Study of porous rubber pipes reinforced with waste tire fiber and pineapple leaf fiber for smart irrigation system

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Abstract. Global trend in waste management involves sustainable development for waste utilization according to the concept of circular economy. Wastes from worn-out tires have been known as a world problem and not yet to be resolved successfully. In this work, wastes from worn-out tires, i.e., ground tire rubber (GTR), reclaimed rubber (RR) and waste tire fiber (WTF) were used to produce reinforced porous rubber pipes as irrigation system for smart farming. Comparative study of porous rubber pipes reinforced with natural fibers (pineapple leaf fiber, PALF) was also carried out. The experiment was divided into 2 parts, i.e., porous sheets (model study) and extruded porous pipes. Compound samples were prepared by mixing GTR, RR, and natural rubber (NR) at a ratio of 60:20:20 (by weight) with other additives by using an internal mixer, then shaped into samples by using a compression molding machine (sheets) and a single-screw extruder (pipes). Samples were vulcanized by a hot air oven. Factors affecting sample properties were studied, such as, fiber types (WTF and PALF) and fiber loadings (0-15 phr). Properties of the samples were characterized, such as, mechanical properties, morphology, water permeability rate, and %diameter swell. It was found that tensile strength was increased up to an optimum point. Modulus (at 10% strain, M10) and hardness were increased with increasing fiber loading. However, %elongation at break had a trend to decrease. Morphologies of the composites made from both fibers were insignificantly different in fiber distribution. By adding the fibers, %diameter swell was clearly improved. Pipe samples were also tested in precision smart agriculture system. It can be proven that WTF and PALF can be used to reinforce the porous pipes and used as a watering device for precision irrigation system.

1. Introduction
Worn-out tires cannot decompose easily as they are complex objects consisting of many components such as crosslinked rubbers, steel wires, fibers, and other additives [1]. Accumulation of waste tires leads to a serious waste management issue and a persistent environmental pollution. To build a sustainable economy, several waste management strategies have been proposed to deal with the increasing number of worn-out tires including retreading, reclaimed rubbers, ground rubbers, etc.[2] WTF is classified as a unique waste according to the European Waste Code 19.12.08 since they have to be burned and/or buried. Nevertheless, these activities pose additional threats, including toxic hazards to soil pollution and groundwater contamination [3-4].
Natural fibers are sustainable materials which are easily available in nature and have advantages like low-cost, lightweight, renewability, biodegradability, and high specific properties. In Thailand, natural fibers are abundantly available both naturally and from agricultural wastes, such as jute, sisal, pineapple leaf, coir, bamboo, rice husk, vetiver grass, etc. The one that is abundantly available and is used very little is PALF. It has good mechanical properties and can be used to reinforce rubbers yielding high modulus and strength [5].

Porous pipes are effective watering devices due to low water consumption, less water evaporation and water consistently and efficiently to plant roots [6]. In previous works [7-8], porous pipes made from rubber were unsuccessfully done due to high %diameter swell and non-linear water rate at high pressure that it was difficult to control. In this work, reinforced porous pipes were made from GTR, RR, NR and fibers. The objective of this work was to study comparatively the effects of WTF and PALF fiber loading to the rubber formulas on the pipe properties resulting in optimum fiber loadings with good mechanical and physical properties. It can be used as a watering device in precision irrigation for smart farming systems.

2. Experimental
2.1 Materials and chemicals
STR 5L NR was purchased from Yong Seng Enterprise Part., Ltd., Thailand. RR, 30 mesh GTR and WTF were obtained from Saeng Thai Rubber Co., Ltd., Thailand. UCD-105 grade RR has 50% rubber content, 29% carbon black content, and Mooney viscosity (ML1+4 (100°C)) of 52. WTF with average diameter of 0.027 mm and 3-4 mm in length was used in this work. PALF with average diameter of 0.063 mm and 6 mm in length was obtained from Mahidol university. Details of PALF preparation and properties were described elsewhere [9]. N-cyclohexyl-2-benzothiazyl sulfenamide (CBS), sulfur, zinc oxide (ZnO) and stearic acid were used for the curing system. A blowing agent and kicker were used to create open-cell structures. All chemicals were used as received. Formulae of rubber compounds were kept proprietary.

2.2 Preparation of 40% fiber masterbatches
NR was masticated in an internal mixer (CT, MX500-D75L90) for 1 min with a rotating speed of 40 rpm and 70°C. Then, fiber (WTF, PALF) was gradually added during 3 min loading time. Fiber masterbatch was then rolled into sheet on a two-roll mill (LabTech, LRM200). Sheeted rubber compound was conditioned at room temperature for 24 h before measurements taken.

2.3 Preparation of porous rubber sheets and extruded porous rubber pipes
Rubbers, GTR, fiber and all chemicals were mixed by using an internal mixer with a rotating speed of 40 rpm and 70°C. The weight ratio of GTR, RR and NR at a 60:20:20. Fiber loadings (WTF and PALF) were varied as 0, 3, 6, 9, 12 and 15 phr. Total mixing time was kept constant at 17 min. Samples were shaped into samples by using a compression molding machine (sheets) (LabTech, LP20) with size 150 x 150 x 4 mm. The upper plate was lifted shortly for 5 s. A single-screw extruder with a screw speed of 30 rpm at 60°C and die diameters of 14 mm (inside) and 18 mm (outside) was used to prepare rubber pipe samples. Pipe samples were vulcanized in a hot air oven at 160°C for 20 min.

2.4 Characterization and testing
Tensile properties were also examined using a universal testing machine (Cometech, QC-536M1) with a crosshead speed of 500 mm/min and the gauge length of 25 mm. Mechanical properties were measured according to ASTM D412. Morphology of porous samples were observed with a scanning electron microscope (SEM) (LEO, LEO 1455 VP). All samples were coated with gold prior to examination. Water permeability and %diameter swell of porous rubber pipe with changing water pressure were determined according to ASTM D3767-03.
3. Results and discussion

Figure 1(a) shows porous rubber pipe made from GTR, RR and NR. It can be used in the smart farming (irrigating) system by connecting the pipe with smart valve and pump systems (Figure 1(b)). Figure 2(a) displays tensile strength (solid line) and % elongation at break (dash line) of samples with fiber types and fiber loadings. Surprisingly, tensile strength of both fibers were insignificantly different and a trend to increase to an optimum fiber loading as fiber loading was increased. However, at high fiber loadings, % elongation at break of PALF was significantly decreased. This might be derived from defects of fiber agglomeration resulted from poor fiber dispersion difficulty in rubber mixing with high fiber loadings. This finding was confirmed by SEM images (3a) and watering tests as high water leaking out with visible holes in the samples. Figure 2(b) shows the effect of fiber loading on M10 (solid line) and hardness (Shore A) (dash line) of composites. Both M10 and hardness seem to rise significantly with increasing fiber loading. The observed behavior is in agreement with other fiber-reinforced rubber systems [10]. In addition, PALF has slightly higher M10 and hardness than WTF since PALF is lignocellulosic material with higher modulus. Typical modulus of the PALF fiber is 20 GPa [11] compared to 2-3 GPa for WTF fiber [12].

![Figure 1. (a) Porous rubber pipe and (b) Smart pump and valve systems.](image)

![Figure 2. Effects of fiber loading on (a) tensile strength and %elongation at break (b) M10 and hardness of porous rubber samples.](image)

Figure 3(b-c) displays SEM micrographs of cryogenic-cracked samples with 6 phr PALF and WTF. It was revealed that PALF and WTF were distributed well in rubber matrix. Voids distribution in the samples were good, but unequal in shape and size.
Figure 3. SEM micrographs of cryogenic-cracked samples (a) 500x of PALF 9 phr, (b) 150x of PALF 6 phr and (c) 150x of WTF 6 phr.

%Diameter swells of porous pipes as affected by water pressure were shown in Figure 4(a). Effect of fiber reinforcement was clearly observed as %swell significantly decreased when PALF or WTF loading was increased in the compounds. %Diameter swell of porous pipe can be related to water permeability as shown in Figure 4(b). As expected, water permeability rate was increased as water pressure was increased. More linear water permeation was observed when water pressure was increased. However, PALF has linear water permeation higher than WTF.

Figure 4. (a) %Diameter swell and (b) water permeability of porous pipes affected by water pressure.

4. Conclusions
Comparative study of porous rubber pipes made from worn-out tire wastes reinforced by waste tire and natural fibers were carried out in order to be used as irrigating device in precision and smart farming systems. It was found that mechanical properties had a trend to increase to an optimum fiber loading as fiber loading was increased. However, PALF has slightly higher modulus than WTF. By adding the WTF or PALF, %diameter swell was clearly improved. In this work, it can be proven that WTF and PALF can be used to reinforce the porous pipes and used as a watering device for precision irrigation systems.

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