PAVING BLOCKS FOR THE ELDERLY: A STUDY OF THE PREPARATION OF CONCRETE MIXED WITH CRUMB RUBBER AND BONDED RUBBER

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ABSTRACT

This research aimed to study the preparation of shock-reducing paving blocks. Typically, the paving blocks are made of concrete mixed with three different materials, namely crumb rubber, bonded rubber, and shock-absorbing rubber. This research focused on studying the effects of crumb rubber on the characteristics of concrete and the impact of fly ash content on the properties of bonded rubber. The tests showed that concrete had less density and compressive strength when the crumb rubber content increased. The concrete with 10% crumb rubber content by sand weight had the highest compressive strength (156.32 kg/cm2). The vulcanization test of bonded rubber using fly ash as a filler revealed that M_H-M_L increased when the fly ash content increased. However, the scorch time (T_{S2}) and cure time (T_{C90}) of the rubber were somewhat stable. The mechanical properties test of bonded rubber found that tensile strength, elongation at break, and rebound resilience tended to decrease; on the other hand, the hardness appeared to increase when the fly ash content became greater. However, the bonded rubber with fly ash as a filler could not be chemically bonded with the concrete mixed with crumb rubber. Consequently, it is advisable to design the characteristics of bonded rubber to be physically adhesive to concrete mixed with crumb rubber.

KEY WORDS: Crumb rubber, Shock-reducing paving blocks, Portland cement, Fly ash

1. Introduction

The elderly are people who are different from other ages. Most of the common accidents they encounter are associated with falling because they have deteriorating physical conditions and unhealthy muscle strengths, especially hip, knee, and ankle joint muscles. Typically, falling affects body movements and causes poor health conditions and other complications, such as hip fracture, sprained ankles, and worse quality of life. Therefore, home construction or landscape design is essential to prevent or reduce the possibility of accident occurrence with the elderly, and appropriate shock-absorbing materials are recommended for use. Previous studies have investigated the preparation of paving blocks that could help to reduce the shock during the walk or movements. They also decrease the possibility of accidents the elderly might encounter [1]. According to the studies, rubber is mixed with concrete to reduce the rubber content, which is more expensive than concrete. With this method, the paving blocks are cheaper, and they can also help to decrease the severity of injuries from falling. The developed paving blocks consist of three components, namely shock-absorbing rubber, bonded rubber, and concrete, as presented in Figure 1.

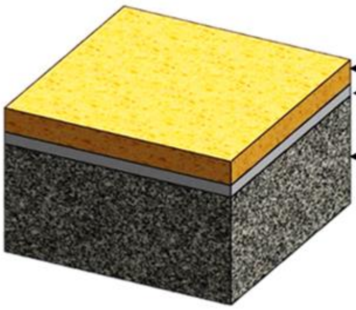

Figure 1 Dimension and components of paving blocks

Concrete is the most commonly used material in construction. It is composed of admixtures, such as stones, sand, pebbles, and water. In addition, other admixtures may be added to yield specifically required properties. After the mixing process, concrete slowly and gradually becomes hardened, and it is easy to mold and form. The concrete hardening occurs from the chemical reaction of water and cement, known as hydration reaction. The cement begins to bond to other materials and eventually forms a hard mass. In light of the possibility that other materials can be added during the concrete mixing process, waste materials and polymer waste have been mixed with the concrete. For example, Nitisuwanluksa [2] investigated the possibility of substituting polypropylene for sand in the production of lightweight bricks. The study revealed that the substitution of polypropylene for sand could reduce production costs. Besides, Amnuaypornlert et al. [3] examined the mechanical behaviors of concrete mixed with ceramic utensil crumbs gathered from a factory in Phayao Province. The fine aggregates were replaced with ceramic shavings, and the substitution of ceramic shavings for fine aggregates increased the compressive and flexural strength of the concrete. However, if the ratio of ceramic shavings was not appropriate, concrete strength would decrease. Also, Tirasakkosol et al. [4] studied the repairing and maintenance of concrete surfaces of roads using synthetic material and asphaltic concrete. Their study showed that the application of synthetic material and asphaltic concrete could effectively reduce damage to road surfaces. Road surfaces would not crack or break owing to their strength and endurance; moreover, the wheel-groove subsidence rate also decreased. Besides the engineering advantages, repairing roads using synthetic fiber sheets also costs less than other road repairing methods at about 42 percent. Boonsung [5] also investigated the compressive strength of paving blocks made from used tap-water filter sand and found a rapid increase of compressive strength at an early stage of cure time. After that, the compressive strength decreased. Therefore, the length of the cure time, rather than the content of used tap-water filter sand, affected the decrease of compressive strength.

In light of the possibility that polymers or other waste materials can be added to concrete, the research team was intrigued in preparing concrete mixed with crumb rubber or rubber powder. Crumb rubber and rubber powder are recycled products of rubber wastes, including old tires and rubber crumbs, which are results from the production process. The gathered rubber wastes are ground using mechanical tools. Crumb rubber applies to various uses, such as fillers in the rubber-sheet production industry, paving blocks, floor mats, and rubber fenders. Crumb rubber is also used to increase the strength of plastic; moreover, it is applied in civil engineering work. Even though crumb rubber initially has a higher cost than other materials like stones, soil, or asphalt, it enhances the quality of civil engineering work. Besides, it also reduces maintenance costs due to its specific properties. Therefore, it is beneficial in the long run [6]. The application of crumb rubber mainly aims to reduce costs, modify or improve some particular properties of the product, and reduce pollution by reusing rubber wastes. Furthermore, the use of crumb rubber in concrete shows that concrete mixed with crumb rubber has a higher capacity to absorb energy, higher elasticity [7], and lighter weight [8] as the crumb rubber has lesser specific gravity than sand or stones.

Fly ash has the main chemical constituents of Silicon Dioxide (SiO_2), Aluminum Oxide (Al_2O_3), Iron Oxide (Fe_2O_3), and Calcium Oxide (CaO). Its secondary chemical constituents are Magnesium Oxide (MgO), Sodium Oxide (Na_2O), Potassium Oxide (K_2O), and Sulfur Trioxide (SO_3). In addition, it also contains moisture (H_2O) [9]. These constituents are similar to components of Portland cement. Previous studies have investigated the application of fly ash as construction materials like cement wall blocks and paving blocks. The studies revealed that fly ash could substitute cement [10]. It could also be a mixing ingredient in ready-mixed concrete for construction work and additional raw material in the production of construction materials, such as roof tiles, stakes, pipes, and prefabricated floors. Furthermore, in their research, Budnumpecth and Tanpaiboonkul [11] examined the appropriate ratio of fly ash substitution for cement. They found that the proper proportion for lightweight concrete was the substitution of cement with 10-percent fly ash. Besides its applications in cement and concrete work, fly ash is also applicable in geopolymer work. Hanjitsuwan et al. [12] studied the substitution of Portland cement in geopolymer fly ash. They revealed a positive effect on the mechanical properties and microstructure. The compressive strength of geopolymer at one week of cure time grew when Portland cement content increased. The increase of the compressive strength displays the decrease in the sizes of gaps and cavities.

Consequently, the research team attempted to prepare bonded rubber to adhere to concrete and shock-absorbing rubber. The preparation of bonded rubber would enhance the application of rubber, which is elastic and excellent for shock-absorbing, with concrete, which is durable but inexpensive, to make paving blocks. Therefore, the present research aimed to study the substitution of crumb rubber obtained from waste recycled for sand in the concrete-layer preparation for shock-absorbing paving blocks. The elasticity of crumb rubber would result in concrete with durability, shock-absorbing ability, and lightweight. Moreover, the preparation of bonded rubber mixed with fly ash was also initiated to enhance the bond of shock-absorbing rubber and concrete. Fly ash functioned as a filler to create a chemical bond between concrete and natural rubber to prepare shock-reducing paving blocks for the elderly.

2. Research Methodology

This research included three parts. The first part studied the effects of crumb rubber on the concrete properties, and the second part investigated the impact of fly ash content on the natural rubber used as bonded rubber. The third part examined the adhesion of bonded rubber and concrete, which was filled with crumb rubber. The research conduct of the three parts aimed to prepare shock-absorbing paving blocks for the elderly, as presented in Figure 2. Figure 2 illustrates the preparation of paving blocks, materials, and research methodology.

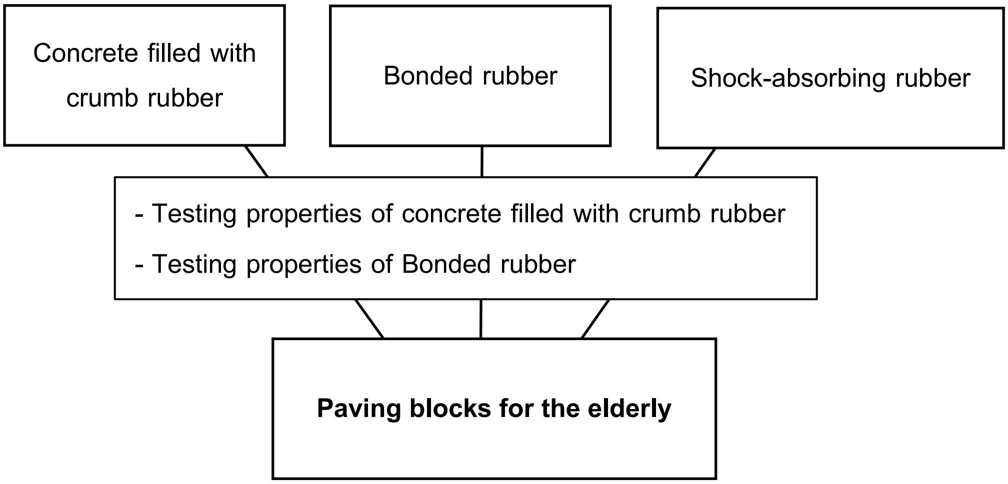

Figure 2 Flow chart of research methodology

2.1 Preparation of Concrete Mixed with Crumb Rubber

Concrete mixed with crumb rubber was prepared using Portland cement with a cement-to-sand ratio of 25:75. The sand was substituted by crumb rubber content of 10, 20, 30, 40, and 40 by sand weight, and water was used 40 percent by Portland cement weight, as presented in Table 1. Then all admixtures were mixed thoroughly. The molding of paving blocks started when the cement paste coated the aggregate evenly. The sample paving blocks were left to harden for 24 hours. Then they were wrapped in plastic film for a cure time of seven days.

Table 1 **Mixture ratio of concrete mixed with crumb rubber**

Mixture ratio of cement and admixtures/water (percent)			
60			40
Cement (percent)	**Sand (percent)**	**Rubber Crumb (percent)**	**Water (percent)**
25	75	0	40
25	65	10	40
25	55	20	40
25	45	30	40
25	35	40	40
25	25	50	40

2.2 The rubber compound used for the preparation of bonded rubber between concrete mixed with crumb rubber and shock-absorbing rubber on the top layer

The formula of the preparation of bonded rubber from dry rubber sheet and modified fly ash content is presented in Table 2. The admixtures were ground in a closed internal mixer, model MX500-TQ, and the rubber sheet was rolled in an open two-roll mill, model ML-D200L450. The rubber vulcanization was tested using a Moving Die Rheometer (MDR) before molding. The molding was done by extruding the rubber into the mold.

Table 2 **Rubber compound formula used in the preparation of bonded rubber**

Material	Volume (phr)
Dry rubber sheet	100
Zinc oxide	5
Stearic acid	1
Fly ash	0, 50, 100, 150
MBTS	1
TMTD	0.1
Sulfur	2.5

2.3 Tests

2.3.1 Test of the properties of concrete mixed with crumb rubber

- The density of concrete was tested using an electronic densimeter. The concrete was weighed both in the air and in liquid. In this study, distilled water was employed in the weighing process because its density was clearly known. Then the density values were recorded.

- Compressive strength was also tested. The sample was prepared in a mold sized 10x10x10 centimeters, as presented in Figure 3. After the seventh day of cure time, the sample was tested for compressive strength using the compression machine.

- Morphology test of the surface of the concrete mixed with crumb rubber was conducted using a scanning electron microscope (SEM), model JSM 5410-LV.

Figure 3 Concrete cubic mold sized 10x10x10 centimeters

2.3.2 Tests of properties of bonded rubber between concrete mixed with crumb rubber and shock-absorbing rubber on the top layer

- The vulcanization time of rubber was tested using a Moving Die Rheometer (MDR). The test showed the minimum torque value (M_L), high torque value (M_H), scorch time (T_{s2}), and cure time at 90 percent (T_{C90}).

- Test of tensile strength of the rubber was conducted using a tensile testing machine at a stretch rate of 500 millimeters per minute and with a 1000 N load cell. A dumbbell-shaped Die-C specimen was prepared, as shown in Figure 4. The test result showed the tensile strength in MPa. The calculation formula is as follows.

$$\text{Tensile strength} = F / A \quad (1)$$

Where F is the force required to break, and A is width x thickness (the cross-sectional area of the specimen while not stretched). Elongation at break (%) was calculated using the following formula.

$$\text{Elongation at break} = [L - L_0 / L_0] \times 100 \quad (2)$$

Where L is the length of the extensometer, L_0 is the initial length of the extensometer (25 millimeters).

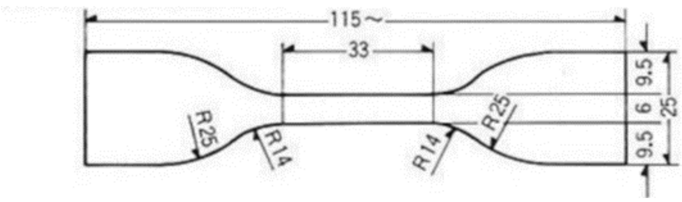

Figure 4 Dumbbell-shaped Die-C specimen

- The rebound resilience of the rubber was tested. First, a round rubber sheet with 12.5±5 mm thickness was put in the rebound resilience tester, model GT-7042-RDA. After that, the iron ball was freely released to hit the round rubber sheet. Then the obtained value was recorded.

- The hardness of the rubber was tested using a Shore Durometer hardness tester. A steel press pin was pressed on the surface of the specimen under the force that made the stand of the press pin completely touch the specimen surface. The value was read 30 seconds after the press.

3. Results

The research results are divided into three parts. The first part shows the effects of crumb rubber content on the concrete properties, and the second part presents the impact of fly ash content on the properties of natural rubber. The third part displays the adhesion between the bonded rubber layer and the concrete added with crumb rubber.

3.1 Effects of crumb rubber content on the concrete properties

The concrete mixed with crumb rubber was prepared from Portland cement with a cure time of seven days. The effects of the substitution of crumb rubber for sand at 10, 20, 30, 40, and 50 percent by sand weight on density and compressive strength of the concrete were studied as shown in Figure 5 and Figure 6.

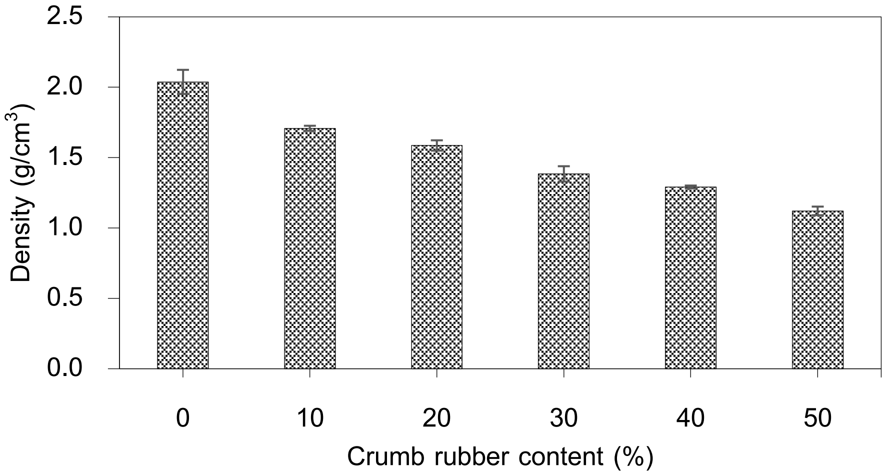

Figure 5 Density of concrete mixed with crumb rubber

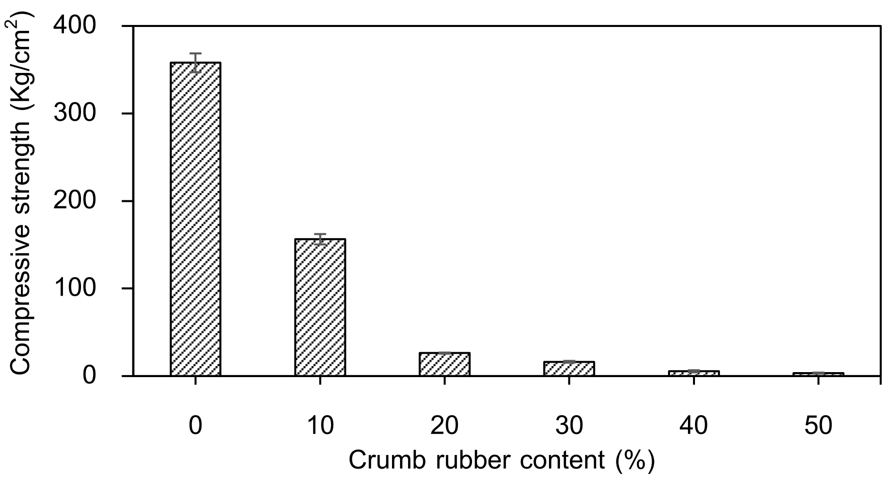

Figure 6 Compressive strength of concrete mixed with crumb rubber

Figure 5 shows the density of concrete mixed with crumb rubber. The increase of crumb rubber content results in the decrease of the concrete density as crumb rubber has 4.11 times less density than sand [11]. Moreover, more crumb rubber content causes more gaps in the concrete, resulting in less density.

Figure 6 illustrates the compressive strength of concrete mixed with crumb rubber. More crumb rubber content causes lesser compressive strength of the concrete. Since crumb rubber has more elasticity than sand, the compressive strength also decreases. Crumb rubber also has specific particle characteristics of ductility and elasticity. Hence, when it replaces sand, the compressive strength of the concrete decreases in relevance to the higher crumb rubber content. It is in line with a study by Amnuaypornlert et al. [3]. In their study, ceramic shavings were added to concrete to substitute fine aggregates and resulted in lower compressive strength of concrete.

The study of the morphology of concrete mixed with crumb rubber, as presented in Figure 7, found that the higher crumb rubber content resulted in uneven distribution of crumb rubber particles and discontinuity of cement phase, causing hole effect [7] between cement phase and crumb rubber. Therefore, the compressive strength of the cement decreases when crumb rubber content increases. However, with 10 percent of crumb rubber by sand weight, the morphology of cement still shows the continuity of cement phase without hole effect between the two phases. Consequently, cement mixed with 10 percent of crumb rubber by sand weight has the highest compressive strength.

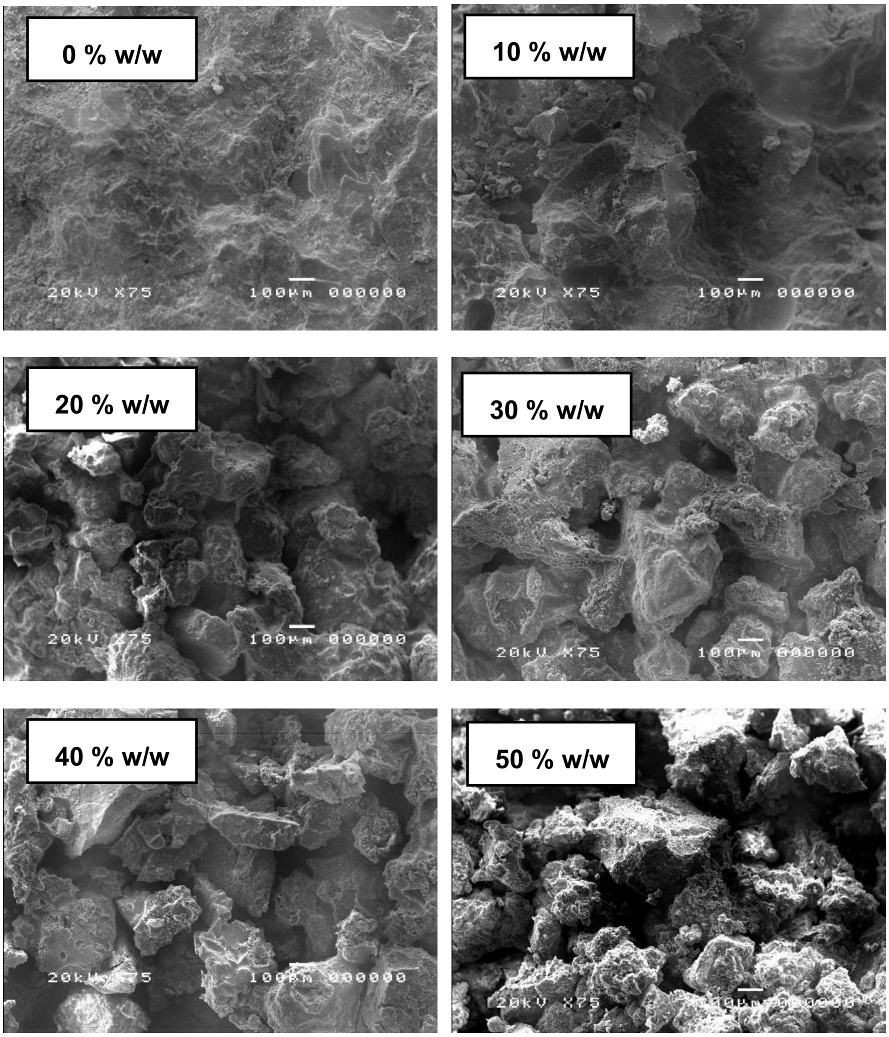

Figure 7 **Morphology of concrete mixed with crumb rubber**

3.2 Effects of Fly ash content on the properties of bonded rubber

3.2.1 The vulcanization properties of bonded rubber prepared from natural rubber with modified fly ash content are presented in Table 3. Scorch time (T_{S2}) and cure time (T_{C90}) of rubber compounds are not distinct when fly ash content increases. Similarly, Sombatsompop et al. [13] studied the effects of silica and fly ash content on the vulcanization of natural rubber and found that the higher silica content increased the cure time (T_{C90}). However, the higher fly ash content resulted in the stability of the cure time (T_{C90}). The cause of the stability of T_{S2} and T_{C90} is that the catalyst is absorbed to the surface of silica, resulting in an increase of T_{C90}. However, iron oxides, such as Al_2O_3, Fe_2O_3, and CaO in fly ash act as catalysts and activators in the vulcanization process, making the T_{S2} and T_{C90} somewhat stable. Furthermore, the mentioned iron oxides cause an increase in M_H-M_L, which indicates the crosslink density of rubber when fly ash content becomes greater. Since iron oxides stimulate the effectiveness of the vulcanization reaction, the crosslink density also increases.

Table 3 **Vulcanization properties of bonded rubber prepared from natural rubber with modified fly ash content**

Fly ash content (phr)	Vulcanization properties				
	M_L (dN.m)	M_H (dN.m)	M_H-M_L (dN.m)	T_{S2} (min)	T_{C90} (min)
0	3.23±0.06	6.67±0.06	3.43±0.06	1.42±0.04	1.92±0.05
50	2.83±0.06	6.70±0.10	3.87±0.12	1.40±0.06	2.04±0.01
100	2.80±0.17	7.07±1.18	4.27±1.01	1.37±0.14	1.93±0.09
150	2.73±0.15	7.23±0.90	4.50±0.75	1.26±0.08	1.87±0.01

3.2.2 Mechanical properties of bonded rubber prepared from natural rubber with modified fly ash content

The effects of fly ash content on the tensile strength of bonded rubber are presented in Figure 8. Tensile strength decreases in accordance with the higher fly ash content when compared to the non-filler case. Interactions or acting forces between particles of fly ash and natural rubber have low strength because fly ash contains high polarity components, such as silicon dioxide (SiO_2) of as much as 24 percent [14] and other iron oxides. These high polarity components are different from those in natural rubber, which has lower polarity. Moreover, the addition of a higher amount of fly ash causes lesser continuity of the rubber phase, resulting in a decrease in rubber strength. Thus, the higher the fly ash content is, the lower the tensile strength of bonded rubber becomes.

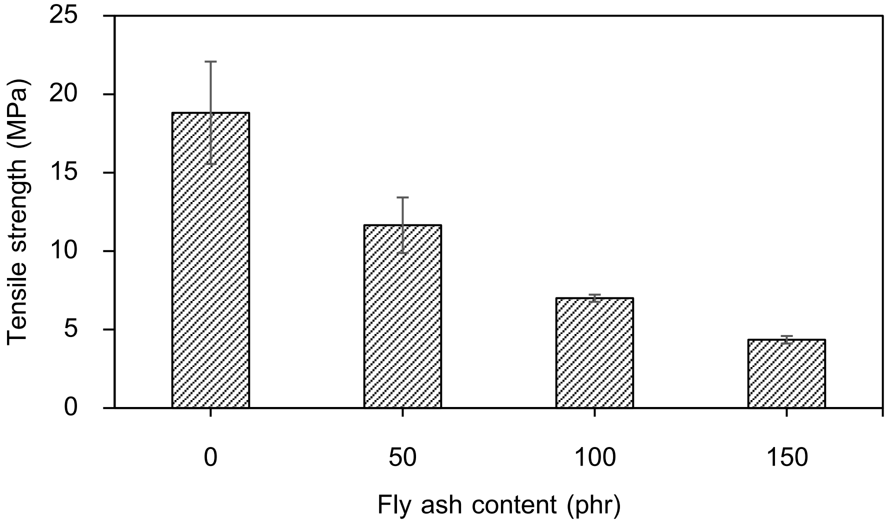

Figure 8 Tensile strength of bonded rubber

The effects of fly ash content on elongation at break of bonded rubber are displayed in Figure 9. Elongation at break decreases when fly ash content is higher. The elongation at break of bonded rubber with 150 phr of fly ash content decreases 49.77 percent, compared with the non-filler case. The elongation at break tends to decrease when fly ash content becomes greater since fly ash particles hinder the movement of rubber molecules, increasing brittleness. Besides, when adding more fly ash content, the continuation of the rubber cycle also decreases. Therefore, the elongation at break of the bonded rubber decreases. The morphology of fracture surface of bonded rubber prepared from natural rubber with modified fly ash content confirms the decrease of elongation at break as shown in Figure 10. The tensile strength test shows that an increase in fly ash content causes an apparent release of fly ash particles. It means that the interaction between the filler and rubber is considerably low [14] due to the incompatibility between natural rubber, which has a continuous phase, and fly ash used as filler.

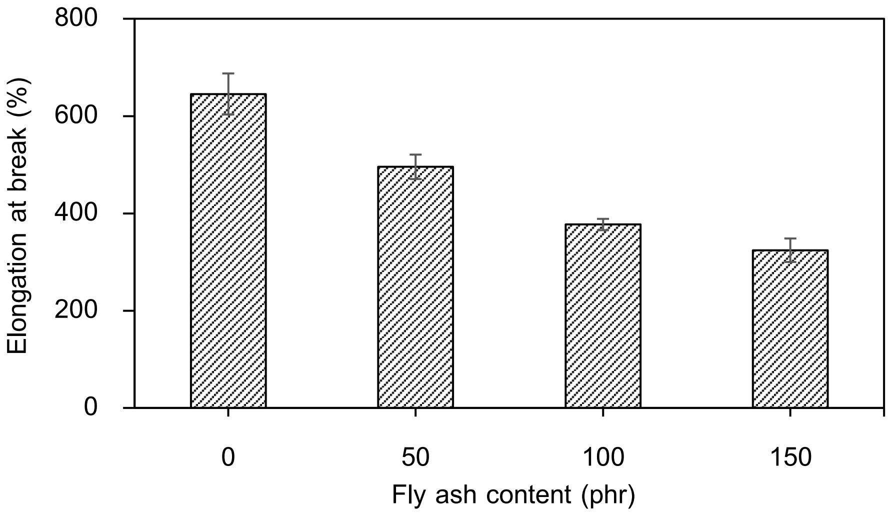

Figure 9 Elongation at break of bonded rubber

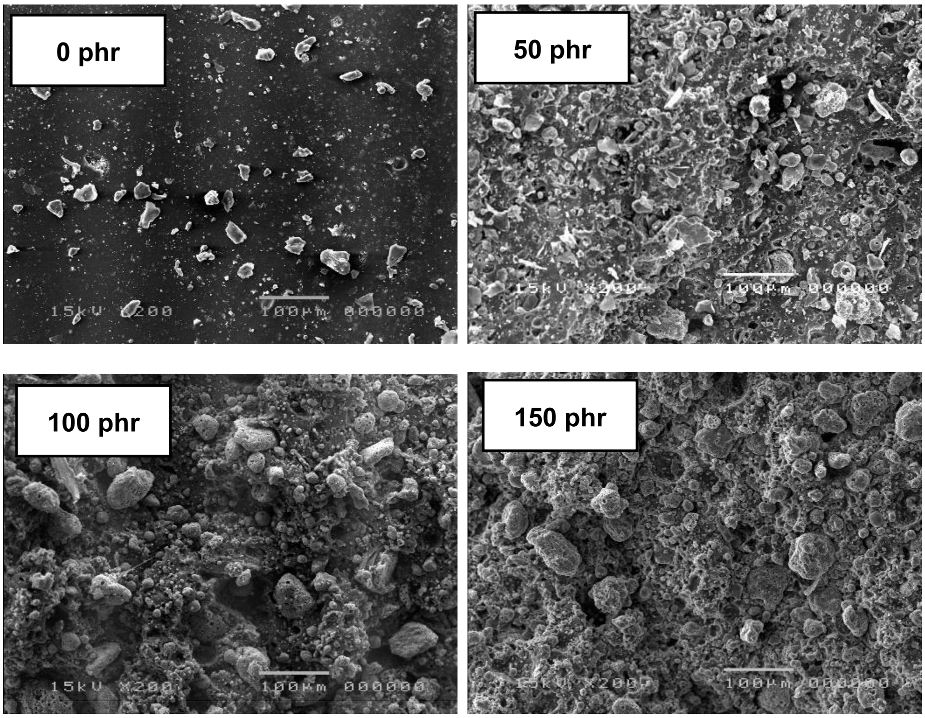

Figure 10 The morphology of fracture surface of bonded rubber prepared from natural rubber with modified fly ash content

The effects of fly ash content on the hardness and rebound resilience of bonded rubber as shown in Figure 11. Hardness tends to increase when fly ash content becomes higher as the fly ash particles hinder the movement of molecular chains of rubber. When the fly ash content increases, the elasticity of rubber decreases, resulting in higher hardness. Furthermore, hardness varies inversely to rebound resilience when compared with rubber without a filler.

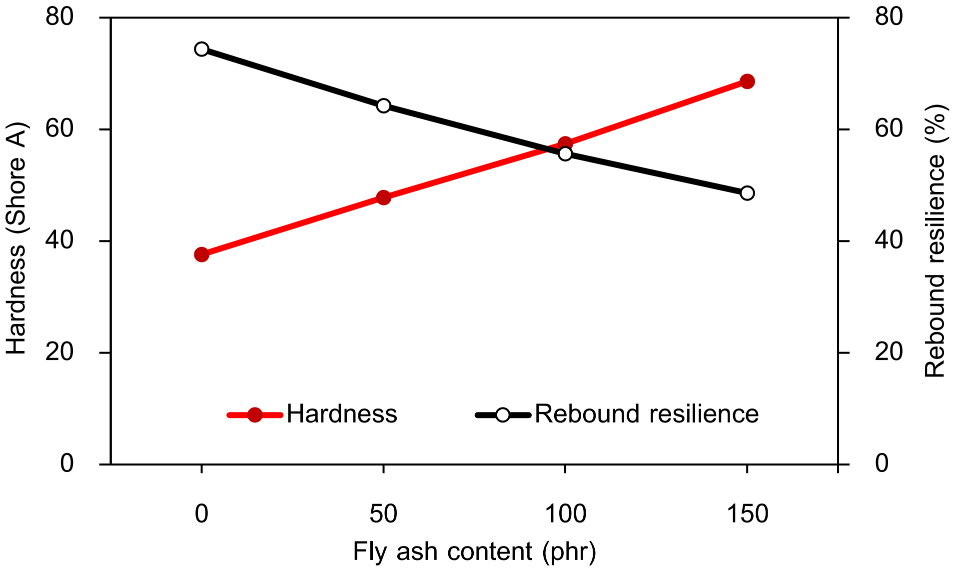

Figure 11 Hardness and rebound resilience of bonded rubber

3.3 The bond between bonded rubber and concrete mixed with crumb rubber

According to the study of the effects of crumb rubber on the concrete properties and fly ash content on natural rubber properties, the substitution of 10 percent crumb rubber for sand by sand weight is the appropriate crumb rubber content, resulting in the highest compressive strength. The proper fly ash content as bonded rubber is 50 and 100 phr, which results in hardness around 50 and 60 Shore A, respectively. It is consistent with the satisfaction survey of the elderly toward the hardness in the previous studies [1]. The test of the bond between bonded rubber and concrete mixed with crumb rubber applied the results obtained from the satisfaction survey. Bonded rubber could not adhere to the concrete mixed with crumb rubber, as shown in Figure 12, owing to the shrinkage of concrete from the surface of bonded rubber with fly ash as a filler. The concrete shrinkage occurs because of the hydration reaction and moisture loss in the capillary pores, which change the concrete volume or the shrinkage of paste. The concrete shrinkage appears to decrease if admixtures can absorb water well [15]. However, the addition of crumb rubber, which is a low hydrophilic material, causes a higher level of concrete shrinkage. Moreover, bonded rubber mixed with fly ash content at 50 and 100 phr, which is commonly used as a hygroscopic material for mixing concrete, cannot absorb moisture from concrete because natural rubber has a continuous phase with a hydrophobic property and can have only 7.9 percent water swelling [16]. Therefore, no chemical reactions that cause the bond occur, resulting in considerably lower bonding strength between the two layers. Consequently, the design of bonded rubber characteristics to physically bond to concrete mixed with crumb rubber, as presented in Figure 13, has been initiated to benefit the making of shock-reducing paving blocks for the elderly. In the process of designing the green print referenced by the previous idea and was a concept to research of Vudjung et al. [1], resulted in shock-absorbing rubber as shown in Figure 14 (A) and formed into paving blocks as shown in Figure 14 (B). For the adhesion test, performed by lifting paving blocks off the ground by holding the shock-absorbing rubber part, the shock-absorbing rubber and concrete were found to be well attached together as shown in Figure 14 (C). Therefore, the knowledge gained from paving blocks research was put into practice at Ban Mad Town Hall, Muang Srikai Subdistrict, Warin Chamrap District, Ubon Ratchathani as shown in Figure 14 (D). It was found that the elderly commented that paving blocks were softer and more comfortable to walk onto than normal concrete blocks.

Figure 12 Concrete shrinkage from the surface of bonded rubber with fly ash as a filler

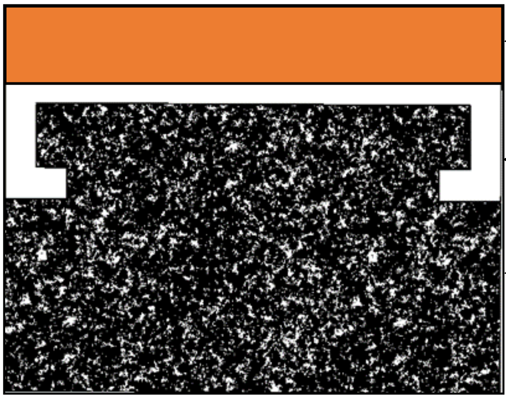

Figure 13 Cross-sectional image of a paving block

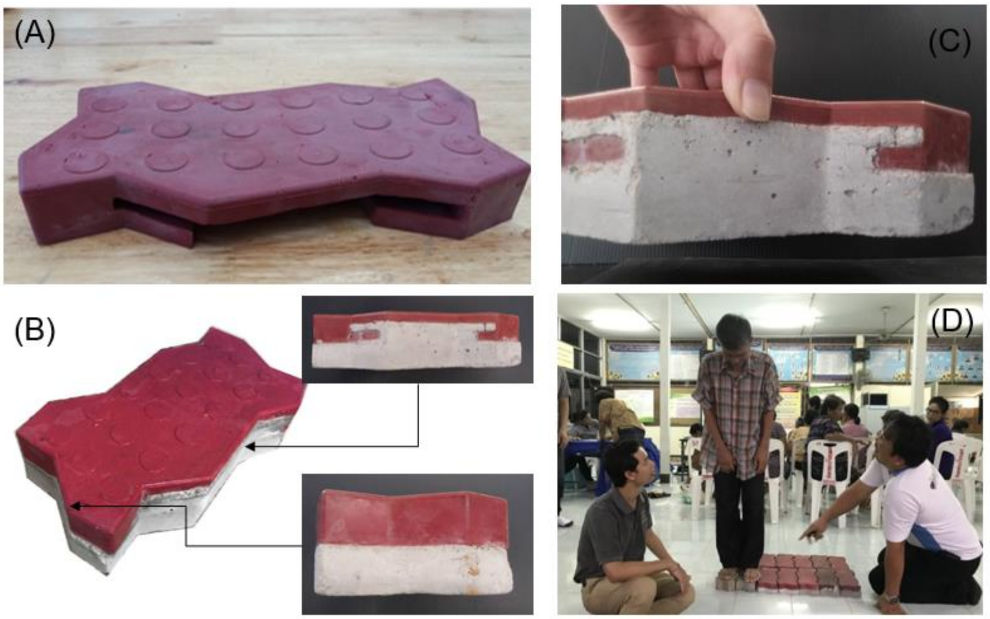

Figure 14 (A) Shock-absorbing rubber [1] (B) Paving blocks (C) Pulling adhesion test (D) Paving blocks test

4. Conclusion

Concrete density and compressive strength appear to decrease when crumb rubber content increases. The test shows that 10 percent crumb rubber content by sand weight results in the highest compressive strength. The vulcanization properties of bonded rubber with fly ash as a filler reveal that M_H-M_L increases when fly ash content becomes greater.

However, T_{S2} and T_{C90} appear somewhat stable. The test of mechanical properties of bonded rubber shows that although tensile strength, elongation at break, and rebound resilience tend to decrease when fly ash content becomes greater, hardness appears to increase. However, bonded rubber with fly ash as a filler cannot be chemically bonded with concrete mixed with crumb rubber. Therefore, it is recommended to design characteristics of bonded rubber to enhance its bonding with concrete mixed with crumb rubber.

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