CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Physical Properties of Acrylonitrile Butadiene Styrene/Glass Fiber Resin (ABS/GF)

The purpose of this research is to improve physical properties of high impact polystyrene with fiber reinforcement. In particular, the focus of the work is on the application for the internal part of electrical appliances, for example, a blower in the air-conditioner. Accordingly, the tensile strength is the most important property among the others. At the present, ABS/GF has been used for such application. Thus its mechanical properties have been measured and used as the bench marks of this study. These are as follow:

Tensile strength	355	kg/cm^2
Flexural strength	548	kg/cm^2
Flexural modulus	2.3×10^4	kg/cm^2
Izod notched impact	8.5	$kg\text{-}cm/cm^2$
Heat distion temperature	90	°C

4.2 Effect of Type of Glass Fiber

In this study chopped glass fiber and milled glass fibers were used. One problem of chopped glass fiber is the uneven number of strands of glass fibers in each bundle which leads to the distribution of the aspect ratio of fiber (L/D).

This affects the bulk density, which in turn creates the problem during processing. In addition, the amount and type of the binders in the strand bundle can cause two problems i.e, too much binder keeps the strand too tight and prevents resin wetting, resulting in poor properties, while too little binder in the strand bundle causes premature blooming of the bundle during processing and increasing the amount of work needed for processing. However, chopped glass fibers are longer than milled glass fibers. They thus have significantly greater tensile strength. With higher content of chopped fibers, the melt flow rate of resin decreases and it will be much more difficult to process, especially for a thin-wall part of electrical appliances.

Milled glass fiber shows different problem. They carry with them a significant amount of strange debris formed in the milling process. This debris represents about 1/4 of the mass of milled glass fiber, especially the shorter grades, and its sharply edged glass pieces and fibers of very short aspect ratio. The weakening effect of this debris probably accounts for 30% to 50% strength loss in milled glass fiber reinforcements that chopped glass fiber do not have, so that chopped glass fibers perform better in composites (7). With higher milled glass fiber content, the melt flow rate of resin also decreases but only slightly.

High impact polystyrene (HIPS) with different types of glass fibers, chopped glass fiber and milled glass fiber were prepared at 10% glass fiber loading with several loading of silane coupling agent. The tensile strength and flexural strength of each composite were measured. Figure 4.1-4.2 shows that the tensile strength and flexural strength of chopped glass fiber are higher than milled glass fiber.

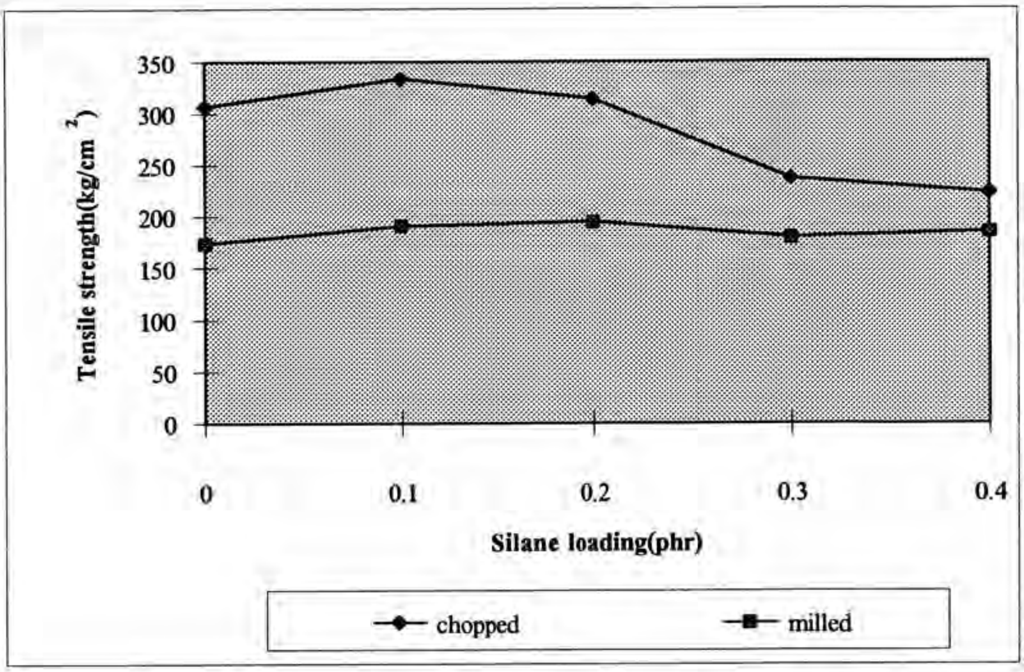


Figure 4.1 Effect of type of glass fiber on tensile strength of HIPS with 10% glass fiber.

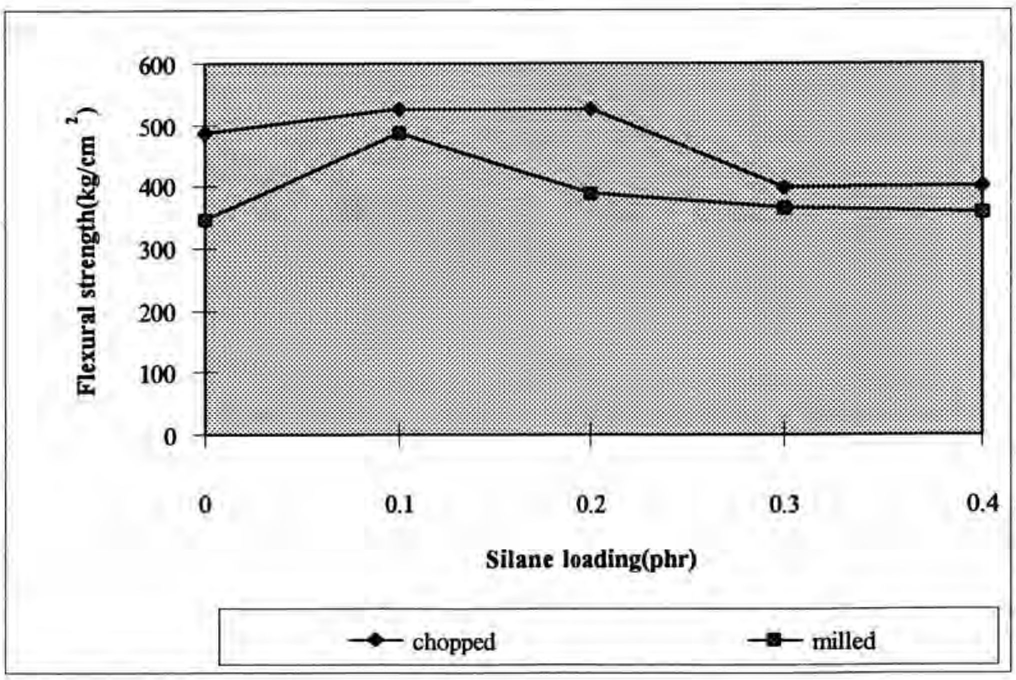


Figure 4.2 Effect of type of glass fiber on flexural strength of HIPS with 10% glass fiber.

This can be explained that chopped strand fiber 3 ± 0.5 mm. in length, which is longer than milled fiber, provides a larger contact area and thus better adhesion with the polymer matrix than milled fiber. That is HIPS with chopped strand fiber is the continuous-fiber-reinforced composite while HIPS with milled fiber is the discontinuous-fiber-reinforced composite. The first one can perform better load-transfer function than the latter. Therefore HIPS with chopped glass fiber shows higher tensile strength than HIPS with milled glass fiber.

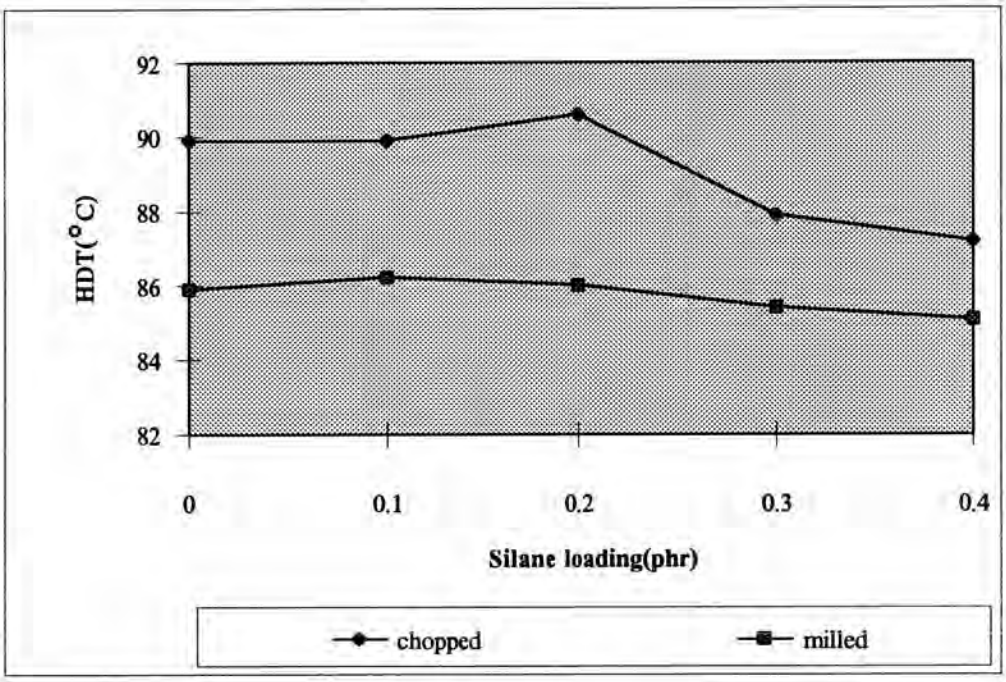


Figure 4.3 Effect of type of glass fiber on heat distortion temperature of HIPS with 10% glass fiber.

For heat distortion temperature, it is the same reason as tensile strength. Figure 4.3 is the plot of heat distortion temperature (HDT) versus silane loading. It also shows that chopped glass fiber has higher heat distortion temperature than milled glass fiber.

From the result of this research, the best glass fiber for this system should be chopped glass fiber. The tensile strength, flexural strength and heat distortion temperature of composite at 10% glass fiber loading can be comparable to ABS/GF. It is known that properties of milled fiber are related to structure, size and manufacturing method used for the continuous fibers from which they are made. However, this research work used only one sample of milled fiber (grade PF E 301 from Nitto Boseiki Co., Ltd.). Therefore, general conclusion on the effectiveness of milled glass fiber on HIPS composite can not be made.

4.3 Effect of Silane Coupling Agent Loading

In order to improve the physical properties of glass fiber/HIPS composites, silane coupling agents were used to modify the glass fiber surface. A-187 or γ-glycidoxypropyltrimethoxysilane was applied to chopped glass fiber with various loading (15).

Figure 4.4-4.6 illustrate the effect of loading of epoxysilane coupling agent on physical properties of the composites such as tensile strength, flexural strength, vicat softening temperature and heat distortion temperature. The epoxysilane coupling agent improved tensile strength of the HIPS/GF composite containing 5%, 10% and 15% glass fiber.

Figure 4.4 is the plot of physical properties such as tensile strength, flexural strength, and heat distortion temperature versus silane loading. It is shown that the composite containing epoxysilane at 0.1 phr had a maximum value of tensile strength. Further increasing in epoxysilane coupling agent resulted in the decrease in tensile strength.

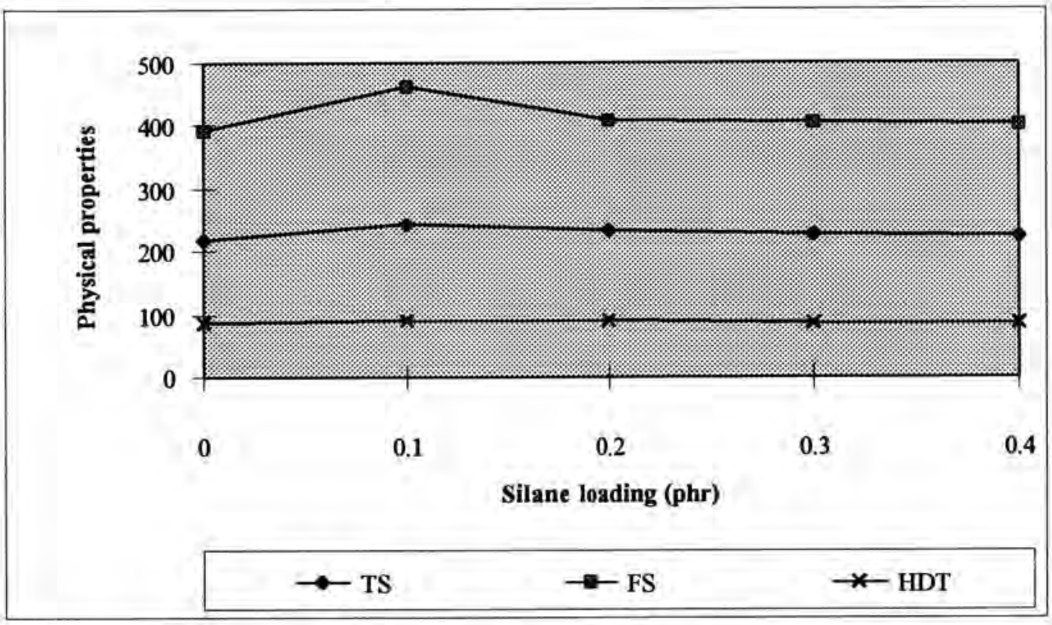


Figure 4.4 Effect of silane on physical properties of HIPS with 5 % chopped glass fiber.

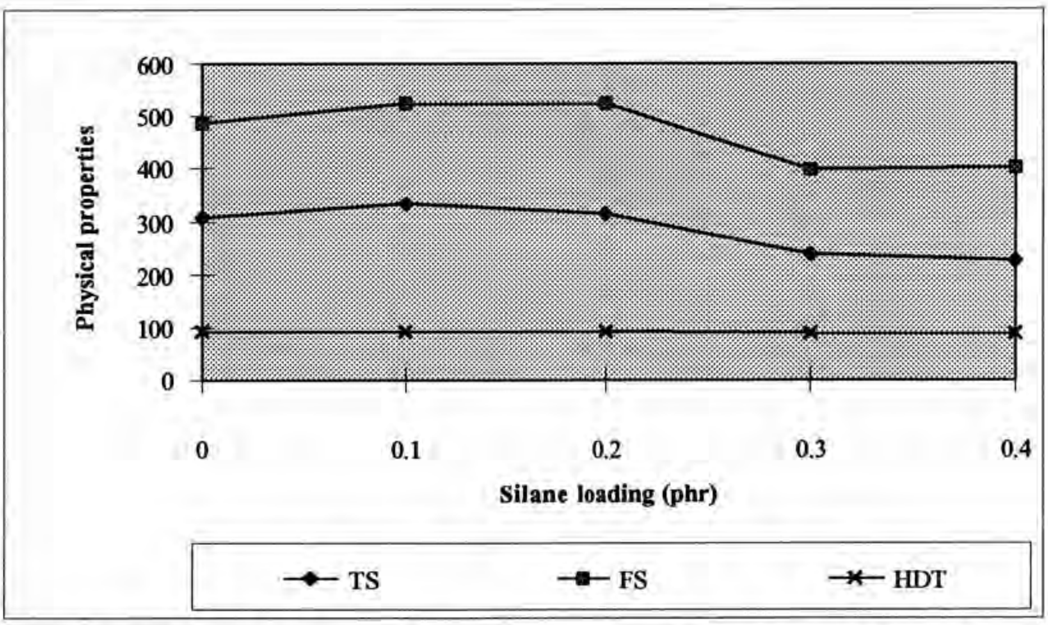


Figure 4.5 Effect of silane on physical properties of HIPS with 10 % chopped glass fiber.

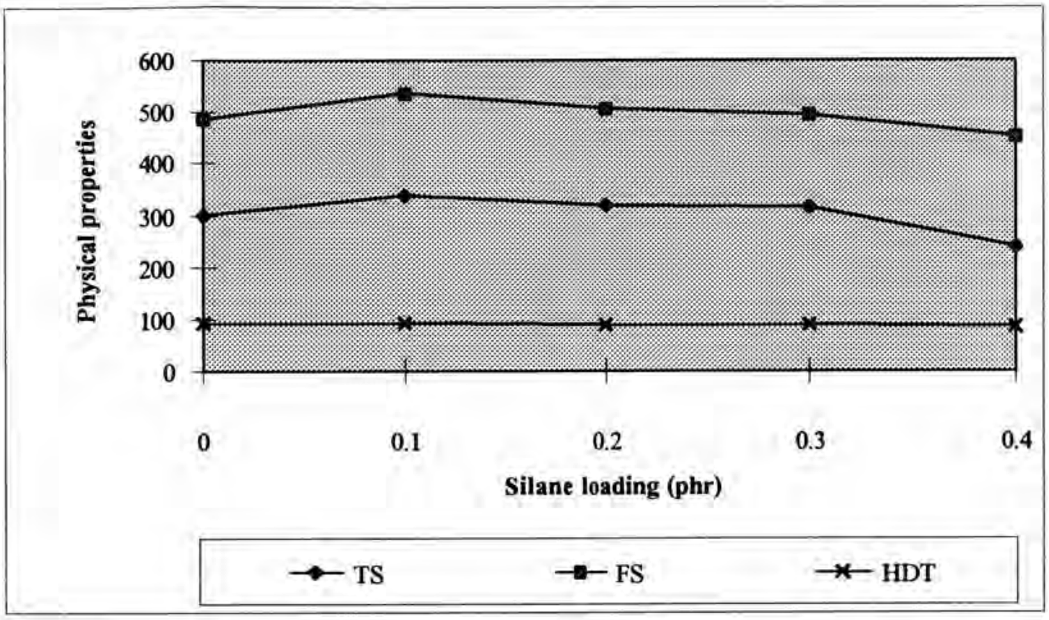
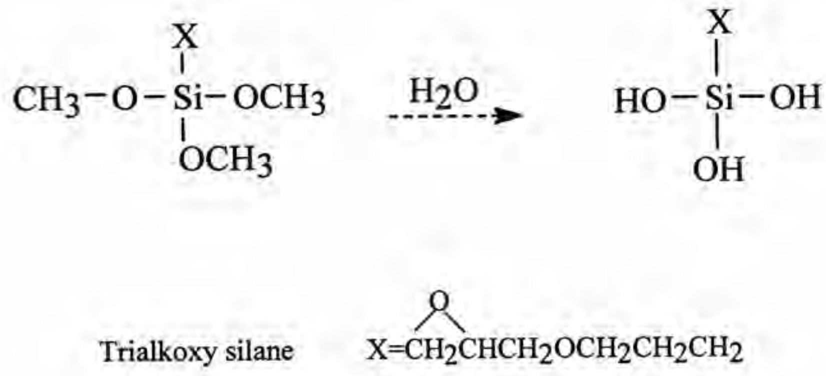


Figure 4.6 Effect of silane on physical properties of HIPS with 15 % chopped glass fiber.

The composites containing epoxysilane at 0.1 phr also had a maximun flexural strength. Further increasing in epoxysilane coupling agent produced the decreasing in flexural strength. Similarly, Figure 4.5-4.6 show the flexural strength of the composite at 10% and 15% chopped glass fiber which slightly increase with increasing silane loading up to 0.1 phr. At 0.2 phr silane loading, the flexural strength decreases. The overall trend is similar to the case of tensile strength of HIPS/GF composite.

According to the results, it can be seen that there is an interfacial adhesion 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 and flexural strength of the HIPS/GF composites (21).

Epoxysilane is organofunctional silane generally recommended for coupling reaction which occurs in the interface between HIPS and glass fiber. At the interface between the silane coupling agents and polymer matrix, three representative mechanisms of the adhesion promotion have been suggested. First, silane coupling agent react chemically with the polymer matrix at the molding temperature, and the interfacial adhesion can be strengthened. Interpenetrating polymer network (IPN) theory is regarded as another mechanism of adhesion promotion. An IPN is formed through the interdiffusion of the polymer matrix and silane in the interphase region. At high temperature in the composite manufacturing process, the silane coupling agents on the glass surface diffuse into the polymer matrix phase and act as a partial solvent of the polymer matrix in the vicinity of the glass fiber surface. However, as the composite cools, the polymer loses its solubility and separates as an interpenetrating phase with the siloxane at the interphase of the composite. Finally, the compatibility of the silane coupling agents with the polymer matrix is a factor in determining the interfacial adhesion strength between the silane and the polymer matrix. When the excess silane is introduced onto the glass surface, a weak boundary layer is formed between the glass fiber and HIPS, and it acts as a lubricant under the load (13-15,22). Therefore the optimum epoxysilane loading was 0.1 phr. The coupling reactions can be shown as follow :



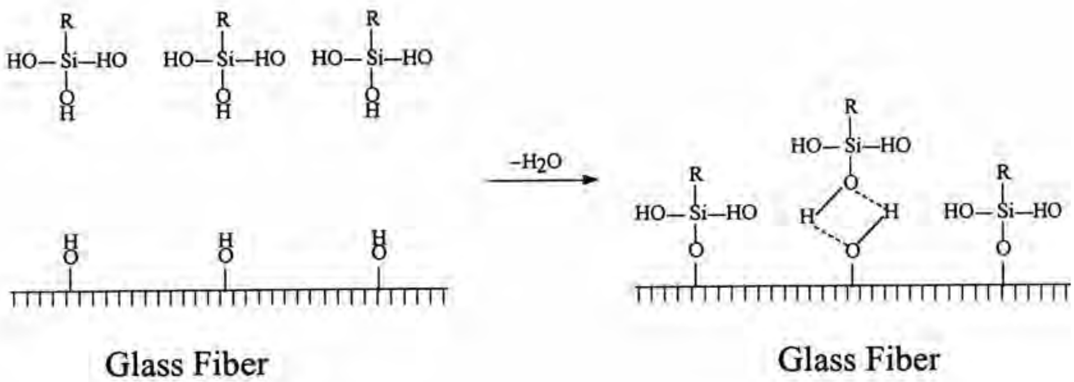


Figure 4.7 The adsorption process of the silane coupling agents onto the glass surface.

The scanning electron microscope (SEM) was employed to investigate the fracture surface of the specimen from the fracture tensile tests. The SEM micrographs show the fracture surface of the HIPS/GF at various percentage of A-187 silane coupling agent.

Figure 4.8 shows the fracture surface of HIPS containing chopped fiber untreated with epoxysilane coupling agent. At 2000X magnification, the SEM micrograph show poor interfacial adhesion. It can be seen from the surface of glass fiber in the breaking region of glass fiber. The "clean" implied the lack of any coating, which indicated the adhesion failure.

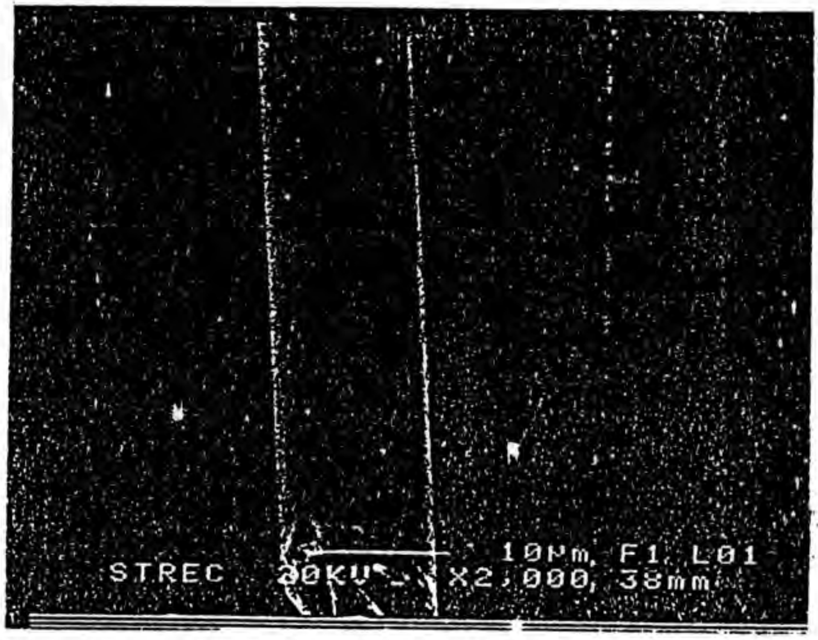
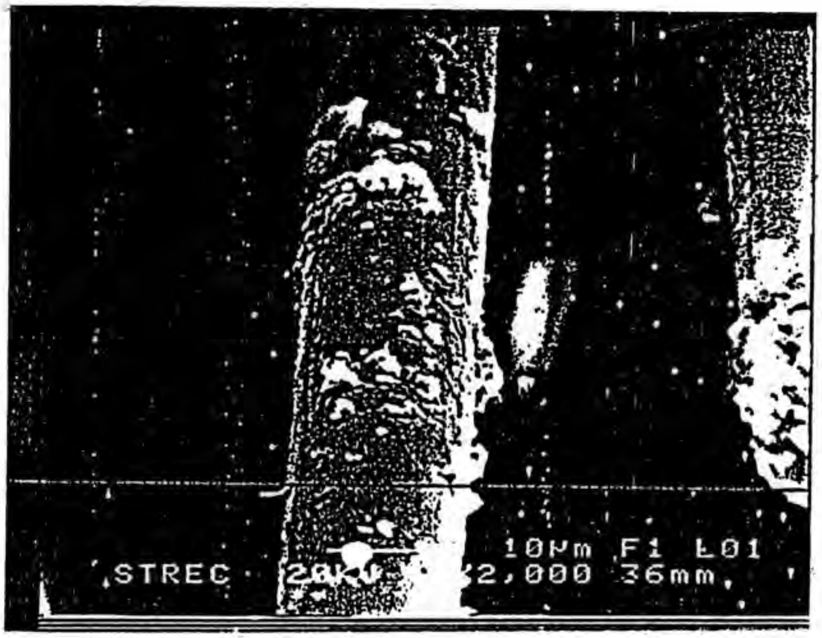


Figure 4.8 SEM micrograph of fracture surface of HIPS/GF without A-187 silane coupling agent.

Figure 4.9 shows the fracture surface of HIPS containing chopped glass fiber treated with epoxysilane coupling agent at 0.1, 0.2, 0.3 and 0.4 phr., respectively. It can be seen that the good interfacial adhesion increase as a function of silane coupling agent loading. For the composite containing A-187 or epoxysilane coupling agent, the coupling agent action between chopped glass fiber and HIPS matrix occurred. It seems to be a chemical bond between glass fiber and HIPS which was induced by the coupling reaction (22,25).

a)



b)

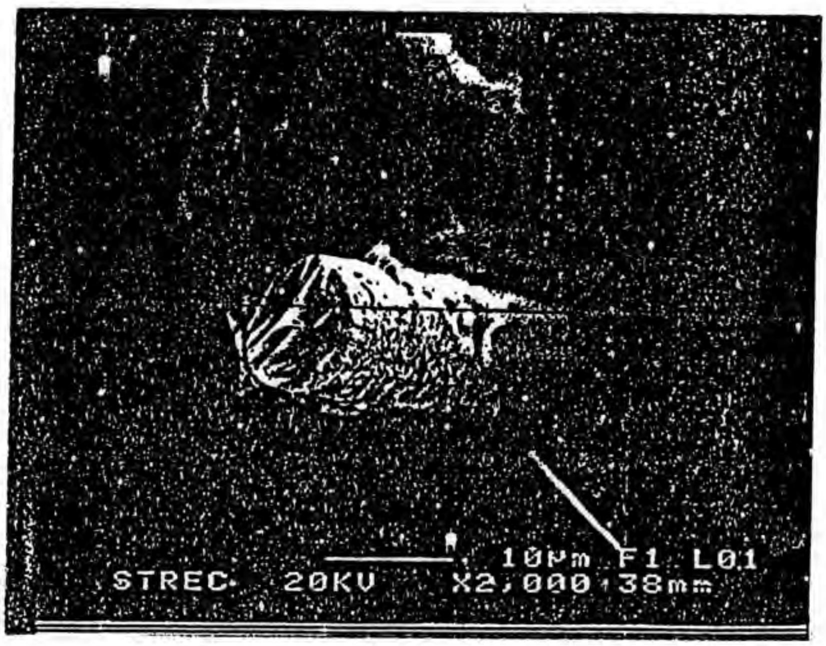
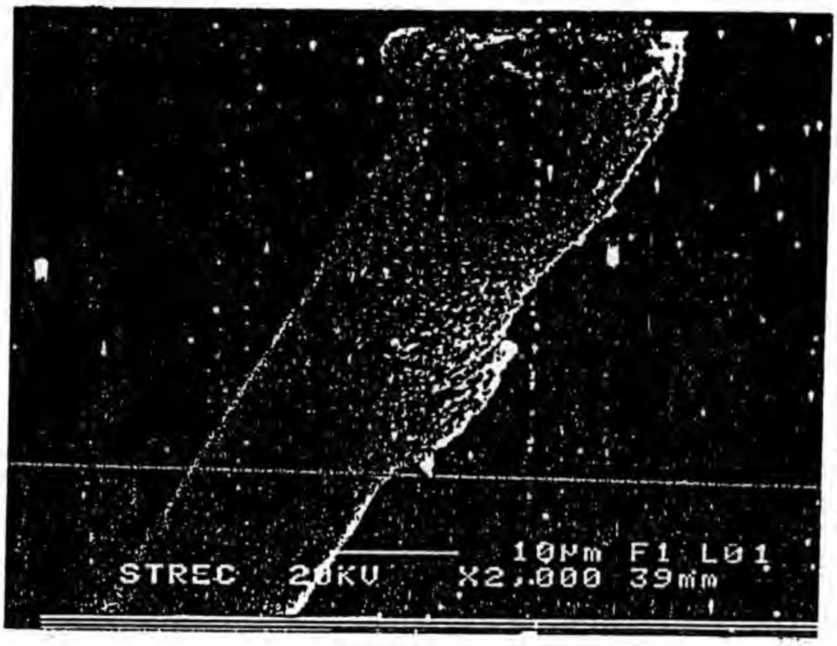


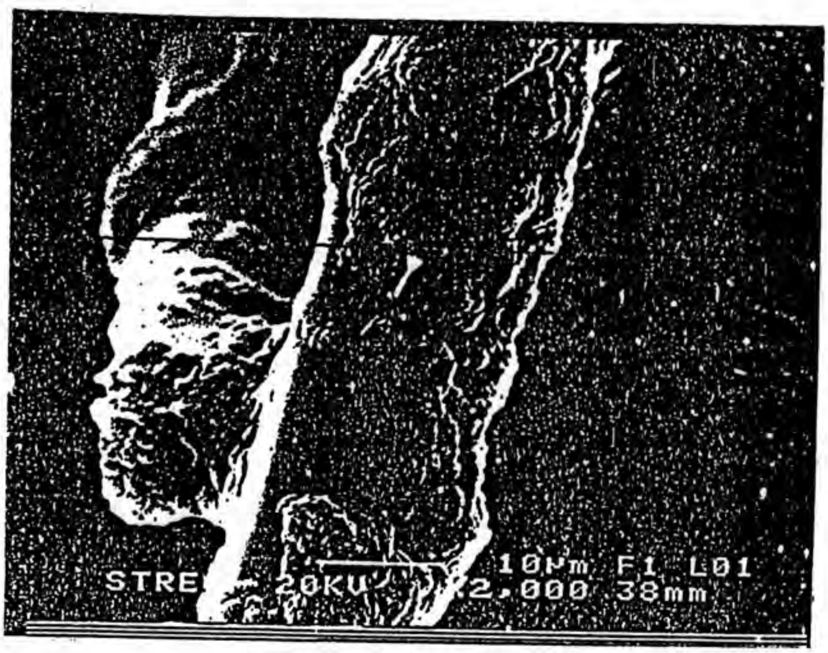
Figure 4.9 SEM photomicrograph of fracture surface of HIPS/GF at 10% chopped glass fibers with A-187 silane coupling.

a) with A-187 0.1 phr b) with A-187 0.2 phr

c) with A-187 0.3 phr d) with A-187 0.4 phr c)


10µm F1 L01
STREC 20KV X2,000 39mm

d)


10µm F1 L01
STRE 20KV 2,000 38mm

4.4 Effect of Chopped Glass Fiber Loading

Figure 4.10 shows the effect of chopped glass fiber loading on physical properties of HIPS with 0.1 phr of silane loading. The deformation behavior of the composite under an applied load can be understood from the tensile curve. In the case of pure HIPS, tensile strength, flexural strength and heat distortion temperature are quite low. Addition of 5% chopped glass fibers result in an increase tensile strength about 12%, flexural strength about 23% and heat distortion temperature about 3 %. Furture addition of chopped glasss fiber rapidly increases the tensile strength, flexural strength and heat distortion temperature.

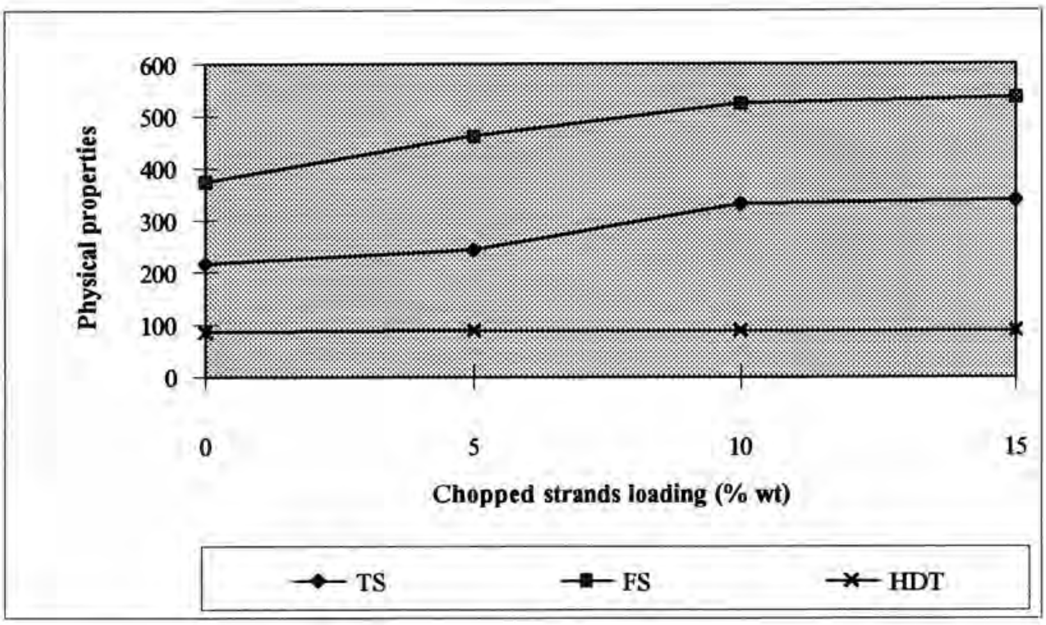


Figure 4.10 Effect of chopped glass fiber loading on physical properties.

It is observed that by adding 10% chopped glass fiber there is an increase of 54% in tensile strength and by further addition there is only an increase of 2%. It can be noticed that above 10% fiber loading, increasing in tensile and flexural strength are less pronouced. This is possibly due to high fiber-to-fiber interactions which was reported by George and Co-workers on effect of fiber loading in Short Pineapple-Leaf-fiber-Reinforced Low-Density Polyethylene Composites.

As expected, the incorporation of fiber increases markedly the composite hardness. Hardness is related with toughness and strength of composite. The density of the composite increases with fiber content due to the close packing of fibers (11).

Figure 4.11-4.13 show the scanning electron micrographs (SEM) of HIPS with 5%, 10% and 15% glass fiber loading, respectively. It indicates the amount of glass fiber in the composite increases with increasing glass fiber loading. However, the SEM indicates the random orientation. Thus mechanical properties of these composites appear to be in medium value (11,26).

Figure 4.11 SEM micrograph of HIPS with 5% chopped glass fiber at 0.1 phr. silane loading.

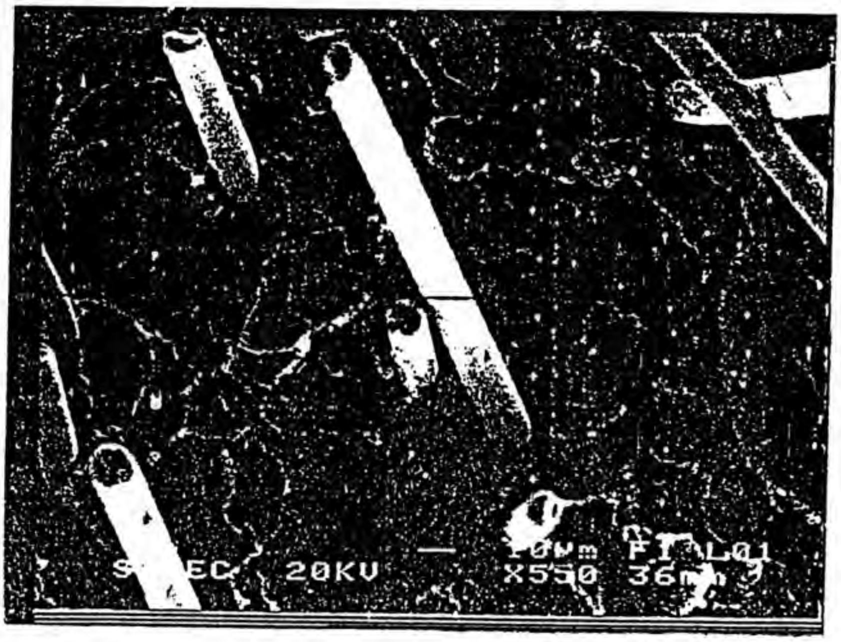


Figure 4.12 SEM micrograph of HIPS with 10% chopped glass fiber at 0.1 phr. silane loading.

Figure 4.13 SEM micrograph of HIPS with 15% chopped glass fiber at 0.1 phr. silane loading.

4.5 Comparision with commercial fiber-reinforced thermoplastics

For commercially available fiber-reinforced thermoplastics (FRTP), short glass fibers are usually added by 10 to 30 wt.% (26). From the results of this study, the best coupling agent loading for HIPS with 10% chopped glass fiber should be 0.1 phr. due to the high physical properties of composite such as tensile strength, flexural strength and heat distortion temperature. This composite was used to inject "Blower" in air-conditioning (see Figure 4.14) system and compared with ABS/GF. The physical properties of HIPS, HIPS/10% chopped glass fiber (HIPS/GF) and ABS/10% chopped glass fiber (ABS/GF) are shown in Table 4.1.

Table 4.1 Physical properties of HIPS, HIPS/GF and ABS/GF.

Physical Properties	HIPS	HIPS/GF	ABS/GF
Tensile strength	215	332	365
Flexural strength	375	524	568
Flexural modulus x 10^4	2	4.18	2.3
Izod notched impact	10.1	8.7	8.5
Heat distortion temp.	86.2	89.9	90

The balancing machine (see Appendix IV) was used to check injection part. The computerized balance instrument calculated and displayed the amount and angle of balance product. The balancing testing have to test every month for at least 3 months. These experiments were carried out for 4 months and repeated 5 times/month. The results are as follow :

	LEFT	RIGHT
1. Unbalance :	0.03 (gr) / 98.4 (deg)	0.06 (gr) / 311.3 (deg)
2. Accept Lt. :	0.20 (gr)	0.20 (gr)
3. QC Test :	**Accept**	**Accept**
4. Correction :	Adding	
5. RPM :	1252	

From this test, ABS/GF and HIPS/GF gave the same balance.

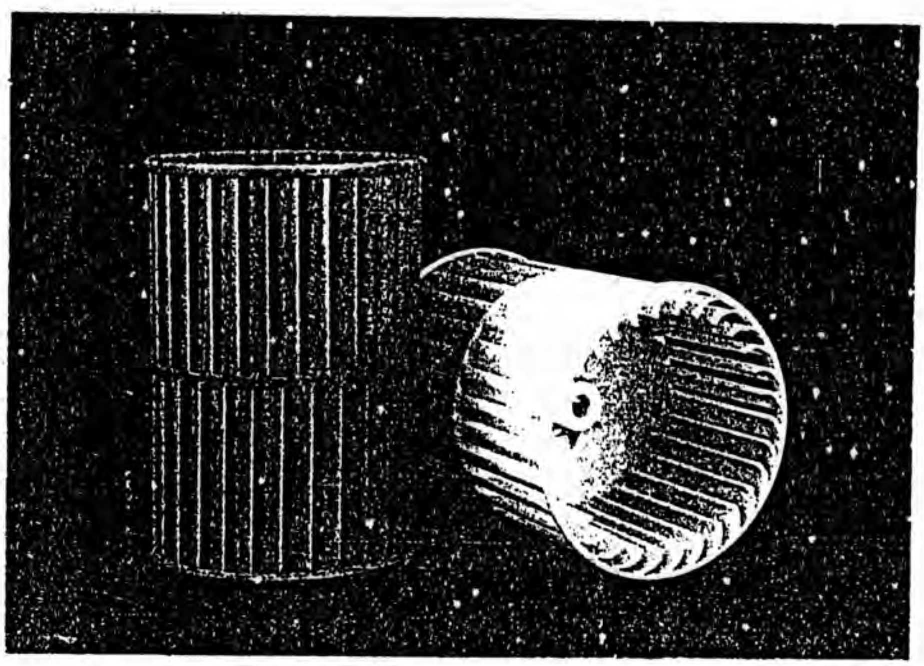


Figure 4.14 A blower of an air-conditioner.

4.6 Economic Consideration

From the result of this research, the best glass fiber for this system should be chopped fiber due to the high mechanical properties of composites provided at various glass fiber loading. In this work, the cost of these composites are based on the costs of HIPS, glass fiber and silane coupling agents. The costs of HIPS resin, glass fiber, A-187 silane were 32, 80 and 800 ฿/kg. respectively, in 1997. Table 4.2 indicates the cost of reinforced-HIPS composite with different glass fiber loading. These composites had good mechanical properties as mentioned above. It can be seen that the cost of composites per kilograms is relatively low. Furthermore, the cost of the reinforced-HIPS is much lower than other engineering plastic in Thailand, e.g., ABS (45 ฿/kg.), ABS/10% of glass fiber (80 ฿/kg.) and POM (90 ฿/kg.) in 1997. Therefore, the price of glass fiber-reinforced HIPS composite will be attractive as an alternative to substitute the high price of the engineering plastic. This work may lead to the development of low-priced engineering plastic substitutes in the future.

Table 4.2 Cost analysis of HIPS- epoxysilane treated glass fiber composite.

Glass fiber loading (%wt.)	Material cost in 1997 (฿/kg.)			Cost of composites[d] (฿/kg.)
	HIPS[a]	GF[b]	A-187[c]	
10	23.4	8	0.8	32.17
15	22.1	12	0.8	34.86

d = [(a+b+c) x 100]/weight at each percentage glass fiber.