CHAPTER V

Result and Discussion

5.1 Aspect Ratio of Fiber

In this study, all fibers were categorized into seven size-groups. The aspect ratio (length by diameter of fiber) was determined from fifty samples of each group. Table 5.1 presents the average and standard deviation of aspect ratio. The data of fifty samples are given in Appendix. In each size-groups, the change in diameter was veried from group to group when the length of each size was not changed much.

Size-Groups (significant variation in diameter)	Fiber Code	Average of Aspect Ratio	S.D.
Size L	L	15.0	4.5
Size M	M	45.3	8.7
Size S (normal)	S	79.7	8.4
Size S with 6-hour treatment of NaOH	S6H	86.0	12.2
Size S with 12-hour treatment of NaOH	S12H	96.3	10.8
Size S with 18-hour treatment of NaOH	S18H	106.6	9.9
Size S with 24-hour treatment of NaOH	S24H	126.5	6.7

Table 5.1 Aspect ratio of seven size-groups.

From table 5.1, it can be shown that the size of each group related to its aspect ratio. The larger size of fiber gave higher diameter and lower aspect ratio. Moreover, the longer time of NaOH treatment provided higher aspect ratio. The amount of lignin removed was dependent on time of treatment [Collier et al. 1998]. When the lignin was removed, the diameter of fiber bundle was also reduced. That led to high aspect ratio.

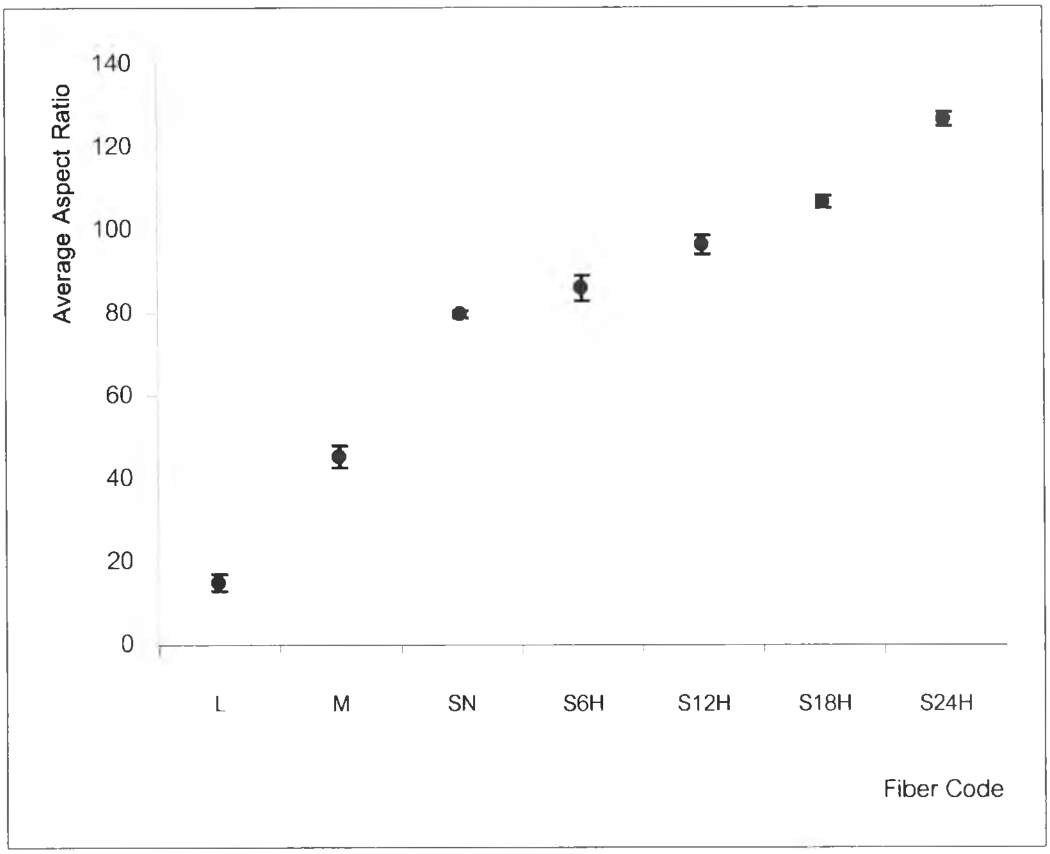

Figure 5.1 Average Aspect Ratio of Each Size-Group

5.2 Coupling Agent Absorption of Fiber

After treating all size of fibers (S-size, M-size, and L-size) with silanol solution and drying in the oven, the weight of all fiber-sizes were compared with that before treatment to check the percentage of silane absorption. The amount of silane absorption is shown in Table 5.2.

Fiber Size	% Coupling Agent Absorption of Fiber
S	38.7
M	30.3
L	24.0

Table 5.2 The percentage of coupling agent absorption in each fiber size.

From the table 5.2, it can be implied that small-size fiber absorbs more coupling agent than large-size fiber does. It could be due to the high surface area of small-size fiber compared with the large one.

The higher percentage of coupling agent absorption of fiber means the coupling agent content in the fiber. There were studies concerned with the effect of coupling agent content on the mechanical properties. Chen et al. [1997] studied the effect of MAPP compatibilizer content on polypropylene (PP). It was reported that an increase in the amount of compatibilizer leads to increasing in tensile strength and tensile modulus in Bamboo fiber / PP composite.

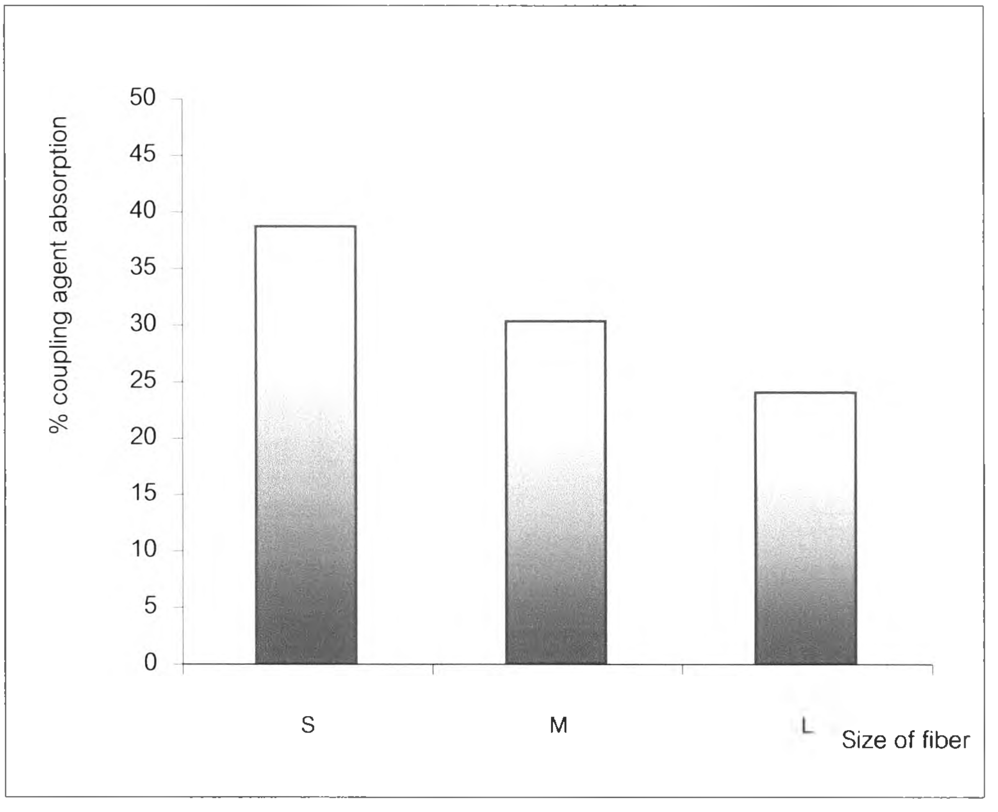

Figure 5.2 Comparison of the percentage of coupling agent absorption at various size of fiber (N=2)

5.3 Effect of Fiber Content on Mechanical Properties

5.3.1 Flexural Properties

Figure 5.3 shows the flexural strength at break of the composite, which used three sizes of fiber (L-fiber. M-fiber, and S-fiber) and without silane coupling agent. Compared with pure PMMA, the flexural strength of composite at 5-wt % of fiber was reduced around 15% to 30%. When the fiber content was increased, all three sizes of fiber made flexural strength slightly decrease. It could be due to the nature of bamboo fiber in low flexural strength across the fiber as shown in Table 2.6 [S. Jain *et al.* 1992].

Figure 5.4 shows the flexural modulus of the composite, which used three sizes of fiber without silane coupling agent. When varying the fiber content, the flexural modulus of composite at 5-wt % increased around 20% to 25% higher than that of pure PMMA. It could be noticed that when the fiber content was increased, all three sizes of fiber made flexural modulus slightly increase. It can be implied that the composite with bamboo fiber has higher stiffness than PMMA without reinforcement.

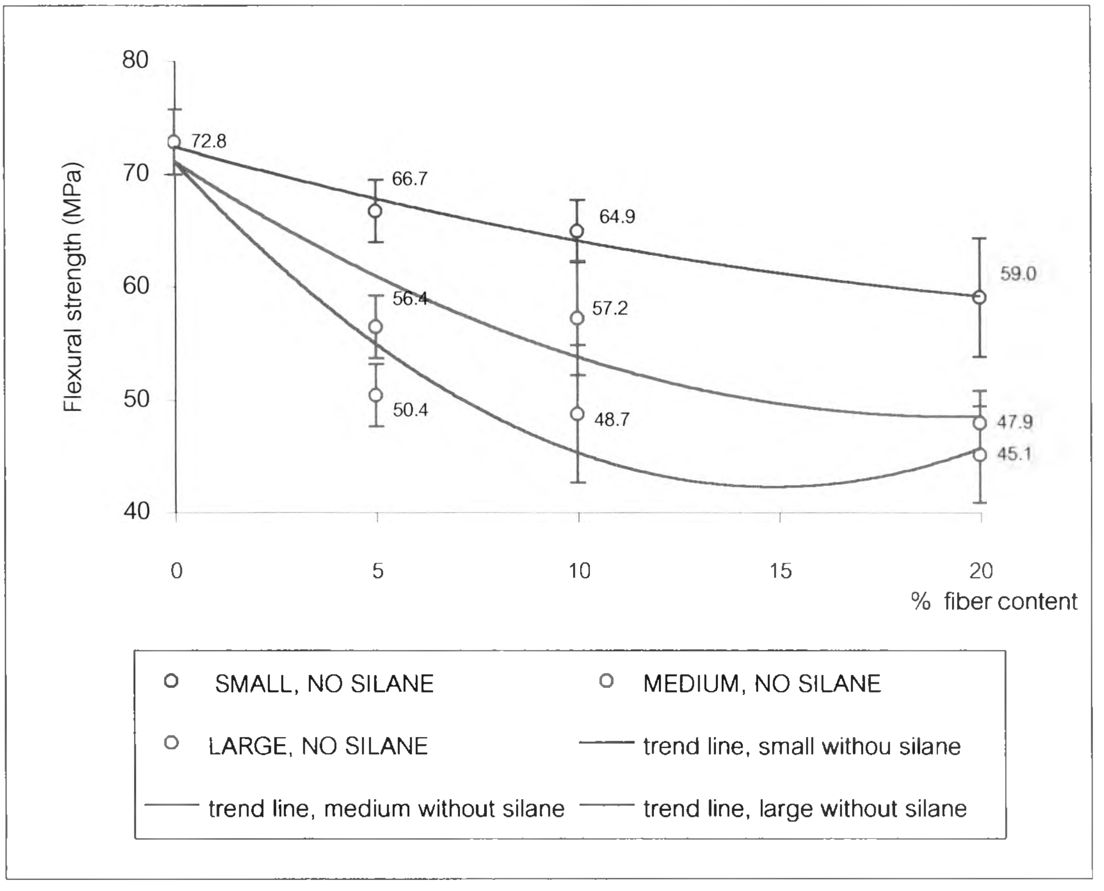

Figure 5.3 Effect of fiber content on flexural strength (without coupling agent)

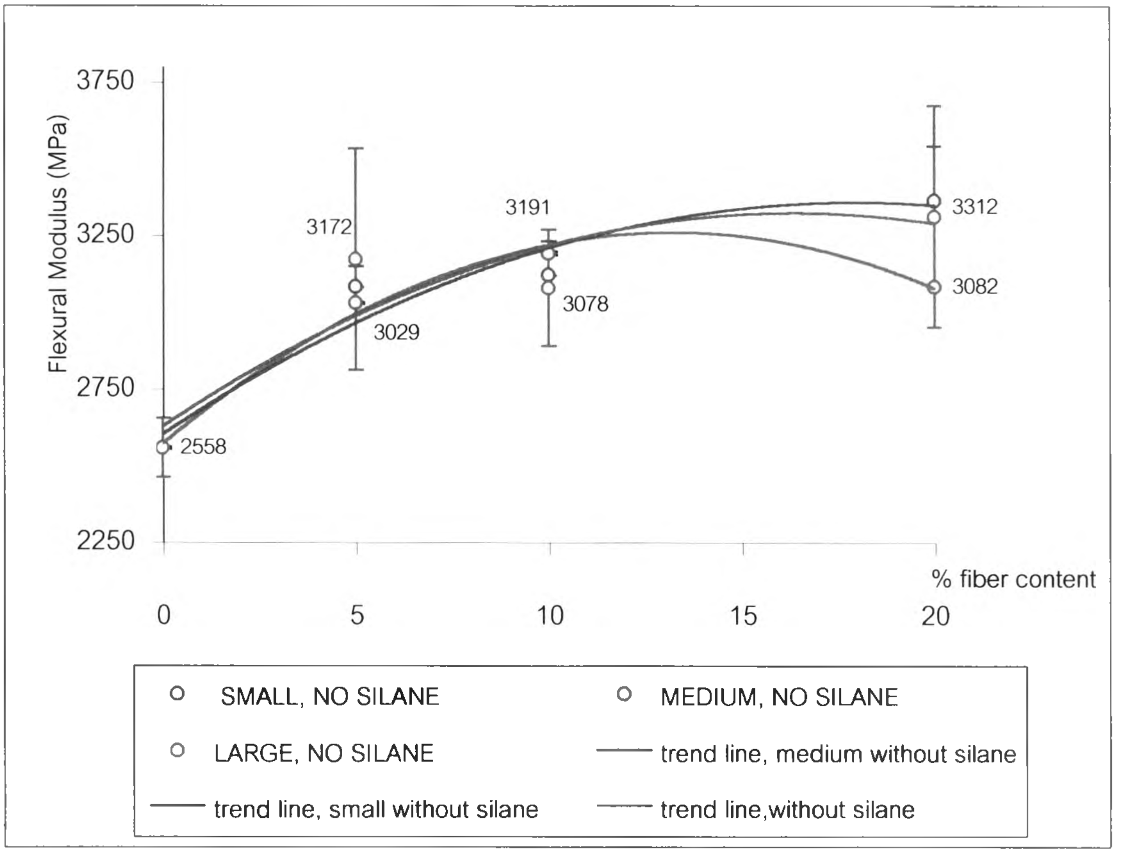

Figure 5.4 Effect of fiber content on flexural modulus (no coupling agent used)

5.3.2 Impact Strength

The effects of fiber content for L-fiber, M-fiber and S-fiber on the impact strength are presented in Figure 5.5. When increasing the content of M-fiber and L-fiber (without coupling agent), the average of impact strength decreased around 15% to 20% for 5-wt %. After increasing more content of M-fiber and L-fiber, the impact strength of both fiber-composites slightly changed, whereas, S-fiber composite had higher impact strength when the amount of fiber was increased. Although there was no coupling agent added, the impact strength of 5-wt% and 20-wt % of S-fiber was higher than that of pure PMMA around 40% and 110% respectively. The cause could be that S-fiber had more surface area and better adhesion between fiber and PMMA than that of M-fiber and L-fiber. This result is rather correspond to the work of Chen et al. [1997] who studied the use of bamboo fiber as reinforcing element in polypropylene (PP). It was reported that using bamboo was able to increase the impact strength of polypropylene. Increasing in the bamboo fiber content could increase the impact strength of the bamboo fiber / PP composite although there was no coupling agent applied.

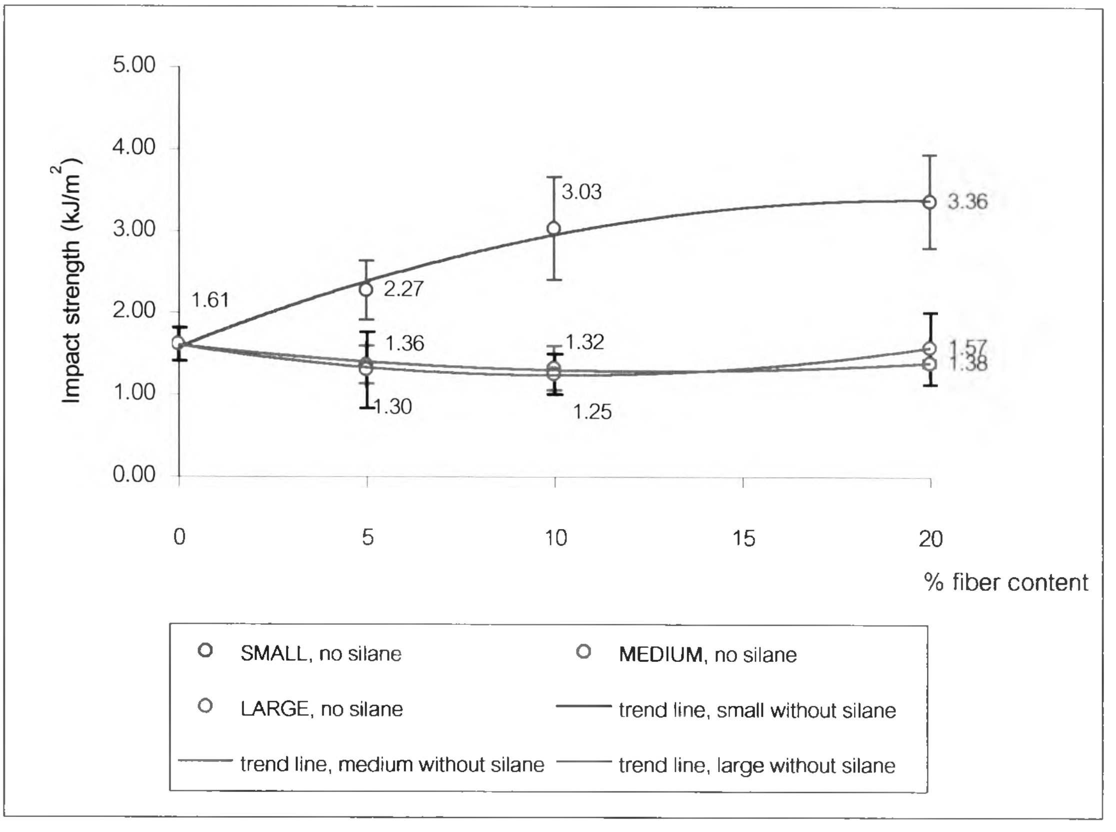

Figure 5.5 Effect of fiber content on impact strength

5.3.3 Compressive Strength

The compressive strength of the composite reinforced with bamboo fiber (S-fiber, M-fiber, and L-fiber) at various fiber contents is shown in Figure 5.6. At 5-wt % of fiber content, the compressive strength of composite is higher than that of pure PMMA around 3 % for L-size composite and 10 % for S-size composite. When increasing the fiber content to 20-wt %, the compressive strength of composite is higher than that of pure PMMA around 24 % for L-size and 36 % for S-size. It can be implied that in general the bamboo fiber has higher compressive strength than that of PMMA. The more content provided the higher compressive strength, especially in the small fiber-size, which had higher surface area than the large fiber-size.

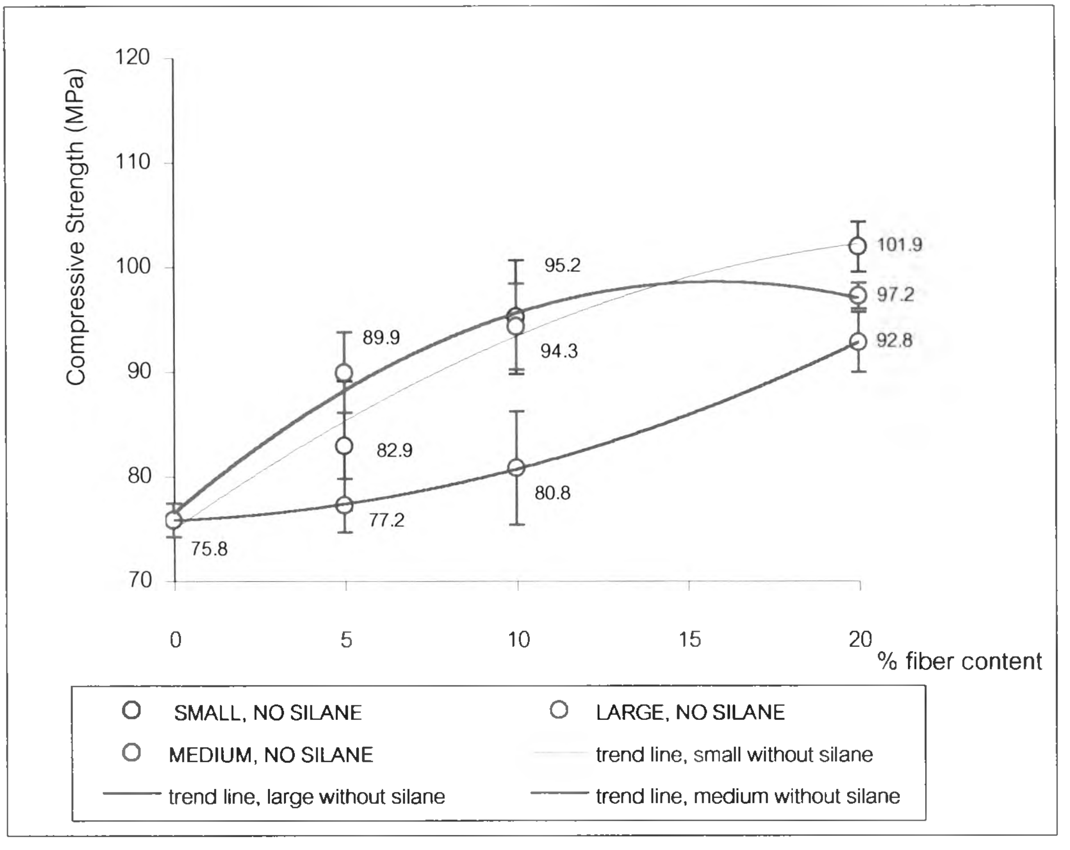

Figure 5.6 Effect of fiber content and fiber size on compressive strength (no coupling agent used)

5.4 Effect of Coupling Agent on Mechanical Properties

5.4.1 Flexural Properties

The effect of coupling agent on the flexural strength of S-fiber composite, M-fiber composite, and L-fiber composite are shown in Figure 5.7, 5.8, and 5.9, respectively. When using the coupling agent in S-fiber, the flexural strength of the composite was obviously lower than that of the non-coupling agent composite. In this case, the better adhesion between the interfacial surfaces of fiber and PMMA makes the more easiness of fracture in the fiber. The reason is that the bamboo fiber naturally has lower flexural strength than the PMMA. Moreover, the coupling agent plays an important role in small fiber more than in large fiber due to higher surface area of small fiber.

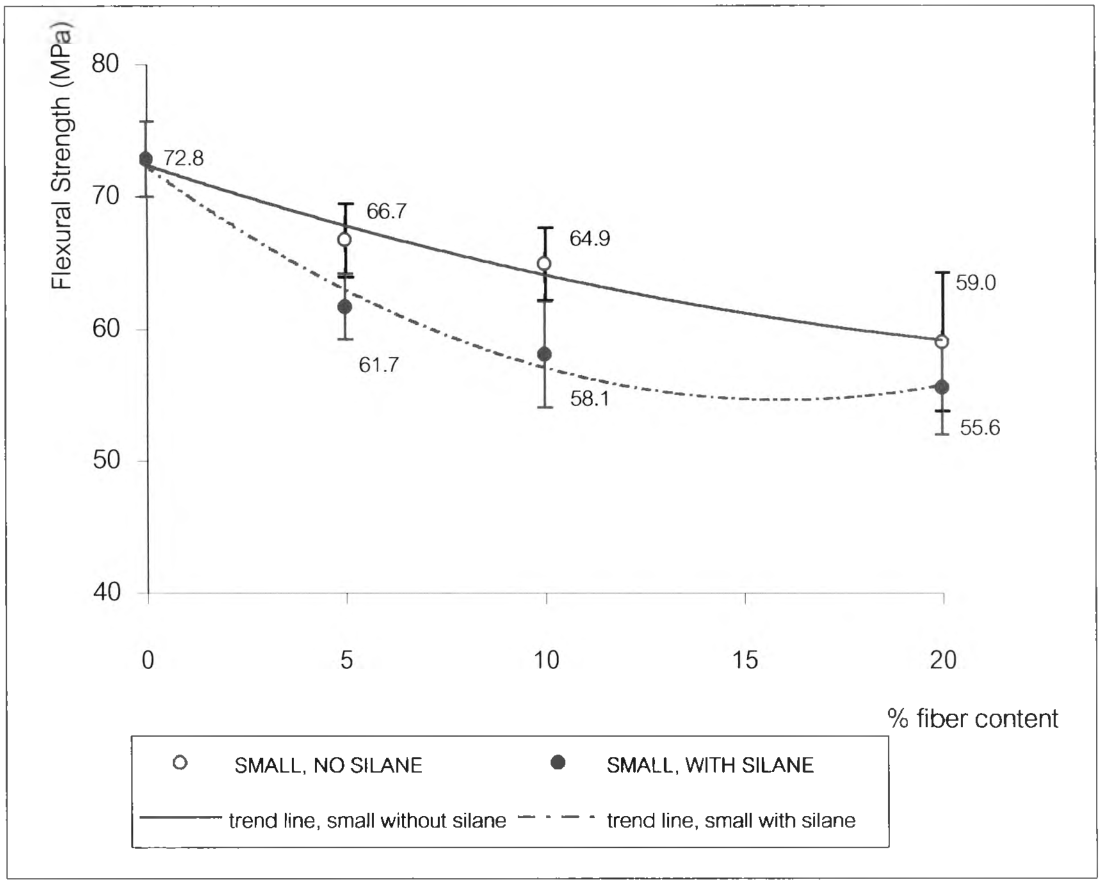

Figure 5.7 Effect of Coupling Agent on Flexural Strength (Small Fiber Size)

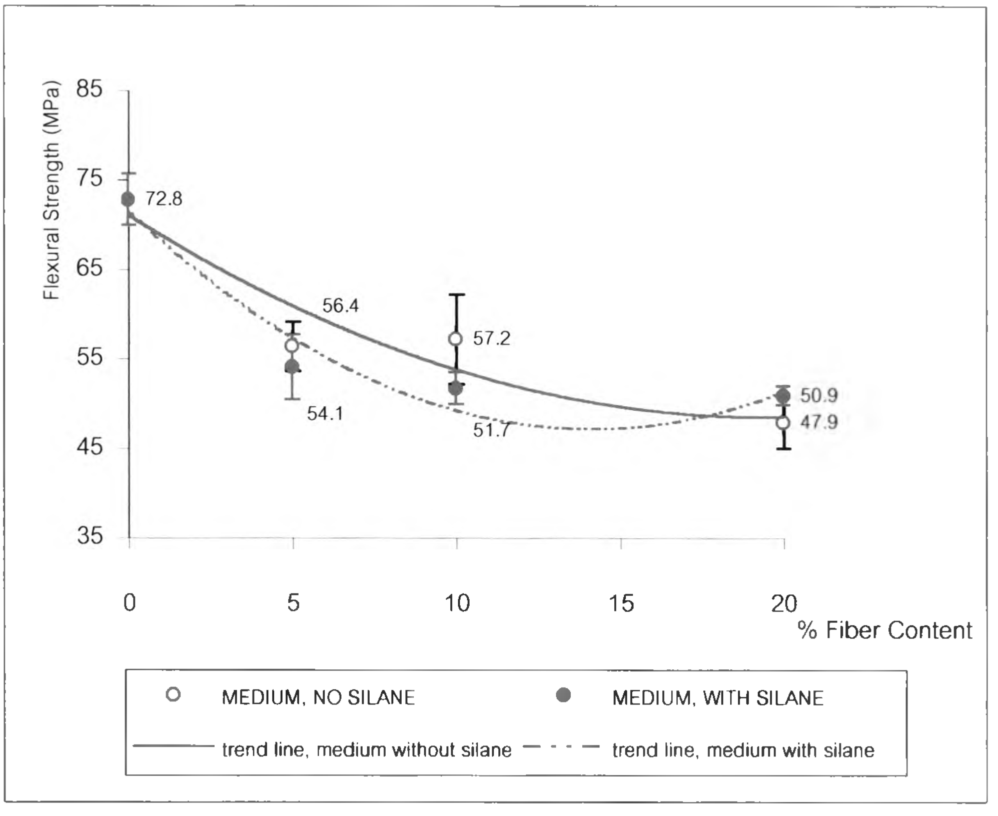

Figure 5.8 Effect of Coupling Agent on Flexural Strength (Medium Fiber Size)

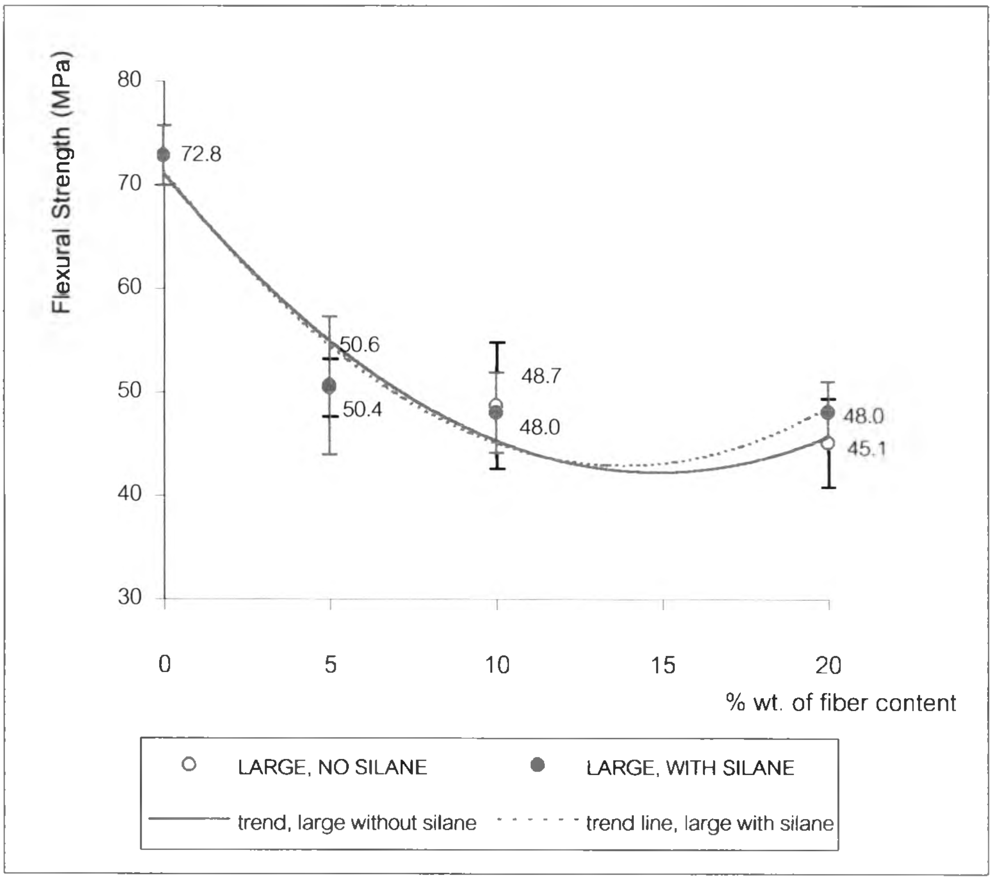

Figure 5.9 Effect of Coupling Agent on Flexural Strength (Large Fiber Size)

Figure 5.10 presents the flexural modulus at break of the composite with S-size fiber when the silane coupling-agent was used. The flexural modulus of non-coupling agent composite did not have significant difference (less than 5%) from that of the composite with coupling agent. It can be indicated that the coupling agent does not have significant effect on flexural modulus. This result shows the same trend in M-size fiber and L-size fiber composite as presented in Figure 5.11 and 5.12.

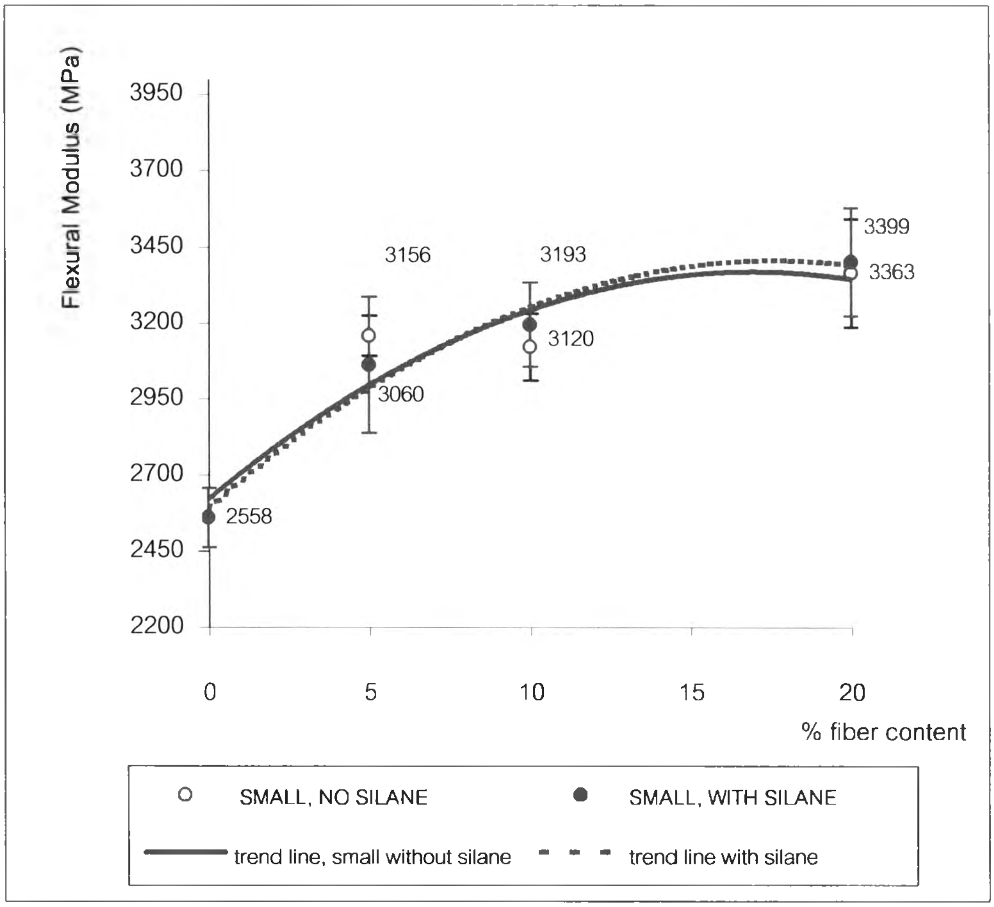

Figure 5.10 Effect of Coupling Agent on Flexural Modulus (Small Fiber Size)

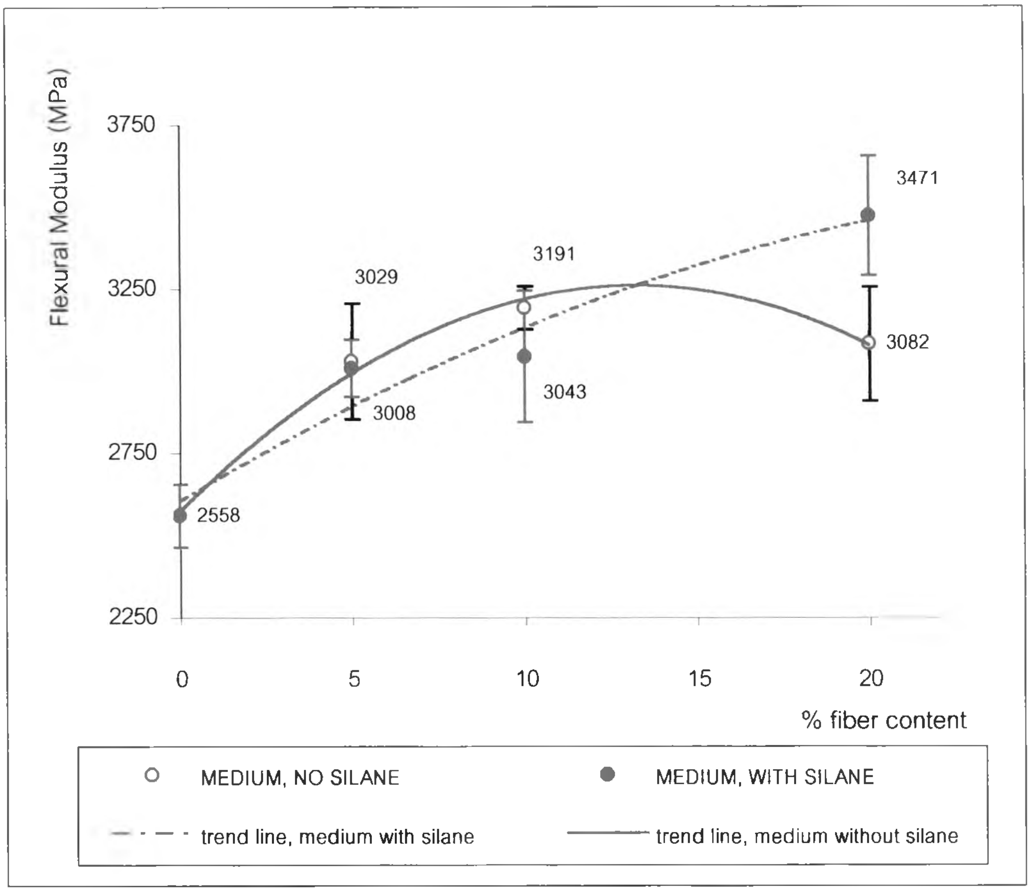

Figure 5.11 Effect of Coupling Agent on Flexural Modulus (Medium Fiber Size)

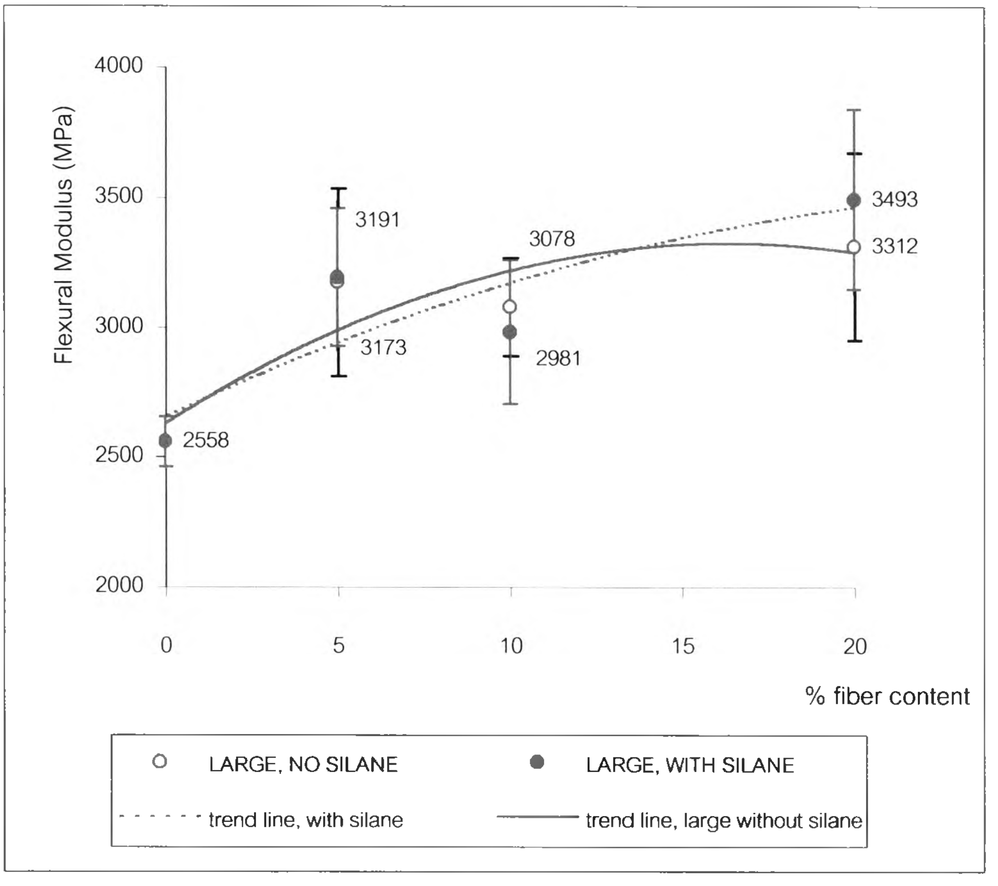

Figure 5.12 Effect of Coupling Agent on Flexural Modulus (Large Fiber Size)

5.4.2 Impact Strength

In Figure 5.13, the impact strength of S-fiber composite with and without coupling agent is compared. It can be noticed that, the impact strength of the composite when using silane coupling agent was higher than that of the composite without coupling agent around 220 % to 260 %. This result is in agreement with the work of Chen *et al*. 1997 who have studied the impact strength of bamboo fiber-reinforced polypropylene composites. This article has demonstrated that using the compatibilizer can improve the adhesion between bamboo fiber and polypropylene. The impact strength of the bamboo fiber-reinforced polypropylene composite with compatibilizer is higher than that of the composite without compatibilizer.

In Figure 5.14 and 5.15, both impact strength of M-fiber composite and L-fiber composite has the same trend as Figure 5.13. However, it can be noticed that at 20-wt % of fiber content, both impact strength of M-fiber composite and L-fiber composite slightly decrease comparing with the composite at 10-wt %.

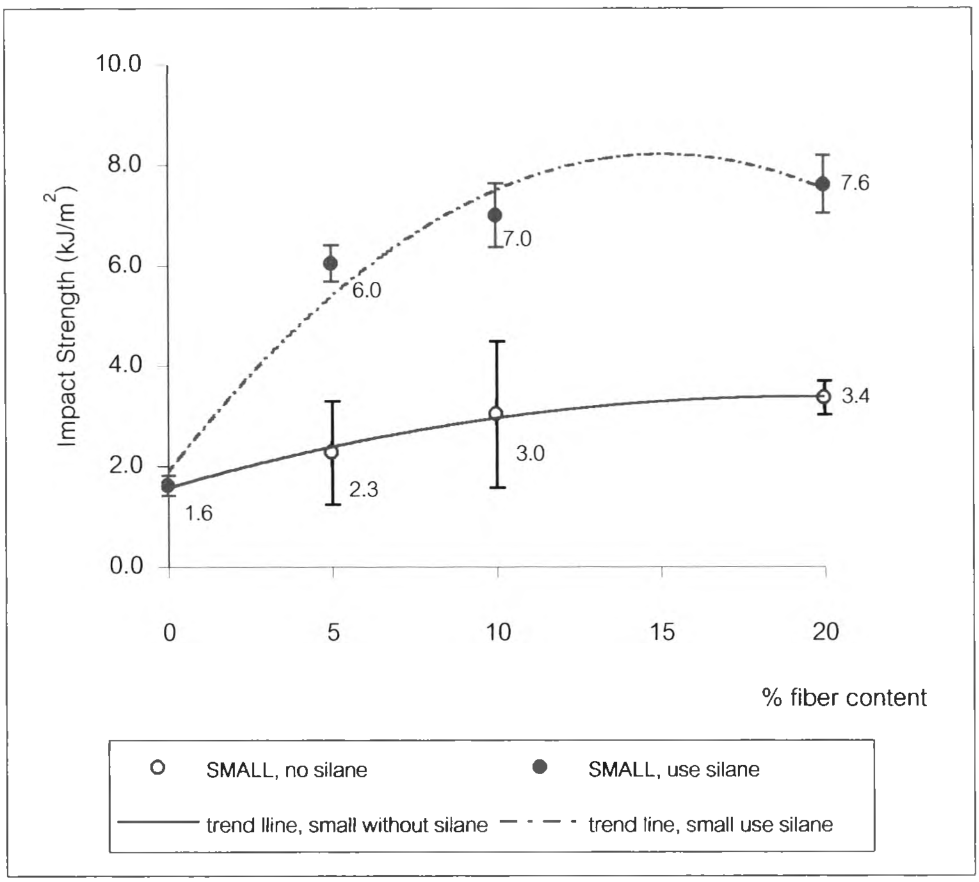

Figure 5.13 Effect of Coupling Agent on Impact Strength (Small fiber size)

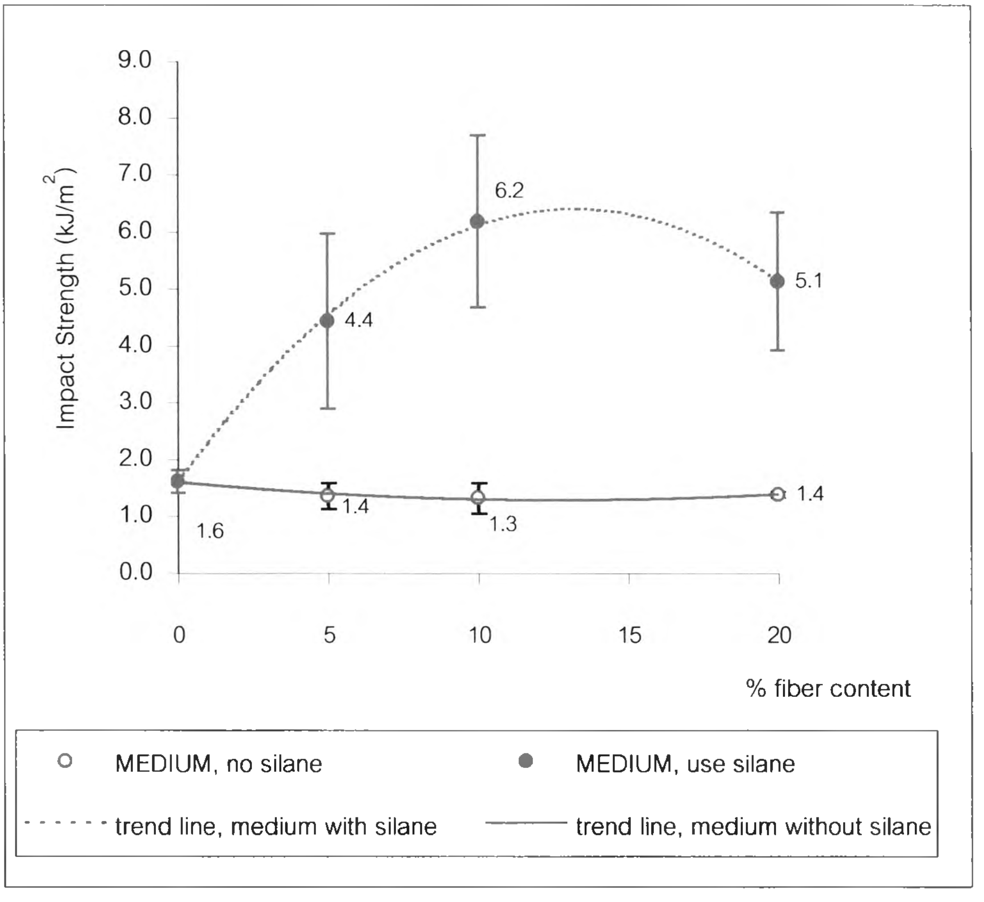

Figure 5.14 Effect of Coupling Agent on Impact Strength (Medium Fiber Size)

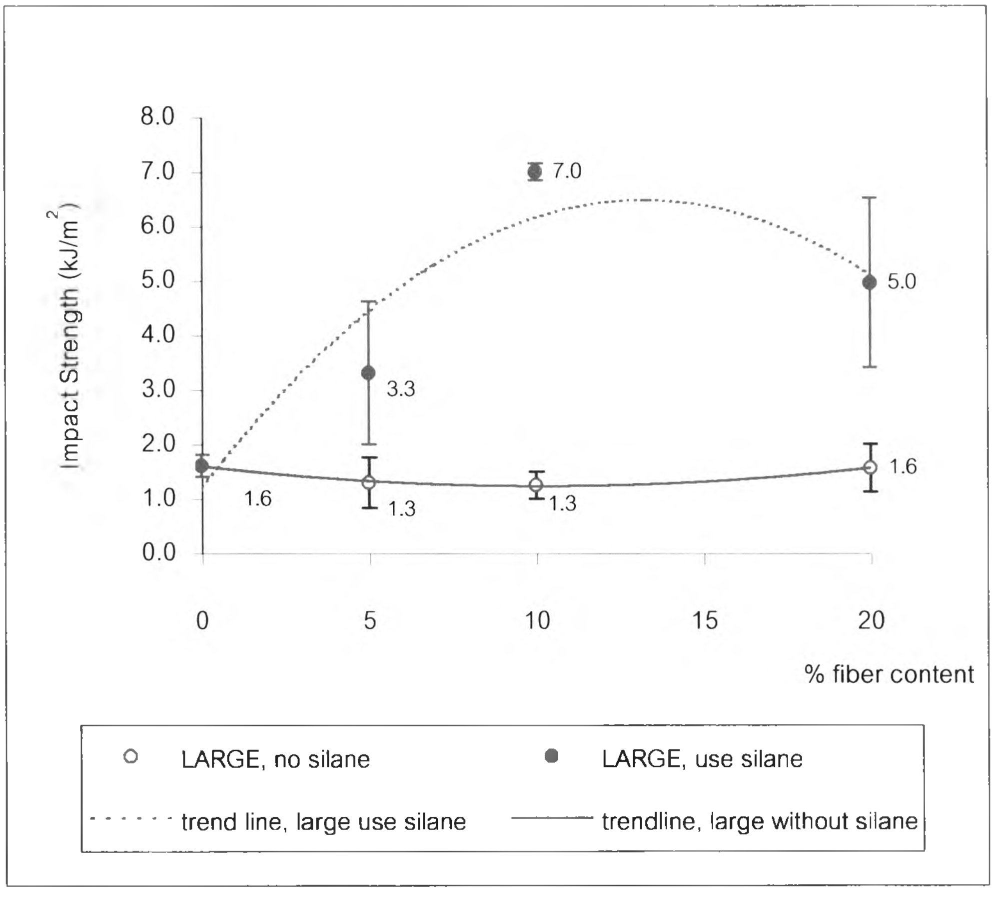

Figure 5.15 Effect of Coupling Agent on Impact Strength (Large Fiber Size)

5.4.4 Compressive Strength

Figure 5.16 shows the effect of coupling agent on the compressive strength at yield of the composite with S-size fiber. In Figure 5.16, the compressive strength of the S-fiber composite with coupling agent is higher than that of the composite without coupling agent at the same content by 15 %. The coupling agent plays the same role in both M-fiber composite and L-fiber composite as shown in Figure 5.17 and 5.18, respectively.

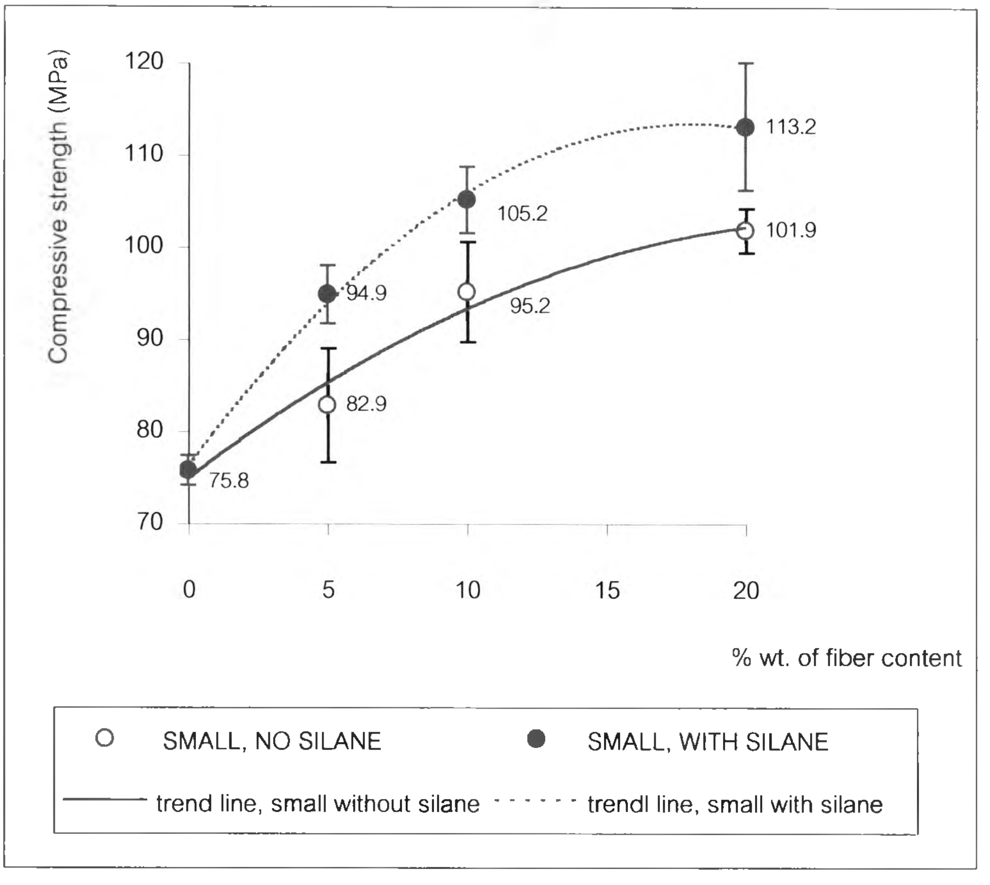

Figure 5.16 Effect of coupling agent on compressive strength (small fiber size)

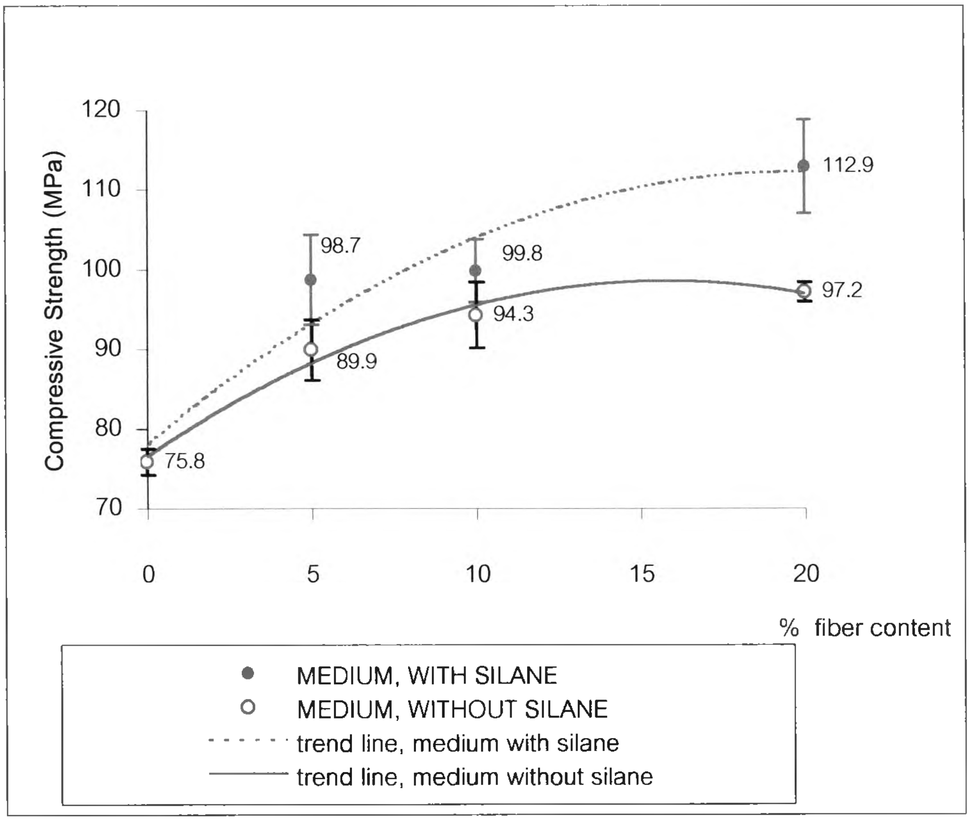

Figure 5.17 Effect of Coupling Agent on Compressive Strength (medium size)

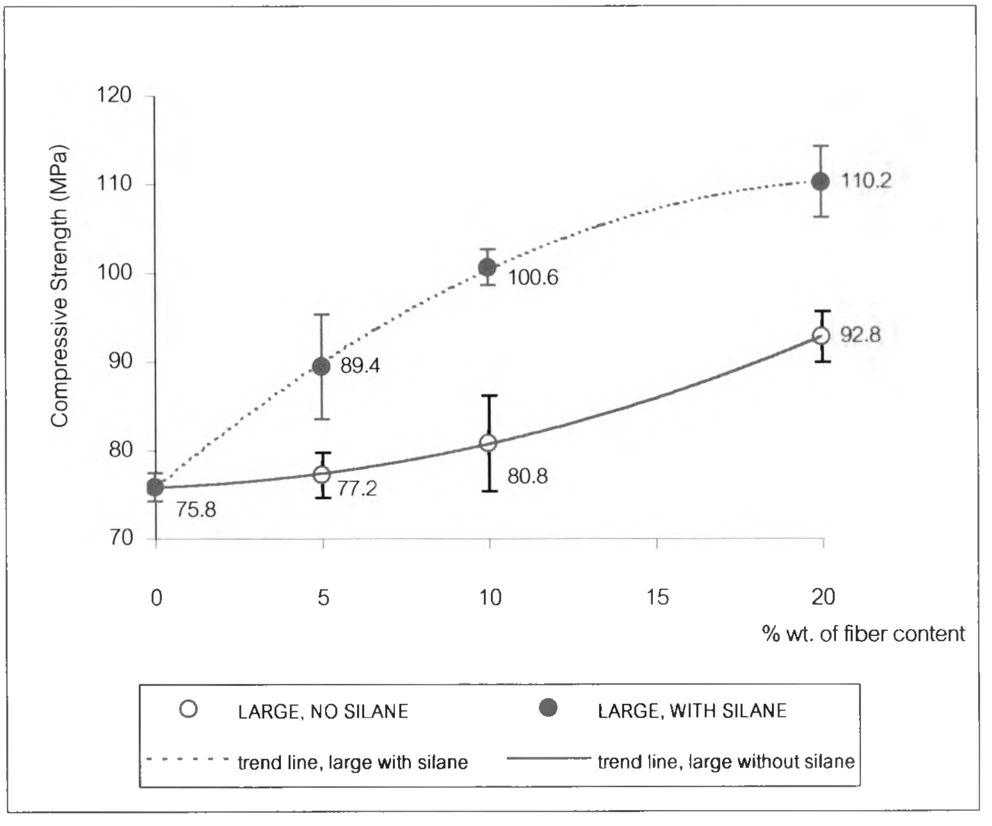

Figure 5.18 Effect of Coupling Agent on Compressive Stength (Large Fiber Size)

5.5 Effect of Aspect Ratio on Mechanical Properties

5.5.1 Flexural Properties

Figure 5.19 shows the flexural strength at break of the composite at various aspect ratios. When the aspect ratio increases, the flexural strength also increases. The flexural strength of the composite with the 24-hour NaOH-treatment fiber (average aspect ratio 126.5) is higher than that of the composite with non NaOH-treatment fiber (average aspect ratio 79.7) around 15 %.

The flexural modulus at break of the composite at various aspect ratios is presented in Figure 5.20. It can be noticed that the flexural modulus increases when the flexural modulus increases. The flexural modulus of the composite with the 24-hour NaOH-treatment fiber (average ratio 126.5) is higher than that of the composite with non NaOH-treatment fiber (average aspect ratio 79.7) around 21%.

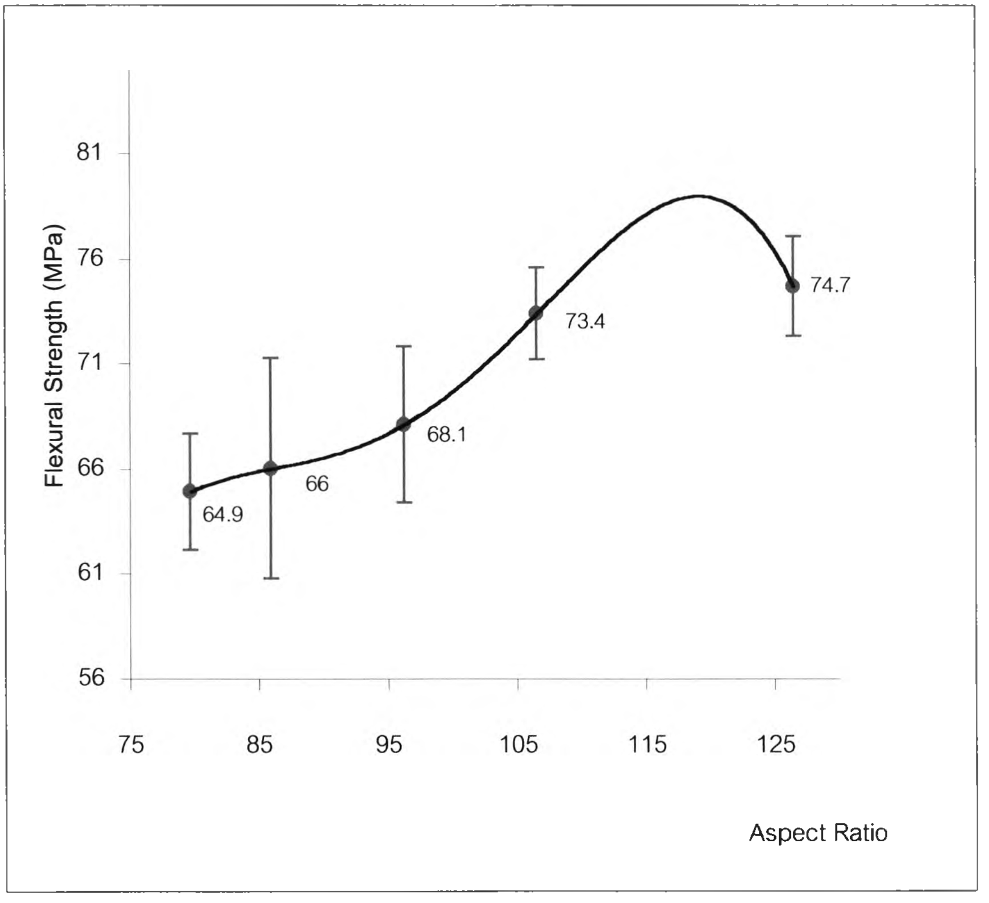

Figure 5.19 Effect of Aspect Ratio on Flexural Strength

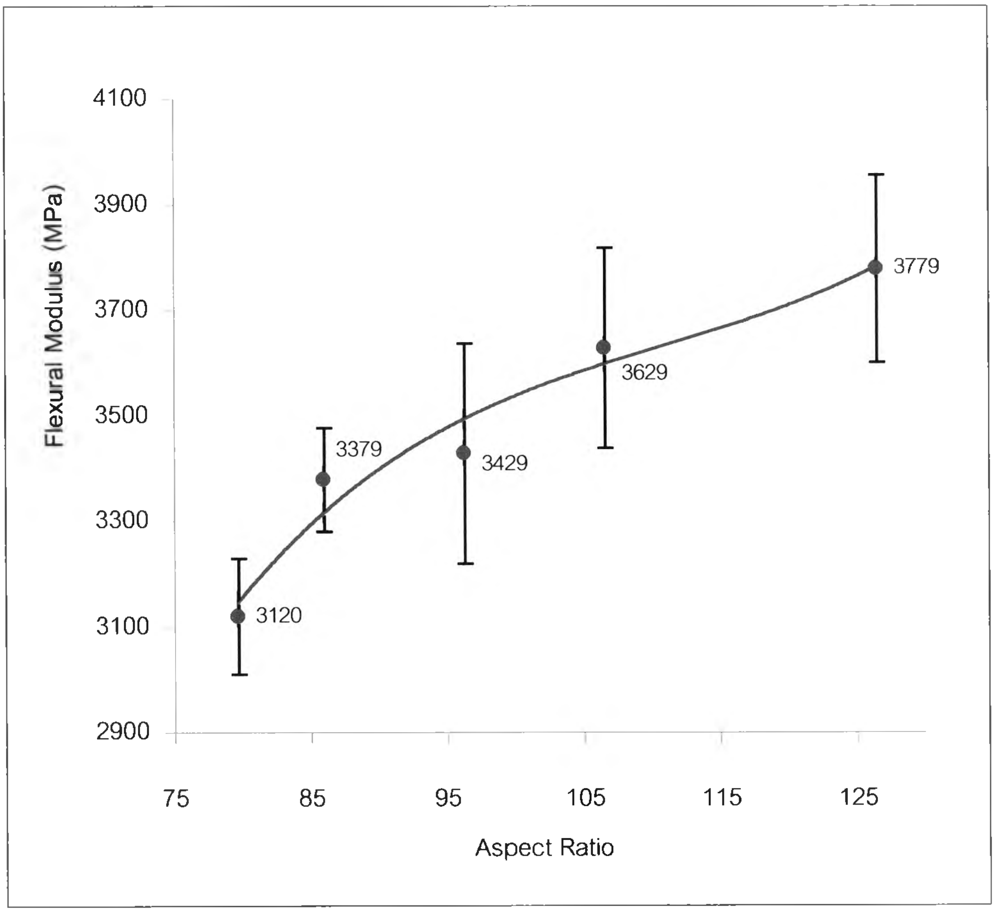

Figure 5.20 Effect of Aspect Ratio on Flexural Modulus

5.5.2 Impact Strength

Figure 5.21 shows the impact strength of the composite at various aspect ratios. It can be seen that the composite with high-aspect-ratio fiber has higher impact strength than that with low-aspect-ratio fiber. The impact strength of the composite with the 24-hour NaOH-treatment fiber (average aspect ratio 126.5) is higher than that of the composite with non NaOH-treatment fiber (average aspect ratio 79.7) around 69 %.

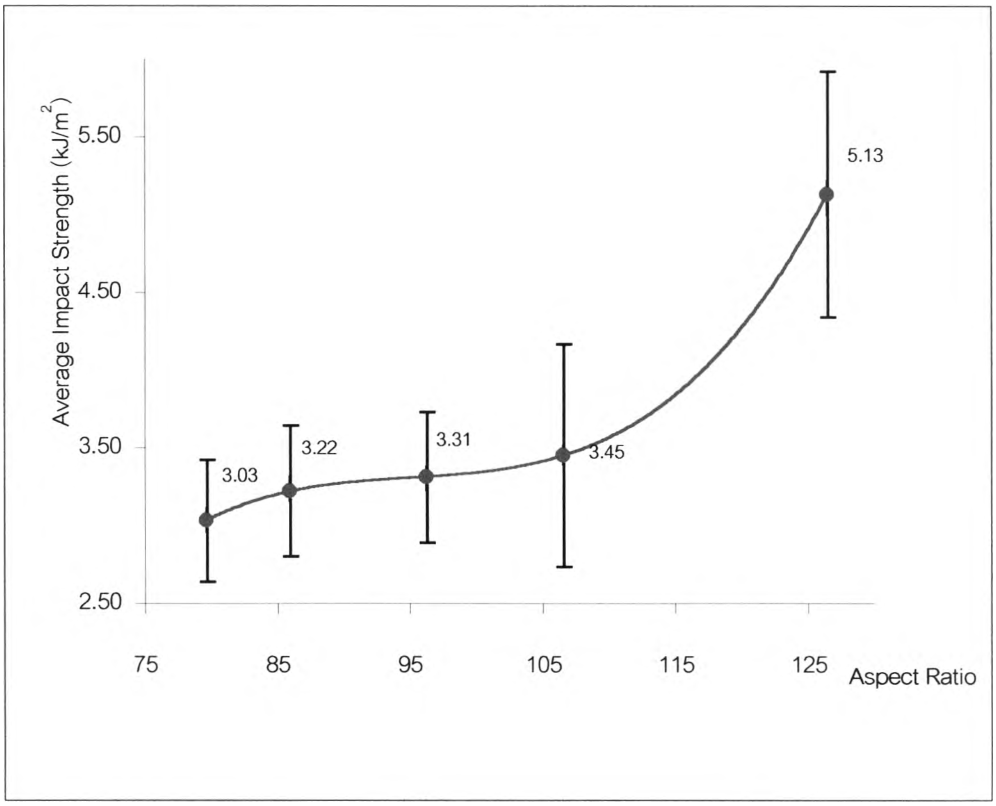

Figure 5.21 Effect of Aspect Ratio on Impact Strength

5.5.3 Compressive Strength

Figure 5.22 shows the compressive strength of the composite at various aspect ratios. It can be seen that the composite with high-aspect-ratio fiber has higher compressive strength than that with low-aspect-ratio fiber. The compressive strength of the composite with the 24-hour NaOH-treatment fiber (average aspect ratio 126.5) is higher than that of the composite with non NaOH-treatment fiber (average aspect ratio 79.7) around 10.7 %.

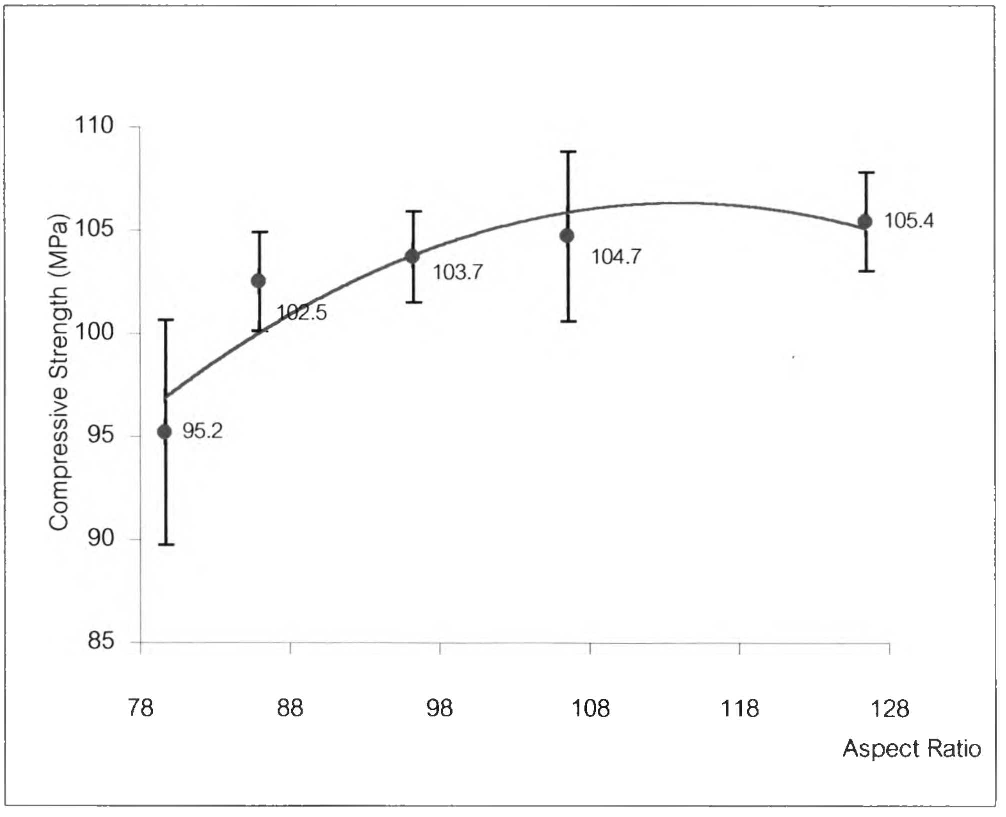

Figure 5.22 Effect of Aspect Ratio on Compressive Strength

5.6 Morphological Study of the bamboo fibers and the composites

SEM showed the appearance of fibers, wettability of matrix on fibers and interfacial adhesion between fibers and matrix. The specimens, cracked during the mechanical property test, were determined in SEM micrographs. The results can be related to the adhesion between the fibers and PMMA. If the fiber pull-out is found, it means it has poor adhesion between two components. On the other hand, if fiber breakage and fibrillation are observed in the fractured surface that means there are some degrees of adhesion between those two components.

Figure 5.23 and 5.24 show the surface of the fibers before and after using silane coupling agent, respectively. It was found that the surface of the fiber before using the coupling agent was rather smooth. After the coupling agent was applied, the surface of fiber was masked with the coupling agent.

Figure 5.25 to 5.28 show the fiber bundle at various NaOH-treatment time. It can be seen that when increasing treatment time, the diameter of fiber bundle was reduced. That leads to increasing in aspect ratio.

Figure 5.29 and 5.30 show the wettability of the composite with the fiber without and with the coupling agent, respectively. It can be seen that the surface of the fiber without coupling agent was smoother than that with the coupling agent. It means that the fiber without the coupling agent also has lower wettability than that of the fiber with the coupling agent.

Figure 5.31 to 5.34 show the surface of the specimen after cracking in various NaOH-treatment time. It can be noticed that there was fiber breakage in many points, it means that there is some degree of adhesion between fiber and matrix.

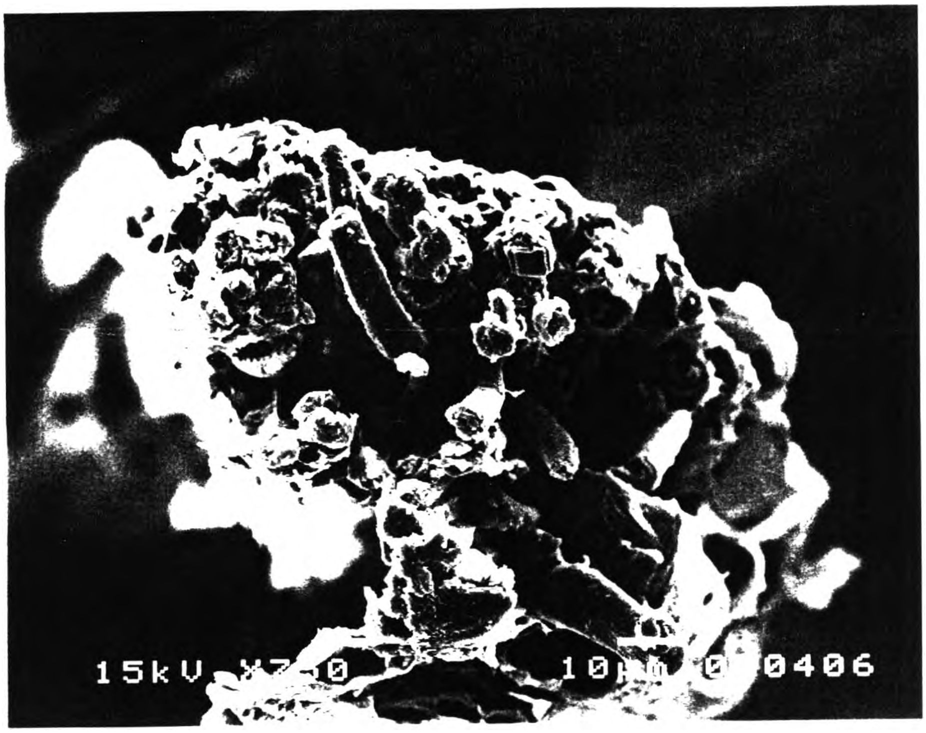

Figure 5.23 SEM micrograph of the fiber bundle surface before using silane coupling agent (X 750)

Figure 5.24 SEM micrograph of the fiber-bundle surface after using silane coupling agent (X 350)

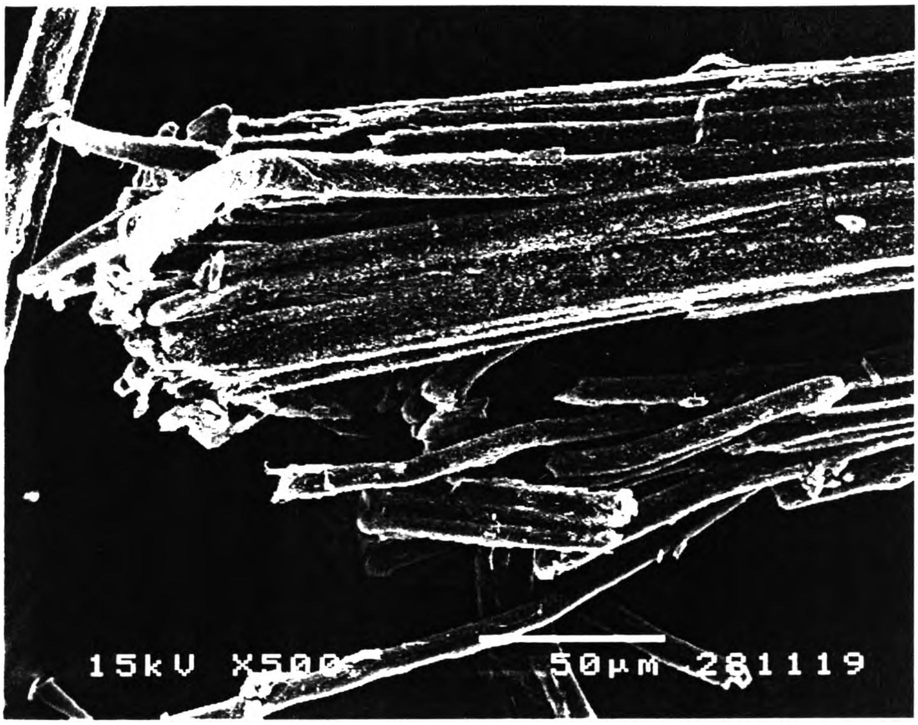

Figure 5.25 SEM micrograph of the fiber bundle after treating with NaOH for 6 hours. (X 500)

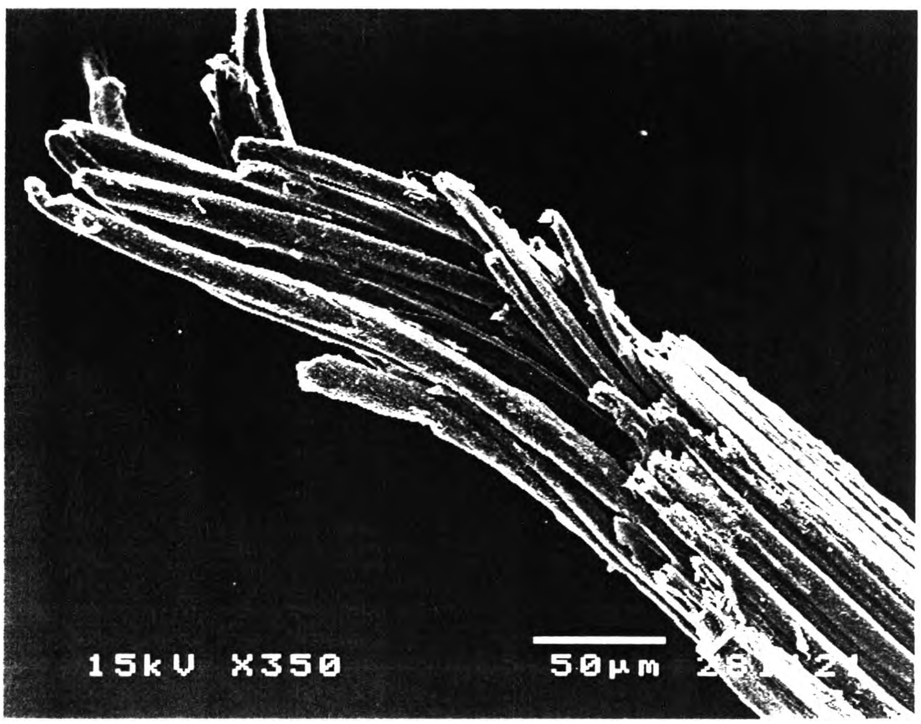

Figure 5.26 SEM micrograph of the fiber bundle after treating with NaOH for 12 hours. (X 350)

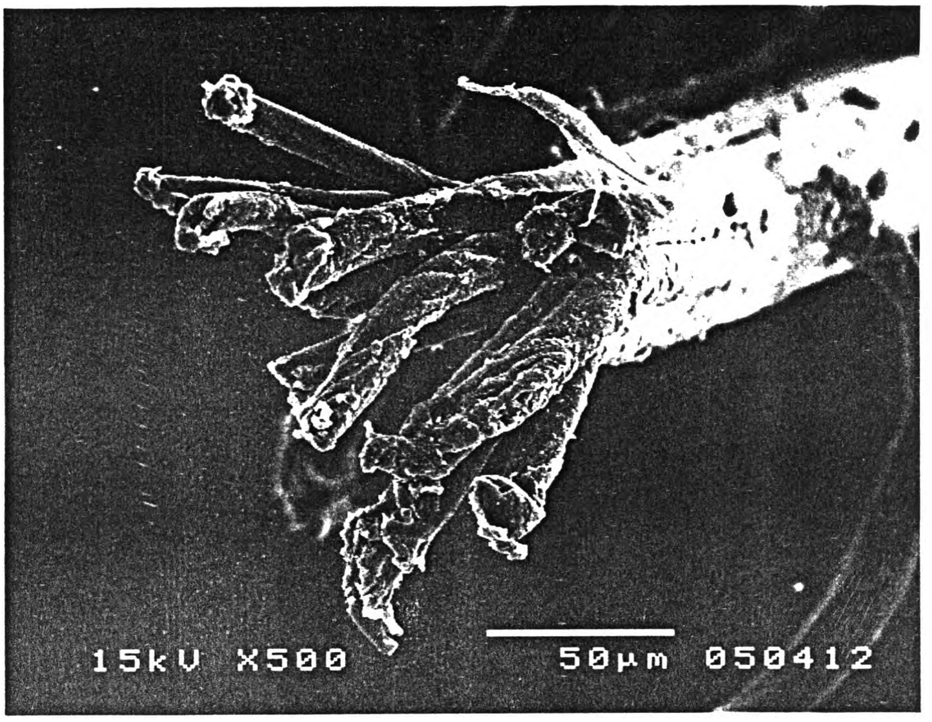

Figure 5.27 SEM micrograph of the fiber bundle after treating with NaOH for 18 hours. (X 500)

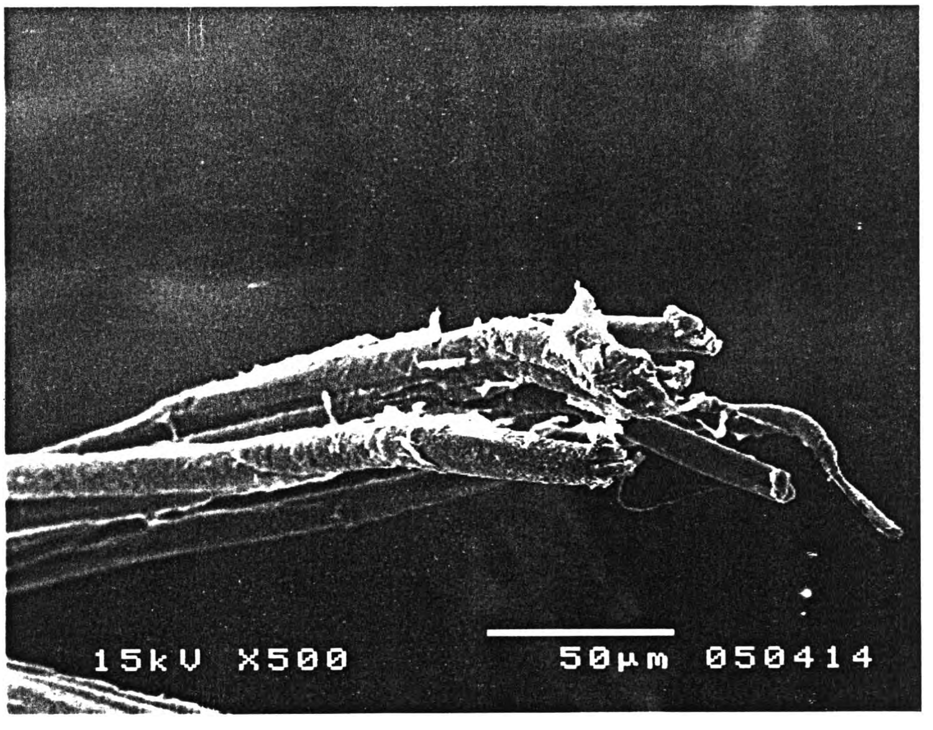

Figure 5.28 SEM micrograph of the fiber bundle after treating with NaOH for 24 hours. (X 500)

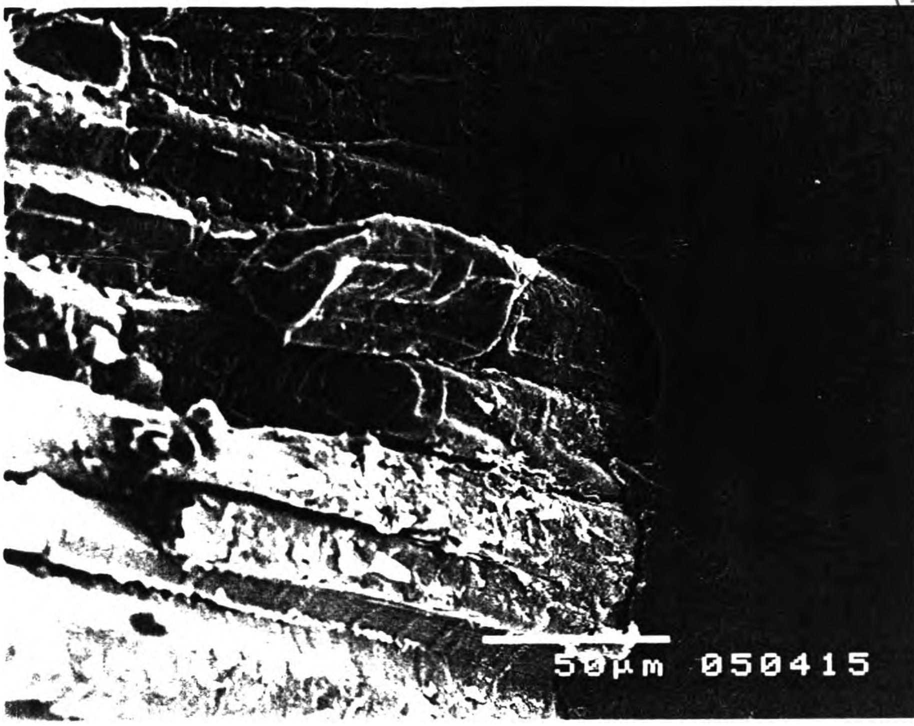

Figure 5.29 SEM micrograph present the wettability of the composite without coupling agent. (X 500)

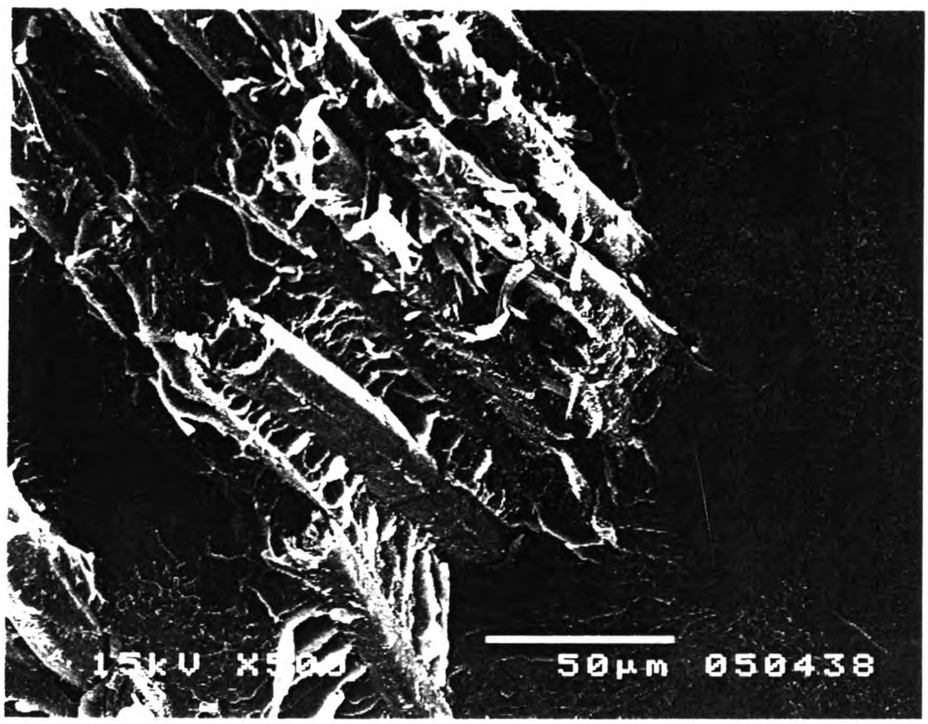

Figure 5.30 SEM micrograph present the wettability of the composite with coupling agent. (X 500)

Figure 5.31 SEM micrograph of the cracking surface after 6-hour NaOH treatment. (X 500)

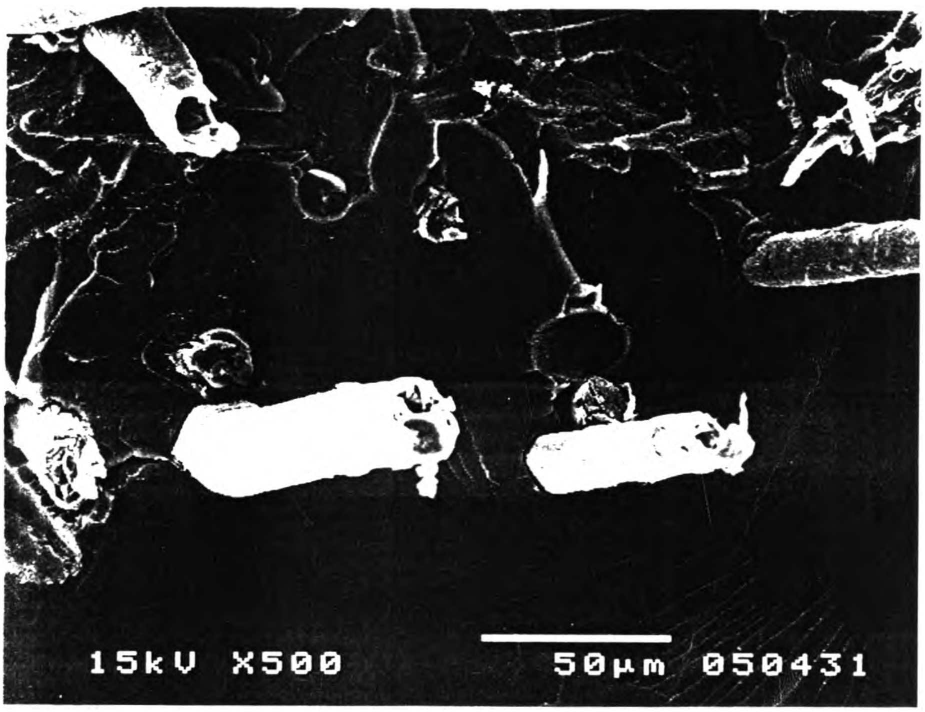

Figure 5.32 SEM micrograph of the cracking surface after 12-hour NaOH treatment. (X 500)

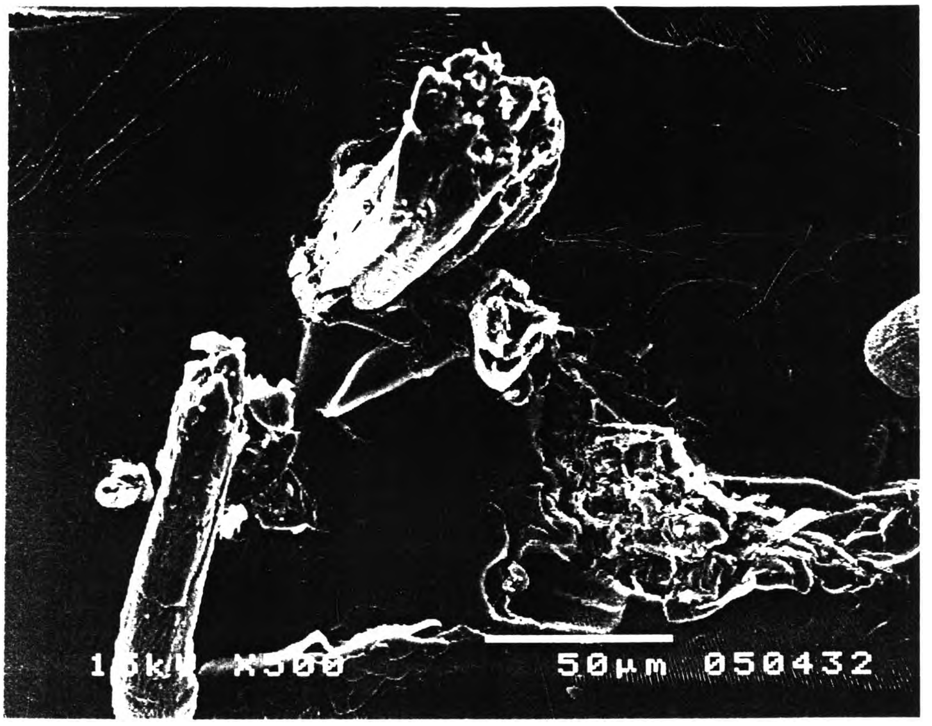

Figure 5.33 SEM micrograph of the cracking surface after 18-hour NaOH treatment. (X 500)

Figure 5.34 SEM micrograph of the cracking surface after 24-hour NaOH treatment. (X 500)