

Using Water-Hyacinth Fiber as a Filler in Natural Rubber

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This research explored the possibility of using water-hyacinth fiber as a filler in natural rubber compounds. Natural rubber (STR20) was mixed with ground fiber and various chemicals. Effects of the amount and the particle size of the fiber on mechanical properties were investigated. It was found that the hardness and modulus of the products with water-hyacinth filler were higher than those without the fiber. As the amount and the particle size of the fiber were increased, the hardness and the modulus (500%) of the products would increase whereas the tensile strength would decrease. However, the abrasion resistance of the products was lower than that in the compounds without the fiber and the resistance would decrease as the amount and the particle size of the fiber were increased. Better mechanical properties of the products could be obtained by using a suitable coupling agent which would enhance the adhesion between water-hyacinth fiber and natural rubber.

Key words: Natural rubber, water hyacinth, reinforcement, composites.

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การใช้เส้นใยผักตบชวาเป็นสารตัวเติมในยางธรรมชาติ

ประณัฐ โพธิยะราช ประกายเพชร พันธุ์ชัยเพชร และ เสาวรจน์ ช่วยจุลจิตร์ (2544)
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เส้นใยผักตบชวาถูกนำมาใช้เป็นส่วนเติมในยางธรรมชาติ ซึ่งกระทำโดยการบดผสมยางธรรมชาติ (เอสทีอาร์ 20) ให้เข้ากับเส้นใยผักตบชวาซึ่งผ่านการบดละเอียดแล้ว พร้อมกับสารเคมีต่างๆ ที่ใช้ในการทำสารประกอบยาง โดยทำการศึกษาอิทธิพลของปริมาณ (5 และ 10 phr) และขนาดของเส้นใยผักตบชวา (ละเอียด ปานกลาง หยาบ) ที่มีต่อสมบัติเชิงกล พบว่าความแข็งของผลิตภัณฑ์ที่ได้ใส่เส้นใยผักตบชวาจะสูงกว่าผลิตภัณฑ์ที่ไม่ได้ใส่เส้นใยผักตบชวา ซึ่งความแข็งจะเพิ่มขึ้นเมื่อปริมาณและขนาดของเส้นใยเพิ่มขึ้น แต่ค่าความทนแรงดึงจะต่ำลงเมื่อปริมาณและขนาดของเส้นใยเพิ่มขึ้นสำหรับค่ามอดูลัส (500%) จะสูงขึ้น เมื่อปริมาณและขนาดของเส้นใยเพิ่มขึ้น ส่วนค่าความต้านทานต่อการสึกหรอของผลิตภัณฑ์ที่ได้ใส่เส้นใยผักตบชวานั้น จะต่ำกว่าชิ้นงานที่ไม่ได้ใส่เส้นใยผักตบชวา ยิ่งปริมาณและขนาดของเส้นใยเพิ่มขึ้นค่าความต้านทานต่อการสึกหรอจะน้อยลง การใช้สารเชื่อมประสานเพื่อเพิ่มแรงยึดเกาะระหว่างเส้นใยกับยางธรรมชาติ จะช่วยเพิ่มสมบัติเชิงกลต่างๆ ของผลิตภัณฑ์ให้ดีขึ้น

คำสำคัญ ยางธรรมชาติ ผักตบชวา การเสริมแรง วัสดุเชิงประกอบ

INTRODUCTION

Thailand is the largest producer of natural rubber in the world. Despite its economic importance, its price has dropped dramatically during the past few years. More research and development in this area should be carried out to increase the value of natural rubber products by finding new applications, in particular for industries.

Meanwhile, Thailand is facing serious water pollution problems, especially in natural water sources such as rivers and canals. One of the main reasons is the widespread of the water hyacinth (*Eichhorinia Crassipes*) plant. Since it can grow and reproduce very fast, it covers the water surface in natural water sources. This prevents oxygen from penetrating and dissolving into the water. A water source can be considered polluted when the dissolved oxygen in the water is lower than a standard limit. Additionally, water hyacinth cover the water surface, so much that it obstructs water transportation. This leads to more fuel consumption and more exhaust to be produced. This research is an attempt to make use of water hyacinth by mixing natural rubber (STR20) with ground fiber and various chemicals.

Prior to curing, raw natural rubber has to be mixed with several chemicals including vulcanizing agents, accelerators, activators, age resistors, plasticizers, and fillers.⁽¹⁾ Fillers can be classified into two types, namely, reinforcing and inert fillers. Reinforcing fillers, in the proper amount, enhance the strength of product.⁽²⁾ However, if

the amount of the fillers is excessive, the rubber might lost its strength. Most of reinforcing fillers are in the form of small particles, such as carbon black or silica.

In 1975, Anthoine proposed that cellulose short fiber could be used as a filler in natural rubber compounds.⁽³⁾ Its anisotropic characteristics increase the tensile strength and modulus of the natural rubber product but decrease elongation at break. It was also reported that, in order to maintain the elasticity characteristic of the product, the amount of short fiber should not exceed 10 phr.⁽⁴⁾

Guth et al. pointed out that the larger the aspect ratio of the fiber, the higher the modulus.⁽⁵⁾ However, the effect can be so great that the product is too stiff and lacks elasticity. According to Boustany, the optimum aspect ratio is around 100-200.⁽⁶⁾ It was also suggested that, in order to improve mechanical properties, using a coupling agent would be of help by increasing adhesion between rubber and fiber.⁽⁷⁾

The purpose of this research is to find the alternative uses of water hyacinths and natural rubber by exploring the possibility of using the fiber as a filler in natural rubber. Effects of the size and amount of water-hyacinth fiber on mechanical properties of rubber products were investigated.

MATERIALS AND METHODS

Fiber Preparation

Water-hyacinth fiber was taken from stems which are approximately 1 m in length and have a diameter of approximately 2.5-3.5 cm. The stems were cut into small pieces 2 cm long, and then they were dried in direct sunlight. Dried stems were ground with

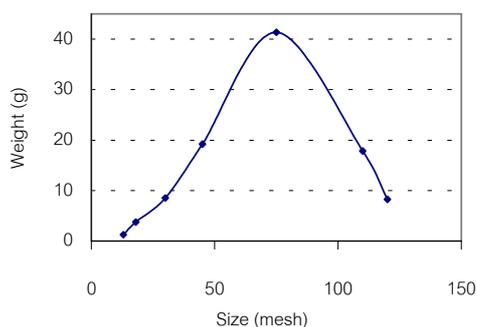


Figure 1. Particle size distribution of water-hyacinth fiber.

Some fiber was treated with a coupling agent. The coupling agent used in this research is aminopropyl triethoxy silane 0.5% w/w. The fiber was sub-merged in the coupling agent solution and then left to dry again.

Table 1. The compounding formula used in the experiment (the chemicals are listed in chronological order during the mixing process).

Chemical	Amount (phr)
STR20	100.0
Stearic acid	0.5
Napthanic oil	4.0

a Retsch Muhle rotary mill, type SR2. The size distribution of ground fiber is shown in Figure 1. Consequently, the fiber was sorted into three groups, that are fine (>100 mesh), medium (50-100 mesh), and coarse (16-50 mesh).

Calcium carbonate	40.0
Zinc oxide	5.0
Antioxidant	1.5
MBTS	0.5
Sulfur	3.5
Grounded water-hyacinth fiber	0,5,10

Rubber Compounding

Natural rubber compounds were prepared using the formula shown in Table 1. The weight of each batch was 500 g. All chemicals were industrial grade and were sponsored by the Rubber Research Institute of Thailand.

Table 2. Curing times: $t_c(90)$ for each formula as obtained from the ODR(c/a - coupling agent).

Formula	$t_c(90)$
No fiber, or c/a	10 min 37 sec
5 phr fine fiber	11 min 11 sec
5 phr fine fiber+c/a	10 min 33 sec
10 phr fine fiber	11 min 34 sec
10 phr fine fiber+c/a	11 min 18 sec
5 phr medium fiber	11 min 6 sec
5 phr medium fiber+c/a	10 min 20 sec
10 phr medium fiber	10 min 47 sec

10 phr medium fiber+c/a	10 min 44 sec
5 phr coarse fiber	10 min 20 sec
5 phr coarse fiber+c/a	9 min 32 sec
10 phr coarse fiber	10 min 11 sec
10 phr coarse fiber+c/a	10 min 35 sec

rubber compound without fiber was also investigated.

The average Shore A hardness of the cured rubber was obtained using a durometer according to ASTM D2240-86. The results are shown in Figure 2.

The rubber compounds were mixed using a two-roll mill (Kadara Seisakusho model R11-3FF) at a temperature of about 70°C. Each batch was mixed on the two-roll mill for about 30 minutes. The mixed compounds were then cured using a hydraulic compression-moulding machine (Carver Laboratory Press model 2625) at 150°C with the pressure of 16,500 pounds. The curing times, as shown in Table 2, were previously obtained using a Monsanto oscillating disk rheometer (ODR), model MDR 2000. The products in the form of rubber sheets were cut using a specimen-punching machine (Wallace Test Equipment, UK). These specimens were used for hardness and tensile tests. The compressed rubber compounds in the form of cylindrical products were used for abrasion resistance testing. In order to study fracture surface morphology, the products were also investigated under a scanning electron microscope (JEOL JSM T-220A).

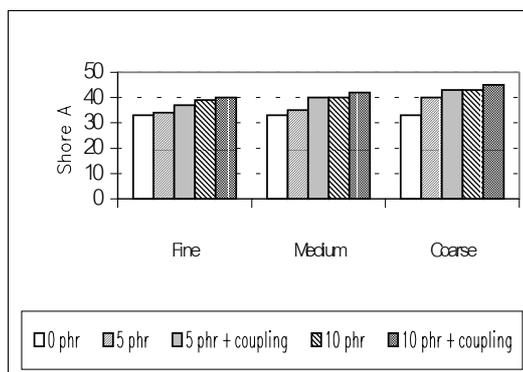


Figure 2. Average hardness of cured rubber reinforced with water hyacinth fiber in various proportions.

Obviously, the average hardness of cured rubber depends on the size and amount of fiber used. Hardness was increased considerably when more fiber was used. Similarly, the average hardness was improved when the coarser fiber was used.

Then modulus and tensile strength of the cured rubber were obtained complying with ASTM D412-83 using a Lloyd L500 Universal Testing Machine. The results were shown in Figures 3 and 4, respectively.

RESULTS AND DISCUSSION
Effects of the Size and Amount of Water-Hyacinth Fiber

Fine, medium, and coarse fiber was mixed with the rubber compound in the amount of 5 phr and 10 phr. The

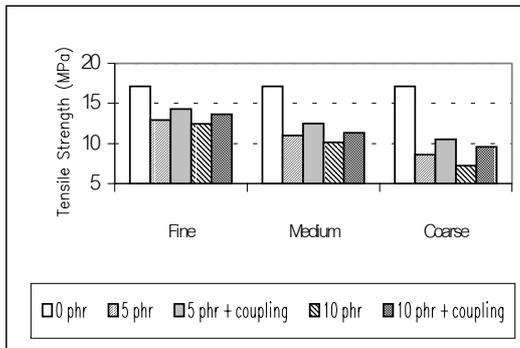


Figure 3. Modulus of cured rubber reinforced with water-hyacinth fiber in various proportions.

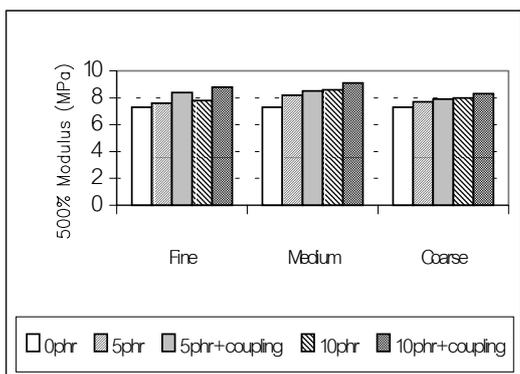


Figure 4. Tensile strength of cured rubber reinforced with water-hyacinth fiber in various proportions.

The modulus of cured rubber was enhanced when more fiber was used. It is believed that a higher hardness and modulus was imparted from the high modulus characteristic of the fiber. The modulus was also improved when coarser fiber was employed. The coarser fiber gave a higher hardness and modulus since it has a greater aspect ratio.⁽⁵⁾

However, the tensile strength was reduced when more fiber or coarser

fiber was used. This confirmed the results obtained by van Rossem⁽²⁾ that continuity in the rubber phase was reduced when a higher amount of fillers was used. In the case of coarser fiber, even though the aspect ratio is greater, the poor adhesion between fiber and rubber and less surface area of filler markedly affected the tensile strength. It was also noticed that the positions where the specimen breakage occurred were frequently at the interfaces between rubber and fiber. Evidently, this implies that adhesion between two components was relatively poor, which can be confirmed by its abrasion resistance.

The abrasion resistance was tested using an abrasion tester (Wallace Test Equipment, UK). Like the tensile strength, the abrasion resistance also decreased. Figure 5 shows the results. Again, poor adhesion between rubber and fiber was claimed to be the cause of poor abrasion resistance.

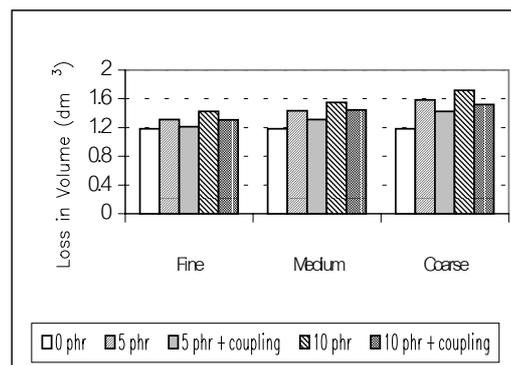


Figure 5. Abrasion resistance of cured rubber reinforced with water-hyacinth fiber in various proportions.

Scanning electron microscope photographs of cured rubber reinforced with water-hyacinth fiber at the fracture surface were studied. An example is shown in Figure 6. It was clearly noticed that the distribution of fiber in the rubber matrix was quite poor, which may be another reason for the regression in some mechanical properties.

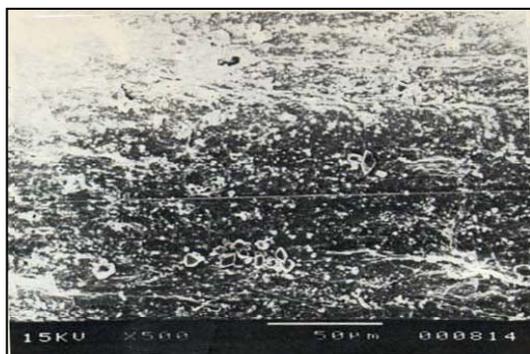


Figure 6. A SEM photograph of cured rubber reinforced with untreated water-hyacinth fiber.

Effects of a Coupling Agent

In order to improve fiber distribution and poor adhesion between fiber and rubber, the fiber was treated with a silane coupling agent. The silane coupling agent is capable of forming an oxane bond between the rubber matrix and cellulose fiber as shown in Figure 7. The amount of the coupling agent was 0.5%w/w as suggested by Derringer.⁽⁷⁾ The treated fiber was then used in the rubber compound. The hardness, tensile strength, modulus, and abrasion resistance of the cured rubber reinforced

with treated fiber were shown in Figures 2-5, respectively.

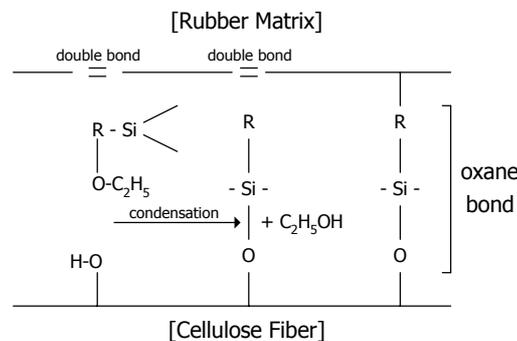


Figure 7. Formation of the oxane bond.

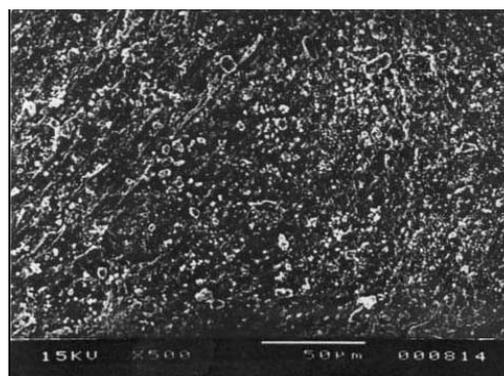


Figure 8. An SEM photograph of cured rubber reinforced with treated water-hyacinth fiber.

The hardness of rubber products containing fiber treated with a coupling agent (as shown in Figure 2) was higher than for those with untreated fiber. The modulus of rubber products (Figure 3) also increased in the case of treated fiber. Introducing the coupling agent also improved the tensile strength (Figure 4) and abrasion resistance (Figure 5), compared with the products

in which the fiber was not treated. Conclusively, the overall mechanical properties of the cured rubber were improved when the fiber was treated with a coupling agent before compounding. This is partly due to a better fiber distribution in the rubber matrix which can be seen in the SEM photograph shown in Figure 8. It was also assumed that chemical bonding occurred between the fiber and rubber as explained above. However, this should be confirmed experimentally in future work.

CONCLUSIONS

Short water-hyacinth fiber was used as a filler in natural rubber. In terms of mechanical properties, it was found that the hardness and the modulus of the rubber products mixed with water-hyacinth fiber were superior to those without the fiber. On the other hand, the tensile strength and the abrasion resistance were decreased, especially in the case of untreated fiber. The amount and the particle size of the fiber also affected the mechanical properties of the rubber products. When the amount and particle size of the fiber were increased, the hardness and modulus of the products would increase, whereas the tensile strength and abrasion resistance would decrease. The decline in these mechanical properties was probably due to the poor adhesion between the rubber and the fiber. This can be confirmed by the microscopy study since it was clearly noticed that the rubber and the fiber were adhered together mostly via physical bonding. In order to increase

bonding between the rubber and fiber, the fiber was treated with a coupling agent before mixing. The effect of the coupling agent was clearly exhibited since several mechanical properties were remarkably improved when the treated fiber was employed. Moreover, in this experiment, some common reinforcing agents, such as carbon black, have not been used. Mechanical properties might be improved in their presence.

Considering the overall properties, it can be concluded that the water-hyacinth reinforced natural rubber can be used in some applications when hardness and modulus is of importance, for example floor covering, shoe soles, or machine mounting. This will increase the market value of natural rubber, also reducing the water pollution caused by water-hyacinth plants.

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