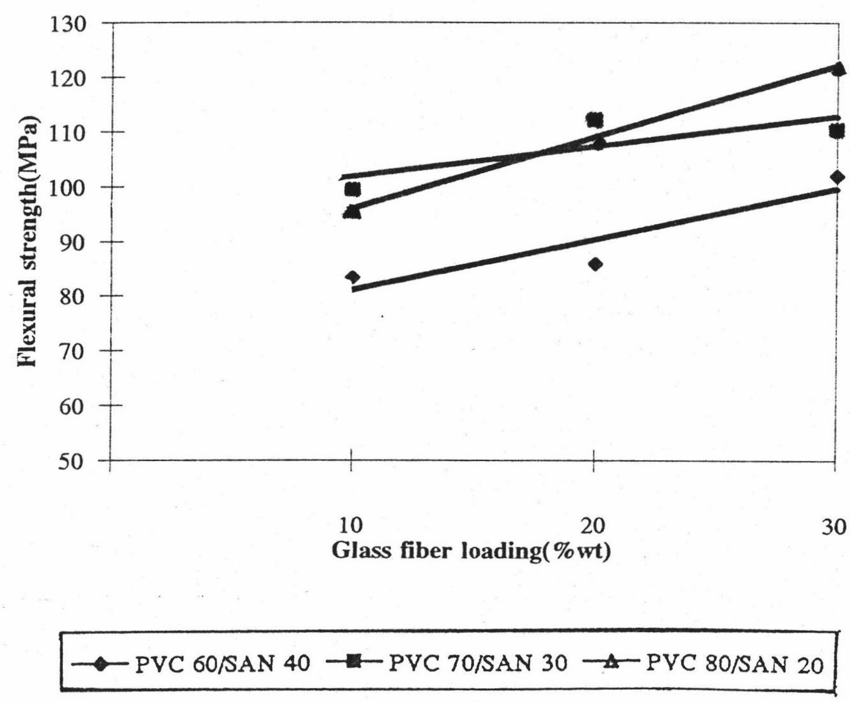

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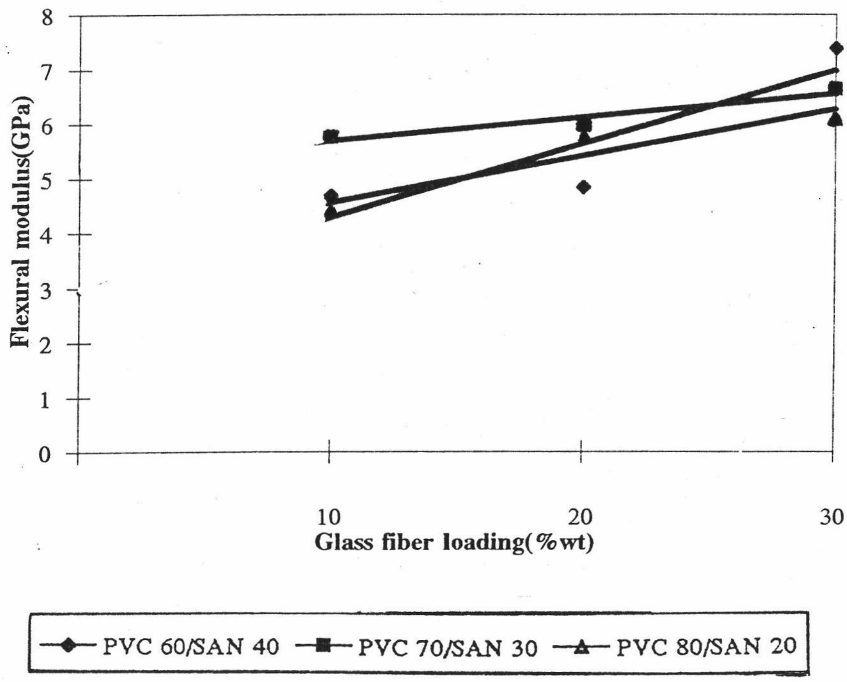
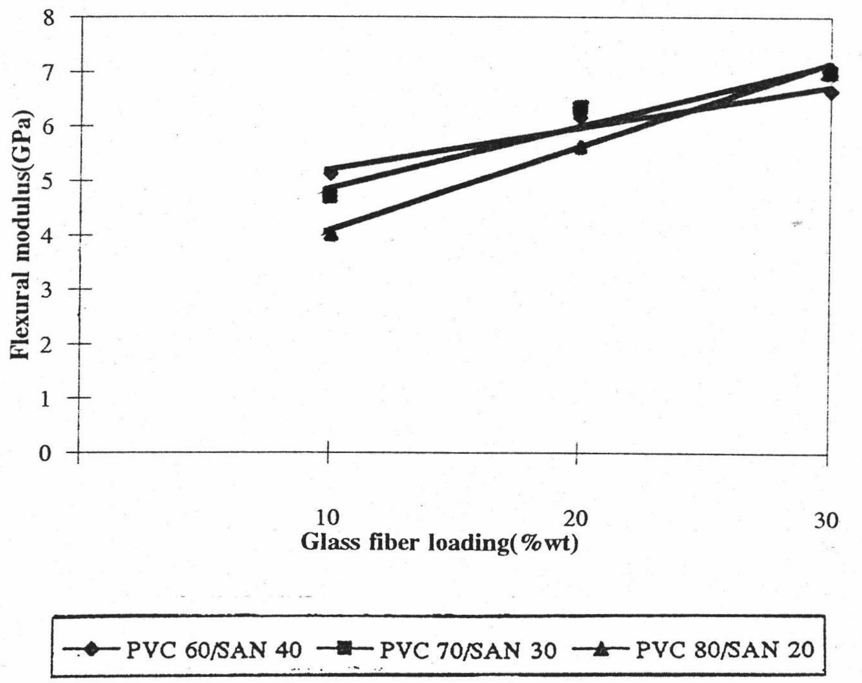
Figure 4.14 Effect of glass fiber loading on flexural strength of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



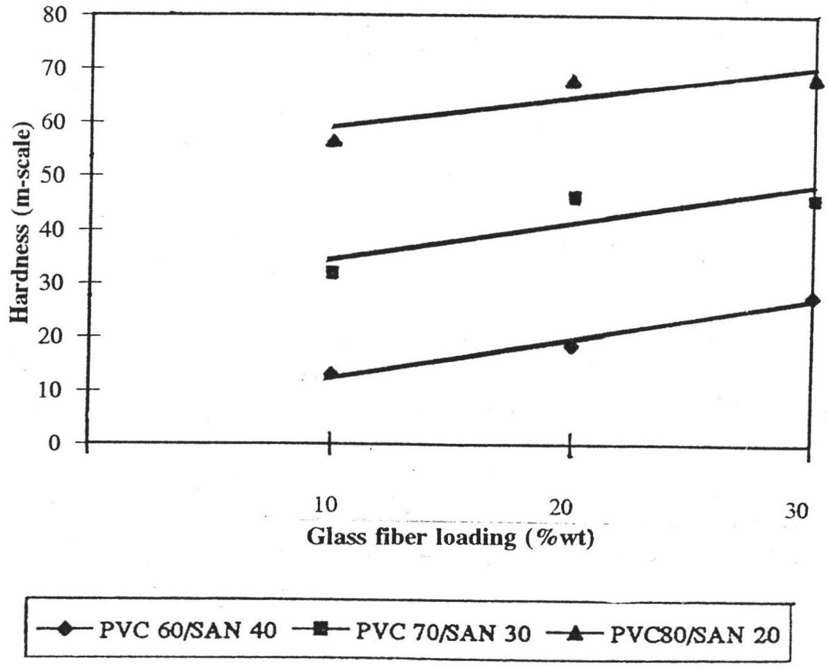
a)



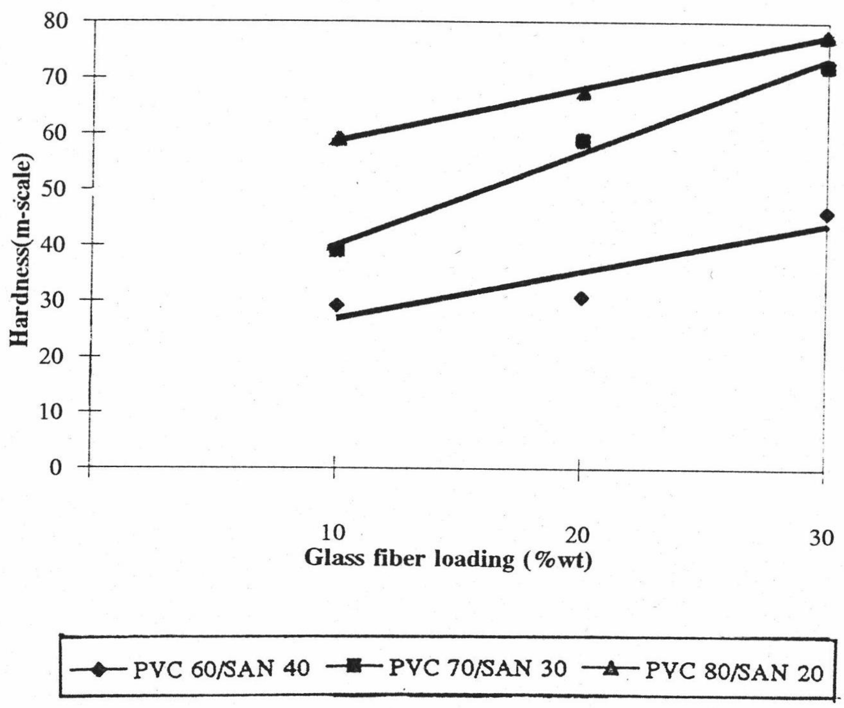
b)

Figure 4.15 Effect of glass fiber loading on flexural modulus of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



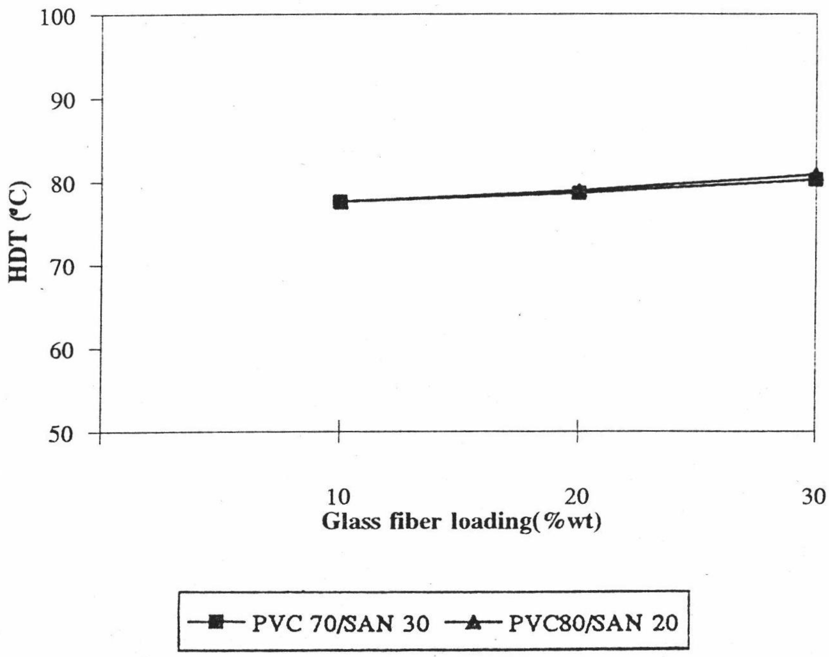
a)



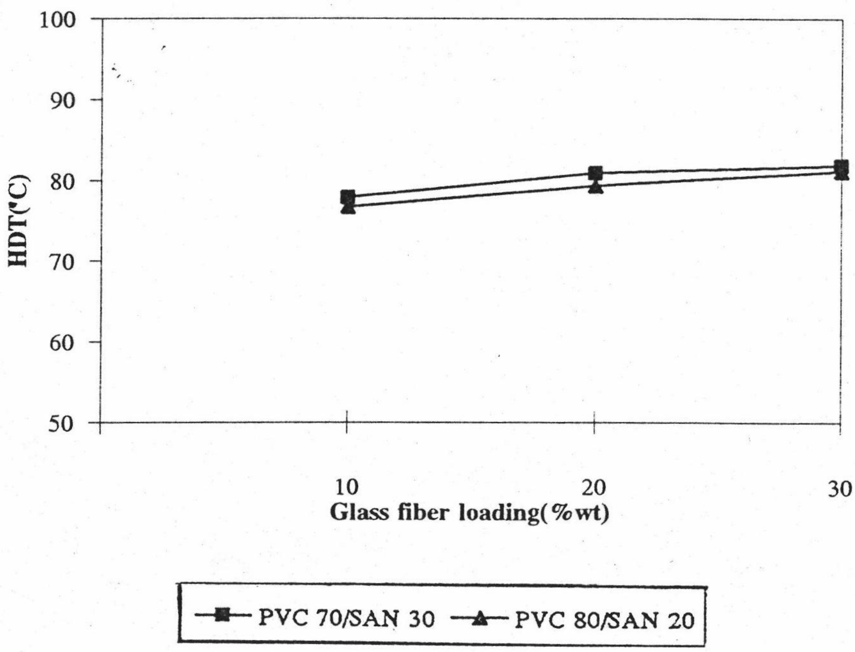
b)

Figure 4.16 Effect of glass fiber loading on hardness of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%



a)



b)

Figure 4.17 Effect of glass fiber loading on HDT of the composites.

a) Aminosilane 0.5% b) Mercaptosilane 2.0%

Table 4.4 Regression Analysis of the Mechanical Properties in the range of 10- 30% by weight of the Glass Fiber Loading.

Mechanical Properties	Silane Coupling Agent	PVC/SAN Composition	Equation	R^2
Tensile Strength	Aminosilane	60/40	Y = 6.980X+42.283	0.9944
		70/30	Y = 3.295X+52.522	0.9995
		80/20	Y = 4.155X+52.352	0.9997
	Mercaptosilane	60/40	Y = 5.335X+51.225	0.9003
		70/30	Y = 7.910X+44.923	0.7911
		80/20	Y = 11.435X+43.39	0.9926
Tensile Modulus	Aminosilane	60/40	Y = -25.89X+113.83	0.7490
		70/30	Y = 8.655X-8.835	0.9501
		80/20	Y = 14.695X-13.408	0.9597
	Mercaptosilane	60/40	Y = 2.72X+15.627	0.9778
		70/30	Y = 6.685X+7.885	0.7991
		80/20	Y = 5.91X+1.76	0.8650
Elongation at break	Aminosilane	70/30	Y = -0.44X+4.2967	0.9231
		80/20	Y = -0.72X+4.55	0.9948
	Mercaptosilane	80/20	Y = -0.39X+4.096	0.9041
Flexural Strength	Aminosilane	70/30	Y = 5.885X+78.332	0.9349
		80/20	Y = 6.075X+79.202	0.9970
	Mercaptosilane	60/40	Y = 9.28X+62.53	0.8512
		70/30	Y = 7.995X +81.668	0.6593
		80/20	Y = 13.03X+69.907	1

Table 4.4 (Continued)

Mechanical Properties	Silane Coupling Agent	PVC/SAN Composition	Equation	R^2
Flexural Modulua	Aminosilane	70/30	Y = 0.435x+4.815	0.9181
		80/20	Y = 0.86X+2.833	0.9129
	Mercaptosilane	60/40	Y = 0.765X+3.6717	0.9587
		70/30	Y = 1.14X+2.573	0.9420
		80/20	Y = 1.535X+1.015	0.9984
Hardness	Aminosilane	60/40	Y = 7.35X+2.316	0.9793
		70/30	Y = 6.95X+20.55	0.7284
		80/20	Y = 5.60X+47.9	0.7433
	Mercaptosilane	60/40	Y = 8.46X+9.88	0.8711
		70/30	Y = 16.65X+6.5167	0.9889
		80/20	Y = 9.4X+49.267	0.9982

From these results, it can be inferred that the increase in glass fiber loading, increased the mechanical properties of composites (except elongation at break). It indicated that the interface between PVC/SAN and glass fiber gained good interfacial adhesions with the role of silane coupling agent.

For the decrease of elongation at break, it can be described by Nielson's model. [22] This model is divided into two cases:

a) Perfect adhesion between polymer and filler, the elongation at break of composite is expected to decrease with increasing filler content because the matrix is modified by filler in carrying load as shown in Figure 4.18a.

b) No adhesion between polymer and filler, the elongation at break is expected to decrease in the lower proportion than the former case. According to a poor adhesion, the transfer of load from matrix to filler through the interfacial bond cannot occur as shown in Figure 4.18b.

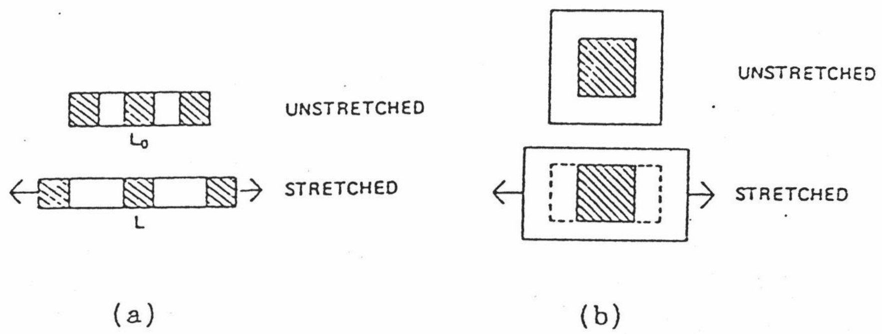


Figure 4. 18 Models for the filled polymer [22].

a) Perfect adhesion b) No adhesion

4.6 Comparision of Mechanical Properties of the Glass Fiber Reinforced PVC/SAN Composites with Different Silane Coupling Agents

The comparison of mechanical properties of the PVC/SAN reinforced with untreated glass fiber, aminosilane treated glass fiber and mercaptosilane treated glass fiber is shown in Figures 4.20 - 4.24.

Figure 4.20 shows the comparison of tensile strength of different composites. Tensile strength of the GF-reinforced PVC/SAN composites containing aminosilane or mercaptosilane was improved. At 30% glass fiber loading, the tensile strength of PVC 80/SAN 20 composite containing untreated GF, GF treated with aminosilane and GF treated with mercaptosilane were 31.07, 68.39 and 88.56 MPa, respectively. Therefore, the increase in tensile strength of composites containing aminosilane and mercaptosilane were 120% and 185%, respectively, compared to untreated-GF composite. It was observed that composites containing mercaptosilane provided the higher strength than the aminosilane.

The comparison of flexural strength is shown in Figure 4.21. Flexural strength of all composites increased with increasing glass fiber loading. The order of increasing flexural strength by using different coupling agents is as follows:

Mercaptosilane > Aminosilane > Untreated

At 30% glass fiber loading, flexural strength of the PVC 80/SAN 20 containing the untreated GF, GF treated with aminosilane and GF treated with mercaptosilane was 76.05, 103.31 and 122 MPa, respectively. Therefore, the increase in flexural strength of composites containing aminosilane and mercaptosilane as 35.8% and 76.05%, respectively, compared to the untreated-GF composite.

Figure 4.22 illustrates the comparison of flexural modulus of different composites. Flexural modulus of all composites increased with glass fiber loading. Flexural modulus reached a maximum value of 7.12 GPa in the PVC 80/SAN 20 composite containing 30% glass fiber treated with mercaptosilane compared to 5.66 GPa in the untreated GF composites. The increase in flexural modulus of composite containing mercaptosilane was 25.79%, compared to the untreated-GF composite.

The comparison of the hardness of different composites is shown in Figure 4.23. Hardness of the composites increased with increasing glass fiber loading. It can be seen that the composites containing mercaptosilane provided the higher hardness than did the aminosilane. The heat distortion temperature of different composites decreased with the rise in glass fiber content as presented in Figure 4.24. The order of increasing in hardness and HDT by using different coupling agents is as follows:

Mercaptosilane > Aminosilane > Untreated.

From these results, it could be inferred that mercaptosilane coupling agent provided the better mechanical properties than did the aminosilane. However, the amino group in aminosilane which shows appreciable basicity leads to the elimination of HCl, this causes a decrease in thermal stability and destroys the polymer matrix/glass fiber interfacial adhesion.

a)

b)

c)

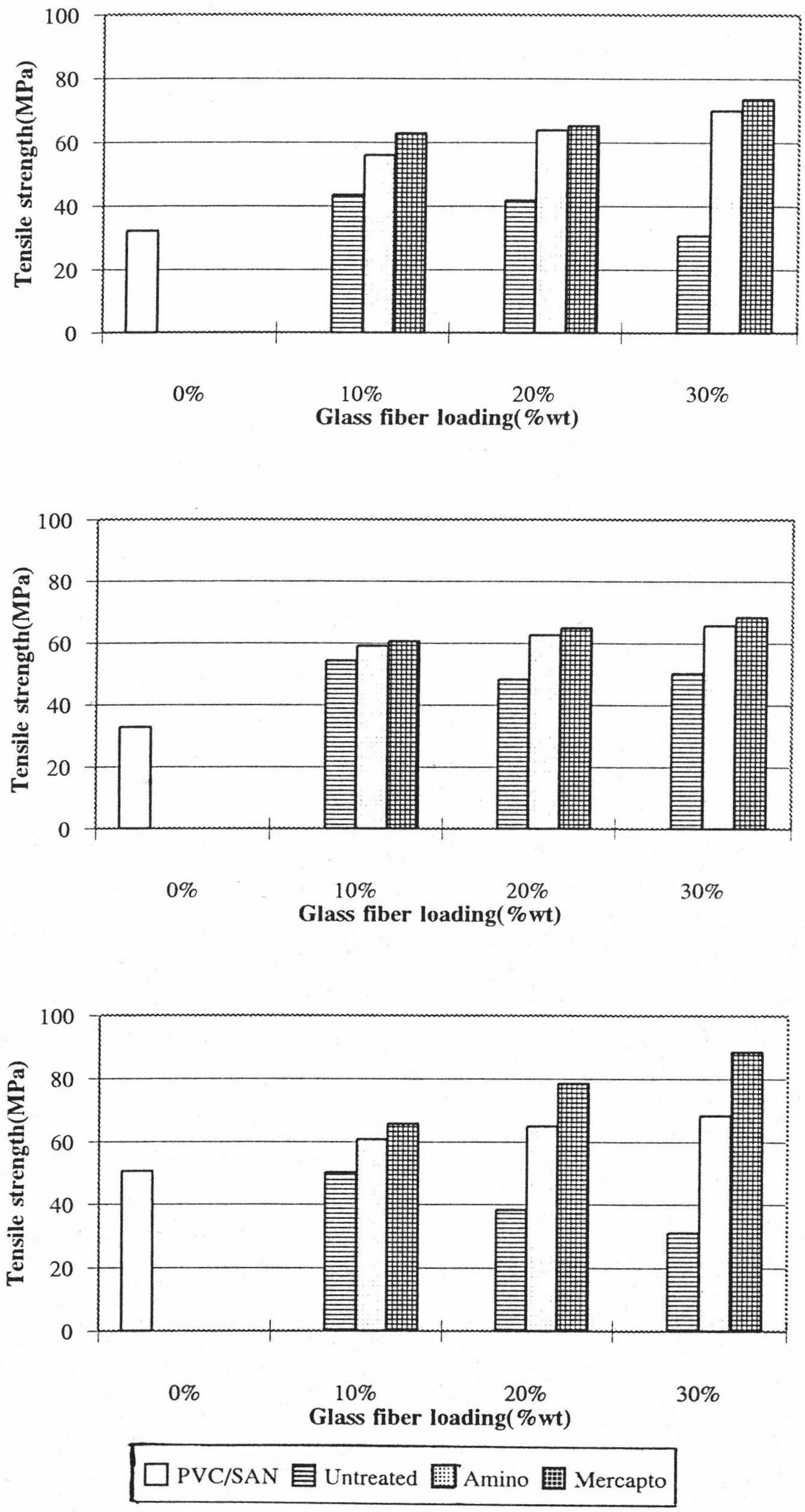


Figure 4.19 Tensile strength vs glass fiber loading treated with different coupling agents. a) PVC 60/SAN 40 b) PVC 70/SAN 30 c) PVC 80/SAN 20

a)

b)

c)

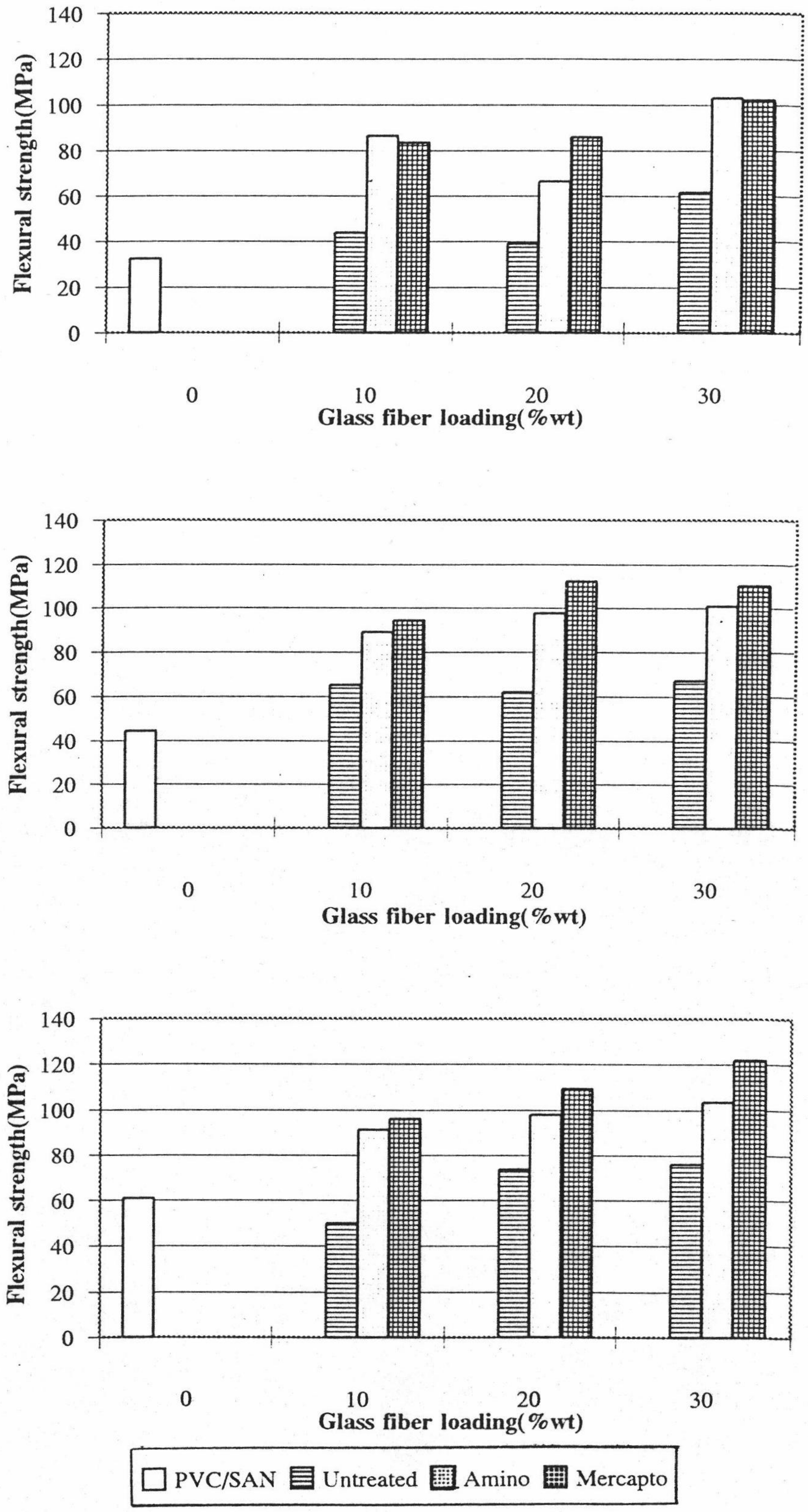


Figure 4.20 Flexural strength vs glass fiber loading treated with different coupling agents. a) PVC 60/SAN 40 b) PVC 70/SAN 30 c) PVC 80/SAN 20

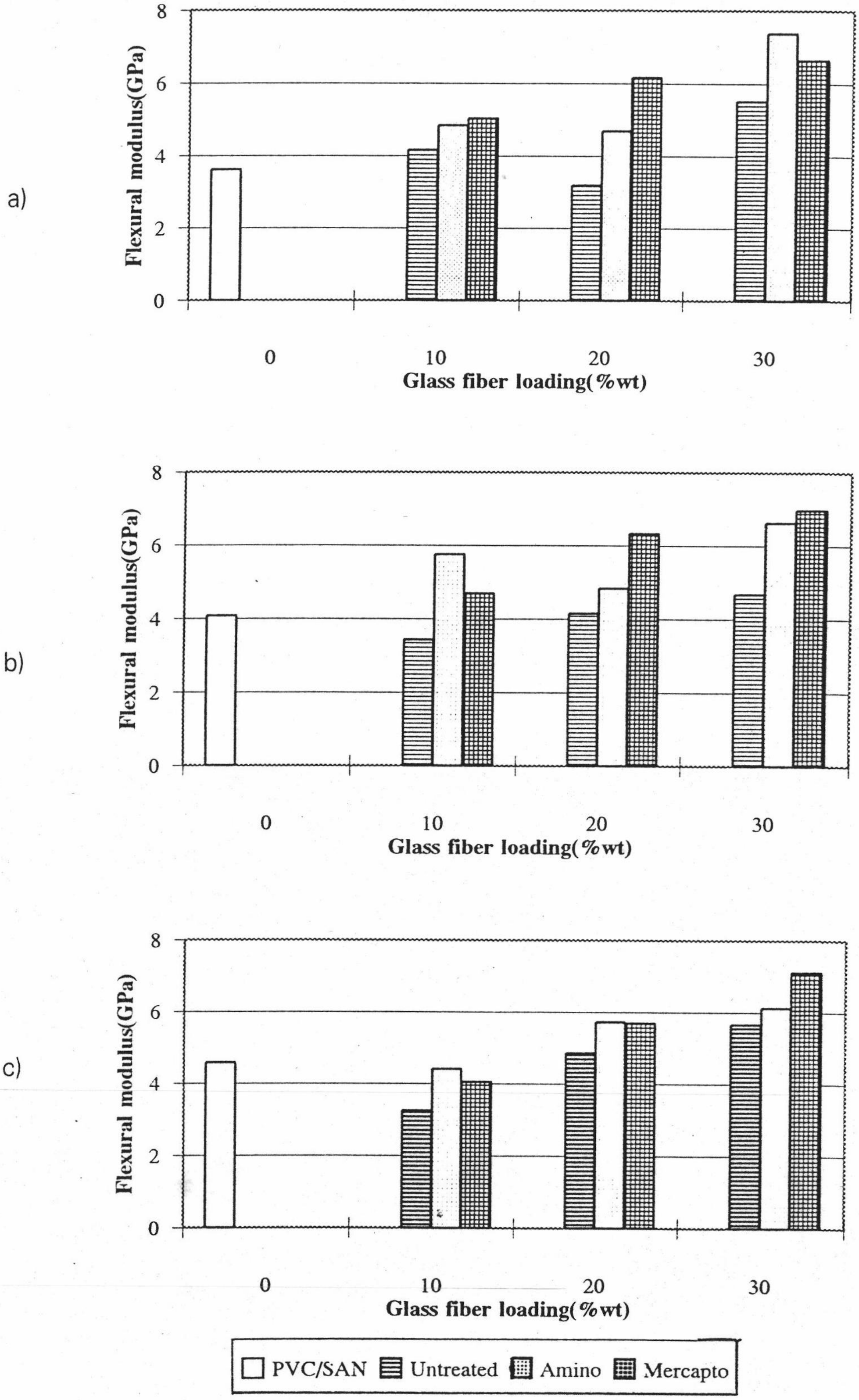


Figure 4.21 Flexural modulus vs glass fiber loading treated with different coupling agents. a) PVC 60/SAN 40 b) PVC 70/SAN 30 c) PVC 80/SAN 20

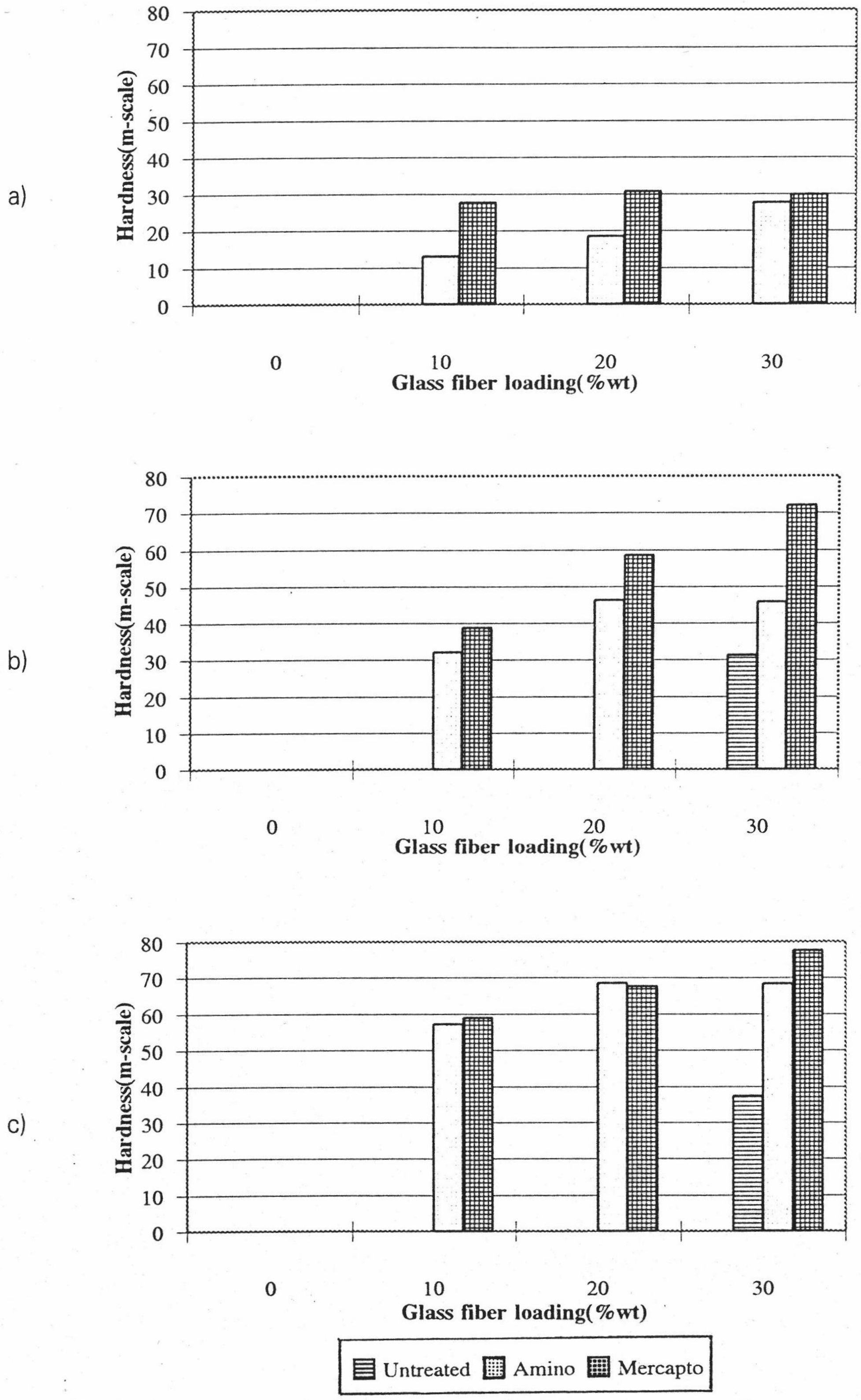
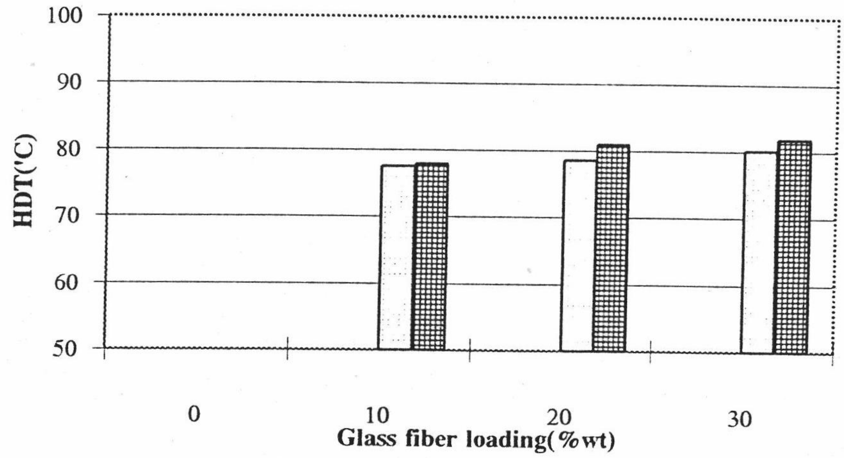
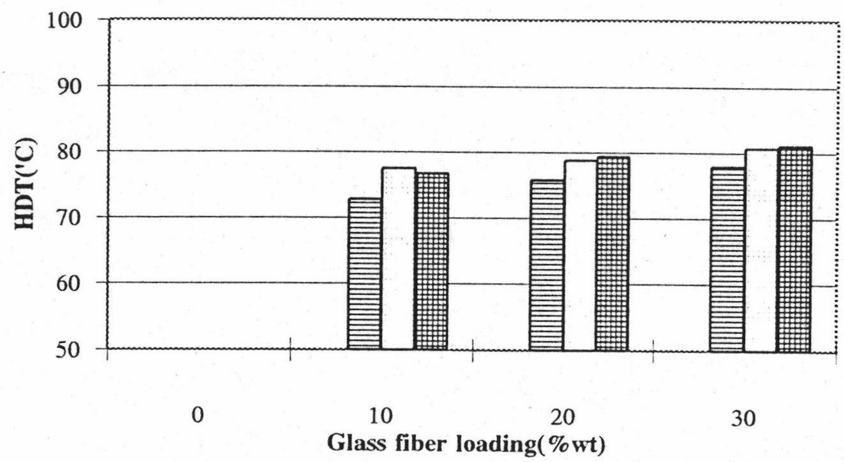


Figure 4. 22 Hardness vs glass fiber loading treated with different coupling agents.

a) PVC 60/SAN 40 b) PVC 70/SAN 30 c) PVC 80/SAN 20



a)



b)

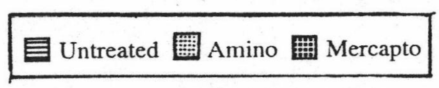


Figure 4.23 HDT vs glass fiber loading treated with different coupling agents.

a) PVC 70/SAN 30 b) PVC 80/SAN 20

4.7 Scanning Electron Microscopy (SEM)

The scanning electron microscope was employed to investigate the fracture surface of the specimen from the uniaxial tensile tests. The SEM electron micrographs show the fracture surface of the composites at various percents of glass fiber.

Figures 4.24-4.26 show the fracture surface of PVC/SAN (80/20) composites containing glass fiber treated with mercaptosilane coupling agent at 10%, 20% and 30%, respectively. At low magnification, the SEM electron micrograph of the GF-PVC/SAN composites reveals the good dispersibility and compatibility of glass fiber treated with mercaptosilane coupling agent in the polymer matrix.

At 1000x magnification, the SEM electron micrograph of the PVC/SAN-untreated glass fiber composite (Figure 4.27) shows poor interfacial adhesion. At the high percent glass fiber content (30%), this adhesion appeared to be reduced greatly as shown in Figure 4.26 b. It can be seen from the clean surface of glass fiber in the breaking region of the glass fiber. The "clean" implied the lack of any coating, which indicated the adhesion failure. And the gaps were seen easily between the fibers and the matrix. These gaps yielded lower strength of the composites, causing the ease in loosing the glass fiber out of polymer.

At 1000x magnification, the SEM electron micrograph of the PVC/SAN treated glass fiber composites (Figure 4.28) shows good interfacial adhesion. For the composite containing aminosilane coupling agent, the coupling action between glass fiber and polymer matrix occurred. It seems to be a chemical bond between glass fiber and polymer matrix which was induced by the coupling reaction.

At 1000x magnification, the SEM electron micrograph of the PVC/SAN-treated glass fiber composites (Figure 4.29) shows the broken glass fibers coated with a layer of matrix by means of the mercaptosilane coupling agent. The glass fibers seem to be held tightly in the polymer matrix. From this figure, no visible gaps between the matrix and the fibers was observed. The coupling action between glass fiber and polymer matrix resulted in excellent strength of the composites.

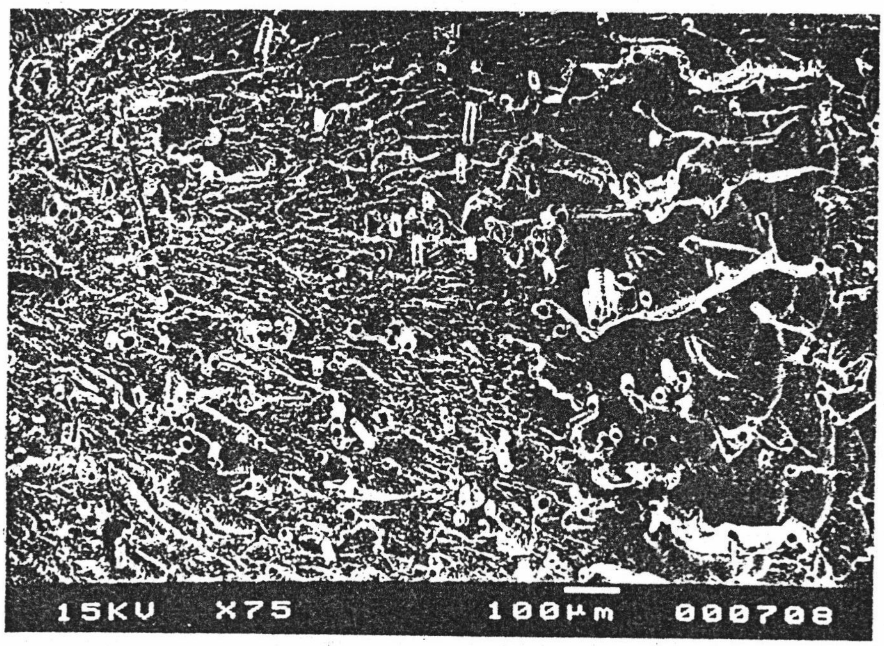


Figure 4.24 SEM photomicrograph of fracture surface of the PVC/SAN (80/20) reinforced with 10% glass fiber treated with mercaptosilane.

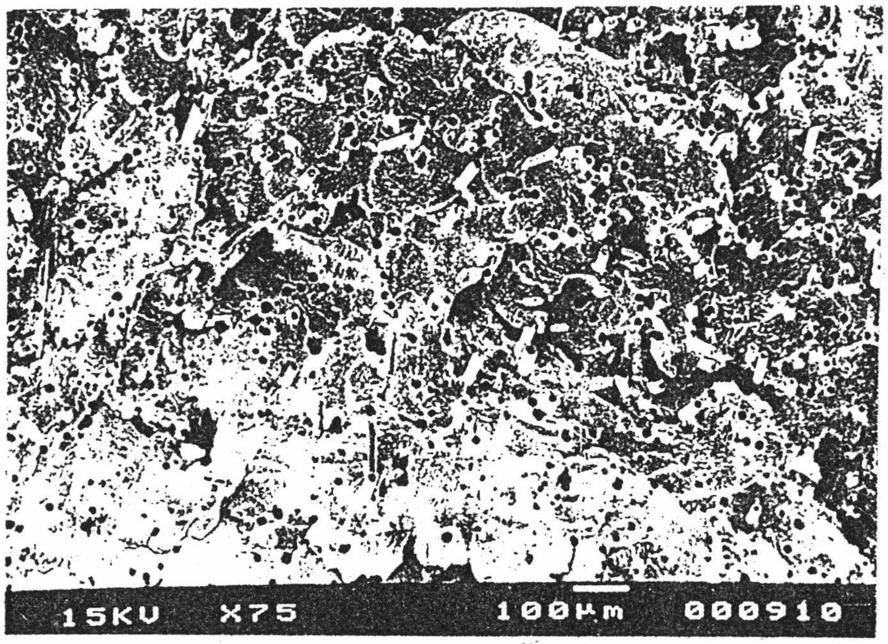


Figure 4.25 SEM photomicrograph of fracture surface of the PVC/SAN (80/20) reinforced with 20% glass fiber treated with mercaptosilane.

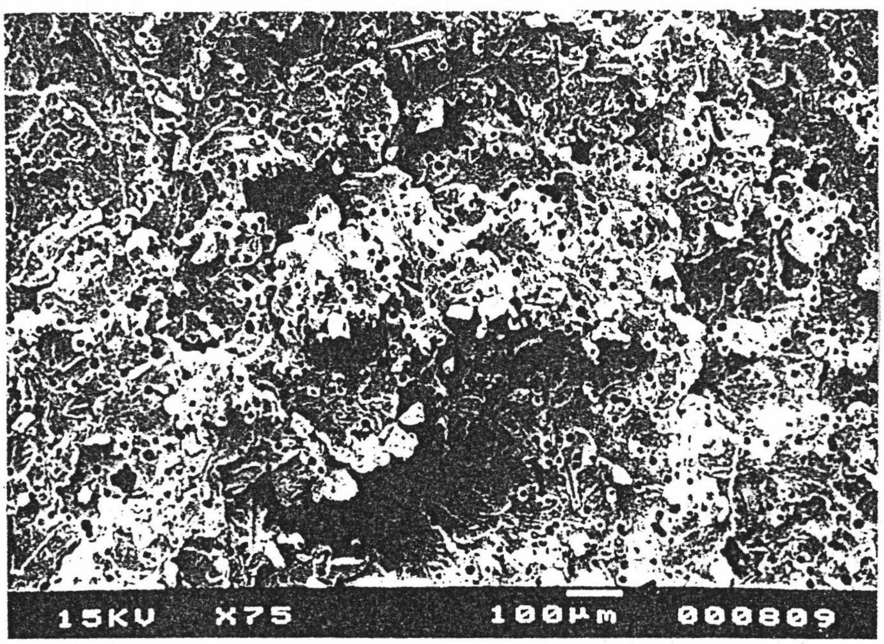
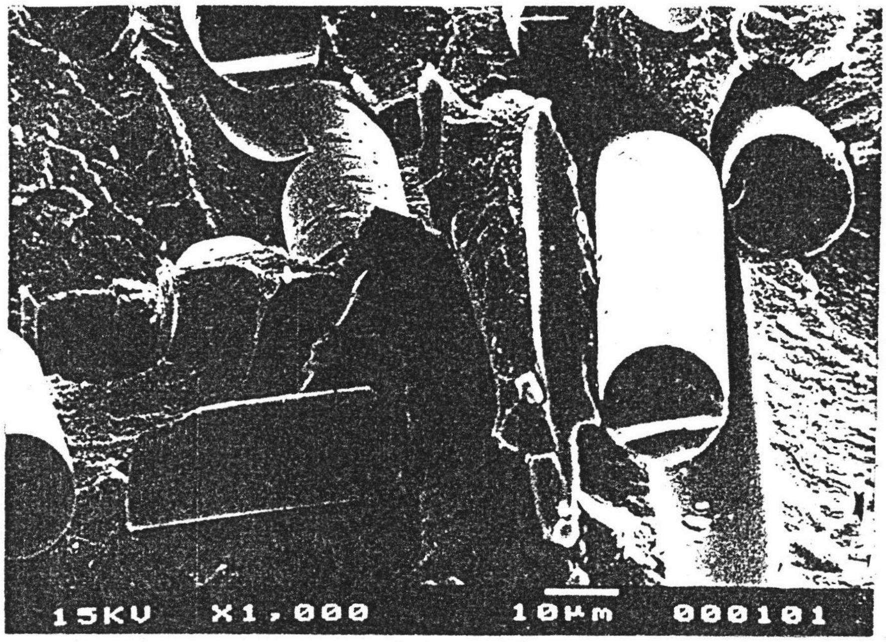
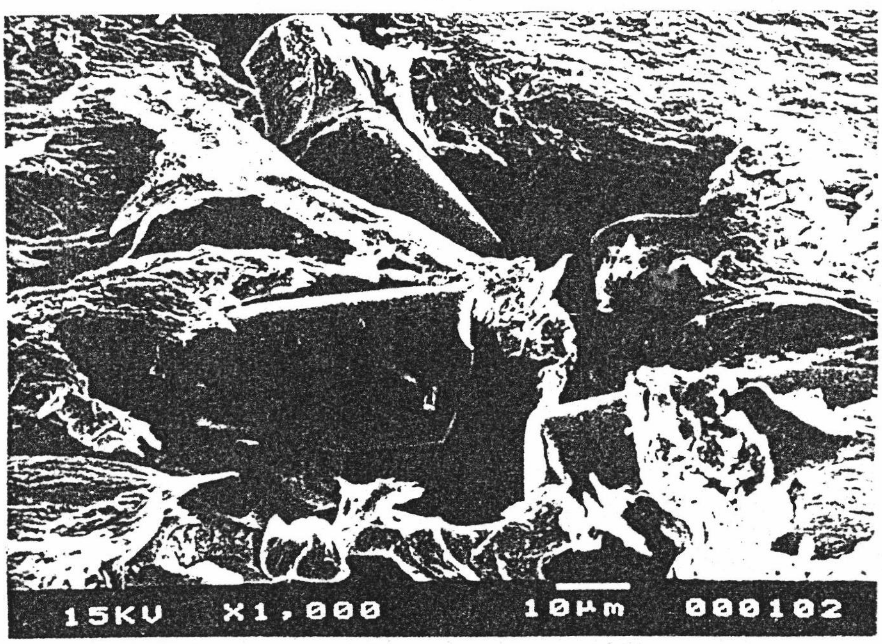


Figure 4.26 SEM photomicrograph of fracture surface of the PVC/SAN (80/20) reinforced with 30% glass fiber treated with mercaptosilane.



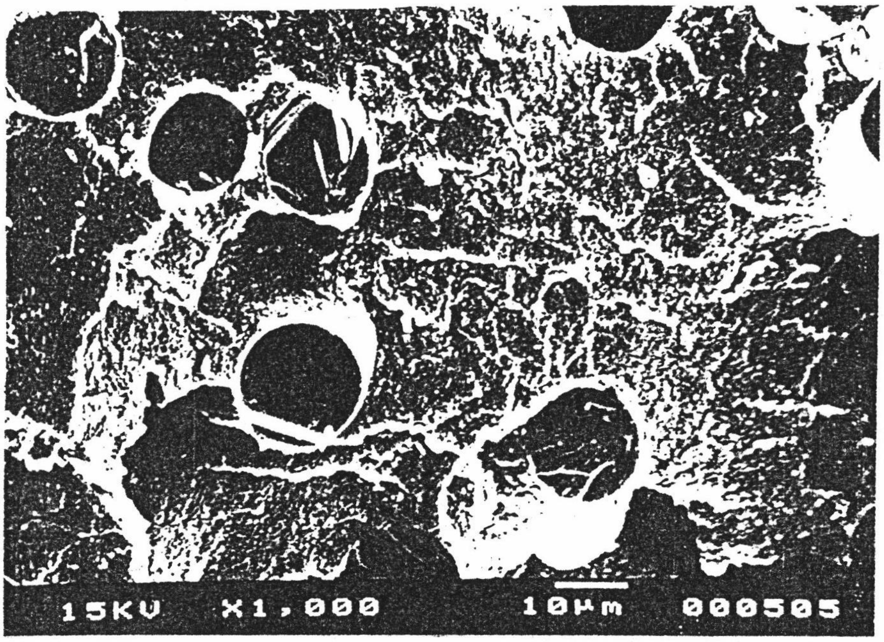
a)



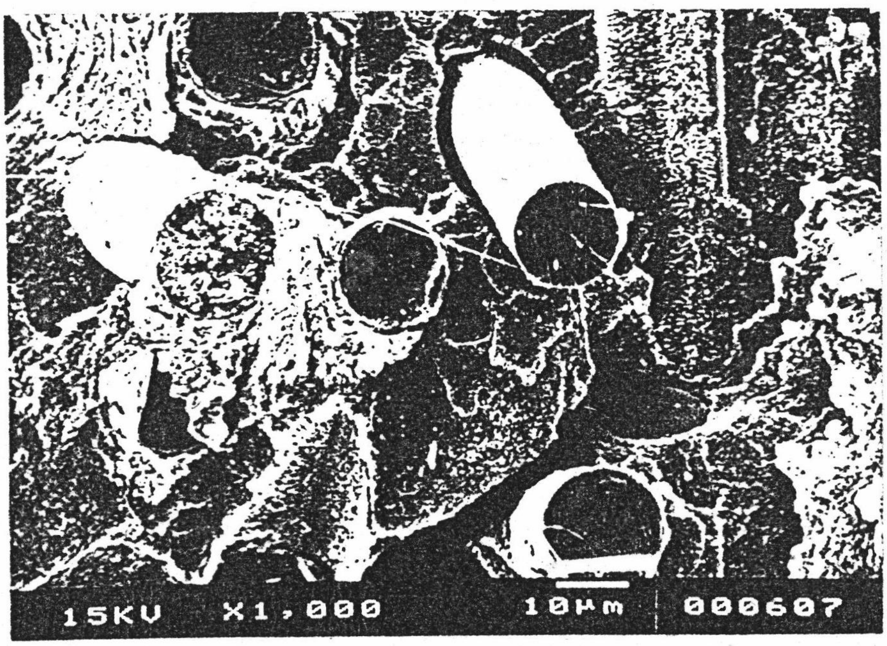
b)

Figure 4.27 SEM photomicrograph of fracture surface of the PVC/SAN reinforced with 30% of untreated glass fiber.

a)PVC 70/SAN 30 b) PVC 80/SAN 20

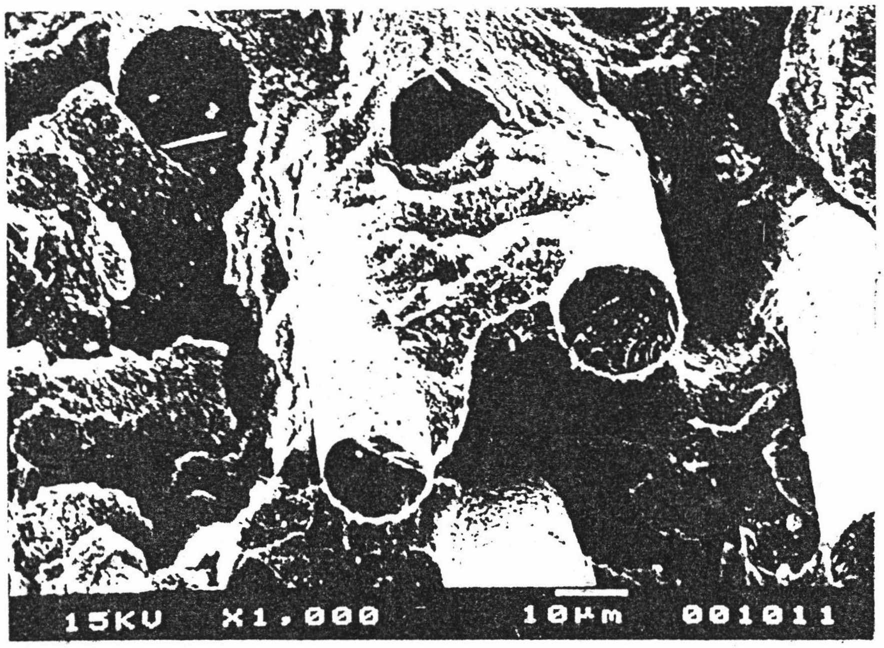


a)



b)

Figure 4.28 SEM photomicrograph of fracture surface of the PVC/SAN reinforced with 30% of glass fiber treated with aminosilane coupling agent. (a) PVC 70/SAN 30 (b) PVC 80/SAN 20



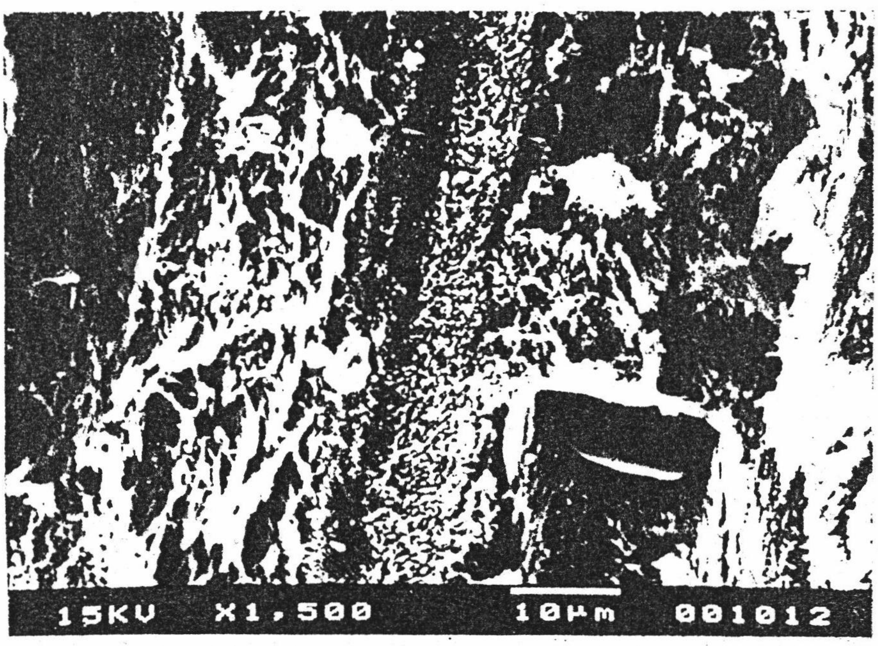


Figure 4.29 SEM photomicrograph of fracture surface of the PVC 80/SAN 20 reinforced with 30% of glass fiber treated with mercaptosilane coupling agent.

4.7 Differential Scanning Calorimetry

DSC curve of PVC 80/SAN 20 reinforced with 30% glass fiber treated with mercaptosilane is shown in Figure 4.29. The DSC curve showed the incompatible blends of poly(vinyl chloride) and a copolymer of styrene-acrylonitrile (SAN). The glass

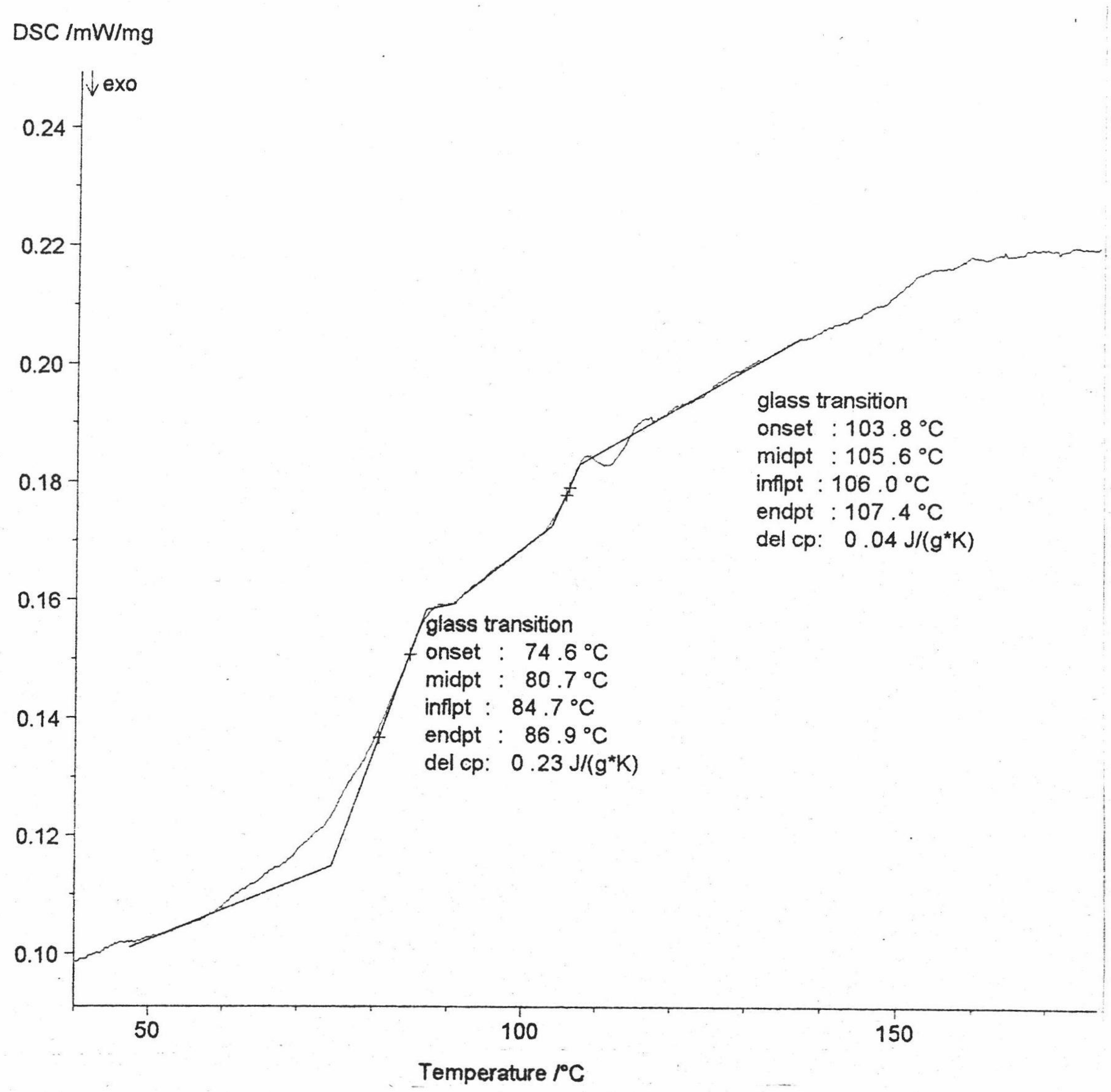


Figure 4.30 DSC curve of PVC 80/SAN 20 reinforced with 30% GF treated with mercaptosilane coupling agent.

transition temperatures of PVC and SAN were observed at 80.7°C and 105.6°C, respectively. Therefore, the curve represented the two-phase polyblend. With the addition of proper silane coupling agent into the polymer matrix, this heterogeneous phase had been improved and the good adhesion between glass fiber and polymer phases was obtained[3].

4.8 Economic Consideration

From the results of this research, the best coupling agent for this system should be the mercaptosilane coupling agent due to the high mechanical properties of composites provided at various glass fiber loadings. In this work, the cost of these composites are based on the costs of PVC, SAN, glass fiber, silane coupling agent and additives. The costs of PVC resin, SAN resin, glass fiber, A-189 silane, lead tribasic sulfate, butyltin mercaptide and stearic acid were 26, 38, 60, 800, 34, 220 and 70 ฿ /kg, respectively, in 1996. Table 4.5 indicates the cost of the reinforced-PVC80 /SAN20 composite with different glass fiber loading. These composites had good mechanical properties as mentioned above. It can be seen from Table 4.5 that the cost of the composites per kilogram is relatively high. However, the cost of the PVC/SAN composites reinforced with glass fiber is much lower than other engineering plastics in Thailand, e.g. ABS (61 ฿/kg), polycarbonate (130 ฿/kg) in 1996. Therefore, the price of the glass fiber-reinforced PVC/SAN composite can be attractive as an alternative to substitute the high price of the engineering plastics. This work may lead to the development of low-priced engineering plastic.

Table 4.5 Cost analysis of PVC/SAN-Mercaptosilane treated glass fiber composites.

Glass fiber loading (% wt)	Starting Materials in 1996 (฿/kg)					Cost of Composites[f] (฿/kg)
	PVC[a]	SAN[b]	GF[c]	A-189[d]	Additive[e]	
PVC 60/SAN 40						
10	14.20	13.83	5.46	1.46	1.28	36.23
20	14.20	13.83	10.92	2.92	1.28	39.51
30	14.20	13.83	16.38	4.38	1.28	42.32
PVC 70/SAN 30						
10	16.56	10.37	5.46	1.46	1.5	35.35
20	16.56	10.37	10.92	2.92	1.5	38.71
30	16.56	10.37	16.38	4.38	1.5	41.58
PVC 80/SAN 20						
10	18.93	6.92	5.46	1.46	1.71	34.48
20	18.93	6.92	10.92	2.92	1.71	37.91
30	18.93	6.92	16.38	4.38	1.71	40.85

f = [(a+b+c+d+e) x 1000] / weight of composite at each percentage glass fiber. Weights of composite at 10, 20 and 30% glass fiber are 1000, 1092 and 1183 g.,respectively.