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BEHAVIOR AND BASIC PROPERTIES OF CRUMB RUBBER CONCRETE

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ABSTRACT:

This study is the research and development of materials in the construction industry by using crumb rubber to replace sand in concrete production. The objective was to study how mixing crumb rubber in concrete influenced the basic properties of concrete. The compressive strength, elastic modulus, weight unit, porosity, and water absorption were the basic properties used in the test. The sand was replaced by crumb rubber at 0% 10%, 30%, and 50% by volume. The results of the study showed that crumb rubber influenced the properties of concrete, causing the unit weight, compressive strength, and modulus to decrease, but also causing the porosity, water absorption, and flexibility to increase. The unit weight of crumb rubber concrete were equal to 2,381.33 2,266.96 1,953.19 and 1,764.74 kg/m^3 respectively. The the porosity were equal to 15.15% 16.49% 19.34% and 20.64% respectively and the water absorption were equal to 6.25% 7.17% 9.57% and 11.70% respectively. The compressive strength were equal to 42.73, 33.64, 25.23, and 11.35 MPa, respectively. The rubber granules behave to the voids in concrete and trapped air on the rubber surface resulting in that behavior. The results of the study revealed that the influenced properties of rubber scraps are suitable for further application in development as building materials.

KEYWORDS: Crumb rubber concrete, Modulus of elasticity, Basic properties, Concrete innovation

1. Introduction

Thailand is the world's largest rubber producer and exporter, accounting for about a third of the world's supply. In terms of the production of rubber in the country, 85-90% is exported, with only about 10-15% used domestically; about half of domestic use is in the tire industry [1]. Nowadays, the automobile industry is growing more every year, so tires are used and abandoned more as well. In the year 2000, roughly 94,000 metric tons of natural rubber, or 38% of the natural rubber produced that year, were used to produce car tires. Later in 2016, the Department of Land Transport reported around 37 million registered vehicles [1]. Assuming those cars changed their tires on time, millions of tires were abandoned annually. With the increasing number of abandoned tires, waste management has become a challenge in Thailand.

Waste tires are very difficult to decompose. Burning is the simplest way to get rid of them. However, this method creates a lot of problems and pollution, especially in terms of smell and smoke. Therefore, this method of burning is not acceptable in some countries. The easy solution to this issue is to just leave the piles. This method has indirect effects: simply turning into a fire source or insect and animal habitation [2]. At present, some countries have

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developed recycling processes for used tires. One of the strategies is to ground the tires into small pieces and use them as an ingredient in asphalt to improve pavement and concrete mixing.

In past decades, crumb rubber has been used to produce construction materials. In particular, Mull et al. [3] modified chemical crumb rubber asphalt in 2002 to improve pavement fracture resistance. It was found that crumb rubber asphalt prevents pavement cracking better than control pavements. In addition, Ding et al. [4] mixed crumb rubber with asphalt to study various properties for use in pavement. The results of the study revealed that plant-produced crumb rubber asphalt enhanced certain properties including high-temperature rutting resistance, low-temperature cracking resistance, moisture stability, and fatigue failure resistance.

In addition to using crumb rubber to improve the quality of pavement, concrete production is an interesting and advantageous way to recycle crumb rubber. Moreover, it is also beneficial for the development of materials in the construction industry for modern innovations, such as high-impact concrete for airport runways, highway pavement, bridge decks, and engineering structures [5]. Consequently, research studies on the importance of rubber concrete began in the early 1990s and have resulted in significant global developments [6],[7]. Liu et al. [5] pointed out that the results of rubber-based concrete have many advantages such as light weight, anti-permeability, anti-aging and crack resistance, wear and frost, which leads to a significant increase in cracking efficiency when used in a high temperature environment. However, few studies have focused on the impact resistance performance of crumb rubber concrete; dynamic loads refer to high strain rates, such as under impact or earthquake loads. Topcu et al. [8] noted that the impact resistance of concrete increased when rubber particles were added to the concrete mix due to the energy-absorbing ability of rubber. Increased rubber particle size helps increase impact resistance. Furthermore, Najim and Hall [9] concluded that crumb rubber concrete was particularly well suited for specialized applications where dynamic response and vibration reduction were top priorities.

In addition to studying the absorption of such energy, the response to structural vibrations due to earthquakes also plays an important role in concrete. Xue and Shinozuka [10] conducted a study of the micro-column model, which was fabricated using rubber concrete of different rubber fractions to assess the dynamic performance of the structure. It was found that the damping coefficient of rubber concrete was increased by 62% compared to normal concrete, and the seismic response rate of the structure was reduced by 27% as a result. However, the use of crumb rubber in concrete production directly influences the mechanical properties of the concrete. Therefore, it should be noted that modern concrete mixed with crumb rubber has several advantages that can be used in construction.

In research studies to obtain new products, it is important to understand the behavior of materials, especially the basic properties, in order to understand and use them correctly. Gupta et al. [11] studied the effects of adding crumb rubber in replacement of fine aggregates by conducting mechanical properties testing. It was found that the mechanical properties were affected by the addition of rubber ash and rubber fibers in concrete. In addition, many researchers have proposed methods for predicting the basic properties of these types of concrete. Huang et al. [12] investigated the correlation of strength reduction factor for crumb rubber as fine aggregate replacement in concrete. The model was developed to predict correct behavior. Lia et al. [13] developed a numerical model to study the bending behavior of ribbed reinforced concrete. It was conducted with the application of the stress-strain model developed in the paper, and the results agreed well with experimental tests. In addition, several researchers have conducted various behavioral prediction studies of crumb rubber concrete. For example, Guo et al. [14] predicted the failure of rubber concrete using a quantitative cloud imagine correlation, while Mousavimehr and Nematzadeh [15] predicted the behavior of crumb rubber concrete after burning. All of these studies were conducted in order to understand the behavior of crumb rubber concrete in order to be able to calculate its basic properties.

All of the above shows that the use of crumb rubber in concrete production is an innovation for building materials. It has shown good results for use in some of the aforementioned purposes. From previous studies, it was concluded that rubber crumb influences various properties of concrete such as mechanical properties, physical properties, etc. Therefore, it is necessary to study the influence of crumb rubber on the properties of concrete to understand how to use it and the possibility of actually utilizing crumb rubber. This research recognizes the importance of the above reasons. Therefore, research was carried out concerning the effects of crumb rubber and how they influence the properties of concrete. In conclusion, this research was conducted as a preliminary guide in the creation of modern concrete

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innovations and to suggest features that are suitable for use. The direct advantage is a new material that is suitable for use. In addition, it has an indirect advantage in terms of helping to eliminate waste; crumb rubber is a material that is more biodegradable and difficult to remove for reuse. Thus, it has a positive effect on the environment.

2. Materials and methods

2.1 Raw Materials

In Ordinary Portland cement (OPC) type 1, river sand, water, and 19 mm crushed rock coarse aggregate are used for the concrete. Ordinary Portland cement (OPC) type 1 is cement according to TIS 15-2547 Industrial Standard. It has a specific gravity of 3.2, average particles by volume of 23.32 micrometres, and a specific surface area of 610 m^2/kg. The main chemical elements are 65.5% and 21.0% calcium oxide (CaO) and silicon dioxide (SiO2), respectively. The river sand has a fineness modulus of 3.0 and maximum size of 5 mm; coarse aggregate with sizes of 10–40 mm satisfies the ASTM C-136-95 [16] specification requirements. Crumb rubber is a fine aggregate material produced by mechanical shredding with a small size similar to sand. Crumb rubber is 2 mm in size, has a specific gravity of 0.89, and has an indeterminate shape and angle, as shown in Figure 1. The sieve analysis of river sand, and crumb rubber is presented in Figure 2 according to standard ASTM C-136-05 [17].

(a) Crumb rubber (b) Rubber particle

Figure 1 Greater magnification of the rubber particle

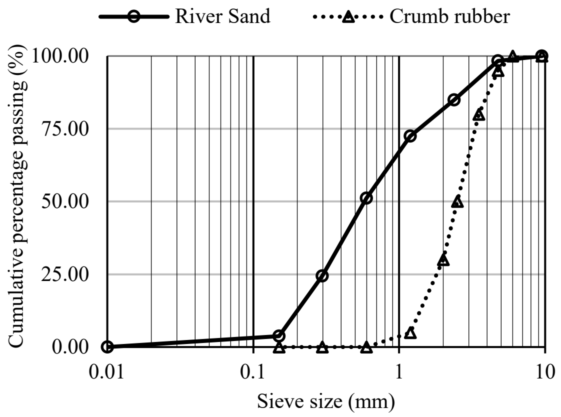

Figure 2 Gradation curve of river sand, and crumb rubber

2.2 Mixes proportions and preparation

The preparation of crumb rubber begins with a shredding process, reducing the size of crumbs to 100 mm - 50 mm, followed by a granulating process that further reduces the size from 50 mm to 10 mm. The separation of steel wire from rubber scrap takes place after the preliminary sorting. Before being fed into the final granulation process, the crumbs are ground to smaller sizes to produce customized crumb rubber by grinding in rolling mills. Gravity and magnetic sieves/separators are used to remove metals and fibres, respectively, in the manufacturing process.

Table 1 shows the concrete mix proportion consisting of four trial mixes at three proportions of crumb rubber replacement and a control mix. The concrete mix design consists of cement: fine aggregate: coarse aggregate of 1:2:4 by volume. The natural fine aggregate (NFA) was replaced by crumb rubber at 10%, 30%, and 50% by volume and the 0.6 is to the water to cement ratio.

Table 1 Concrete mix proportions (kg/m^3)

Sample ID	Cement	River sand	Crumb rubber	Coarse aggregate	Water
RC0	305	635	0	1275	185
RC10	305	571.5	21.3	1275	185
RC30	305	444.5	64.0	1275	185
RC50	305	317.5	106.6	1275	185

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Sample production begins with the preparation of the material according to the designed mix. The materials used must be clean and free from impurities. Subsequently, the concrete is mixed in a cement mixer, and compatibility should be checked periodically. When combined well, the prepared crumb rubber is introduced into the concrete mixture and mixed together; compatibility should still be checked periodically. When the mixture is homogeneous, samples are collected in a cube sample size of 150 x150 x 150 mm and a cylinder with a diameter of 150 x 300 mm.

2.3 Methods and Test procedure

To study the behaviors of crumb rubber concrete, basic properties were tested for analysis and prediction. The unit weight, water absorption, and porosity were tested first in accordance with ASTM C318-92 [18] and ASTM C20 [19], respectively. The compressive strength was tested by sample cube 150 x 150 x 150 mm. Stress-strain relationship and elastic modulus was tested on standard ASTM C 469 [20] by cylinder sample of size 150 mm x300 mm at 28 days in air curing for curing and molded 24 h later testing machine in the loading test device was a UTM 500 tons, and measure displacement sensor with precision of 0.001 mm.

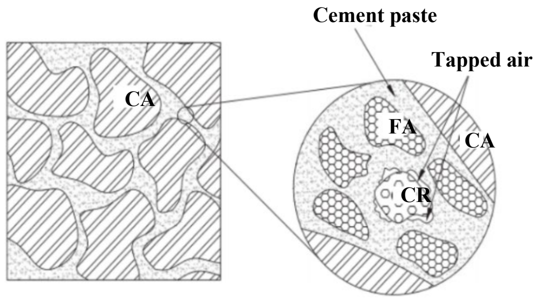
3. Results and Discussions

3.1 porosity, water absorption, and unit weight

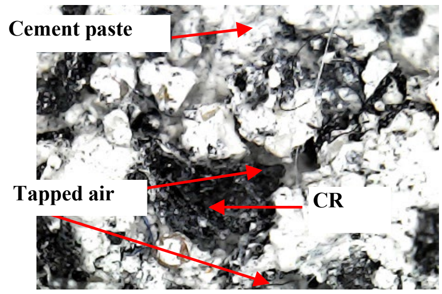
Porosity, water absorption, and unit weight are physical properties of concrete materials; the values are shown in Table 2. It was found that in the mixture at 0% 10%, 30%, and 50% the unit weight was reduced between 2,381.33 2,266.96 1,953.19 and 1,764.74 kg/m3 respectively and the porosity was 15.15% 16.49% 19.34% and 20.64% respectively and the water absorption was 6.25% 7.17% 9.57% and 11.70% respectively. From the results of the experiment, it was found that the porosity and water absorption increased when increasing the rubber content. On the other hand, the unit weight is reduced. The rubber granules will cause porosity. In addition, rubber granules are also able to trap infiltrated air, which means increased interconnected porosity [21]. Therefore, the larger the volume of rubber the greater the porosity. Mohammed [22] explains that the rubber surface area binds with loose cement mortar, resulting in trapped air on the rubber surface as shown in Figure 3(a). Considering the microstructure of crumb rubber concrete in this study, as shown in Figure 3(b) found to be comparable with the behaviour of the particles as shown in Figure 3(a). Therefore, concrete mixed with crumb rubber form capillaries that are easily filled with water, resulting in crumb rubber concrete that have higher gaps and water absorption. Also, increasing the rubber content affects the physical properties by giving concrete high water requirements, viscosity, and a negative effect on workability [23]. Therefore, Ling [24] found that the higher w/c, the density of the rubber concrete is increased at the same proportions. Further, the unit weight decreases at the same w/c ratio, as the rubber content is increased.

Table 2 Test result of rubber concrete property

Sample ID	Weight (kg)	Unit weight (kg/m^3)	Porosity (%)	Water absorption (%)
RC0	8.04	2,381.33	15.15	6.25
RC10	7.65	2,266.96	16.49	7.17
RC30	6.59	1,953.19	19.34	9.57
RC50	5.96	1,764.74	20.64	11.70



(a) Microstructure model of crumb rubber concrete [22]



(b) Microstructure of crumb rubber concrete

Figure 3 Microstructure of crumb rubber concrete

Considering the relationship between the water absorption and porosity of crumb rubber concrete, it was found that both values increased as the rubber content increased, as the previous reason. However, it is worth noting that the rising trend is a straight line with similar slopes. The linear regression of the two relationships was analyzed. The correlation

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is obtained according to Figure 4, which provides more than 90% accuracy. Comparing the water absorption and porosity shown in Figure 5, there is a linear relationship. It was found that when crumb rubber concrete increased the porosity, water absorption was increased as well. This increase will be increased at the same rate (Slope = 1). This is also consistent with previous research [25]-[27] which found that the amount of water absorption increases with the volume of the gap and change in a linear relationship. Therefore, the linear equations obtained from this experiment can be represented in the predictive analysis between the two variables.

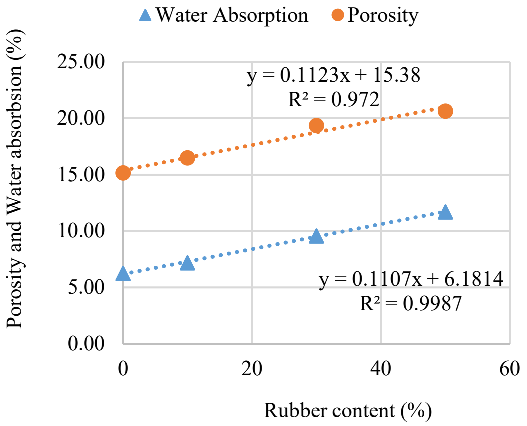

Figure 4 Relationship of porosity and water absorption to rubber content

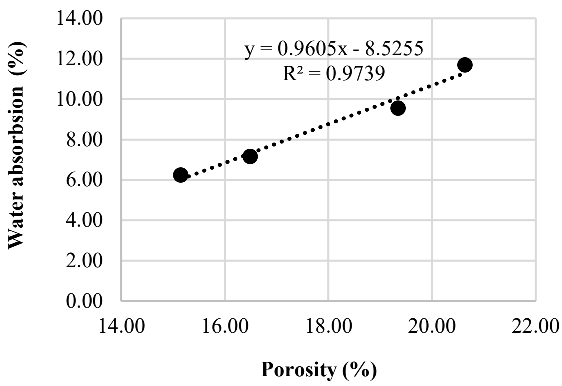

Figure 5 Relationship between porosity and water absorption

3.2 Compressive strength analysis and elastic modulus

The compressive strength and elastic modulus obtained in this experiment is shown in Figure 6. It was found that the compressive strength would decrease as the quantity of crumb rubber increased. Compressive strength at 0%, 10%, 30%, and 50% were equal to 42.73, 33.64, 25.23, and 11.35 MPa, respectively, decreasing by 21.2, 40.9, and 73.4%, respectively. The increasing of crumb rubber replacement of sand by 50% will make the compressive strength decrease greatly by 73%. For this reason, the reduction in compressive strength is due to the compression force exerted in the rubber-containing material; the rubber serves to support the force. The rubber has a soft and smooth surface, which is an important factor in reducing the adhesion force between the rubber and cement place. It also increases the amount of the weakest phase and interfacial transition zone [28]. On the other hand, the rubber particles are much weaker than the surrounding matrix. There is a lack of adhesion between the rubber particles and mixture. Thus, cracks quickly form around rubber particles in the mixture, which is an accelerated part of the deterioration of concrete as a result of the lack of adhesion between the rubber particles and mixture. The specific gravity, unit weight of sand and rubber are very different changing tires by weight, which may decrease the amount of binder to total mass ratio. The conversion of aggregate to crumb rubber results in a large weight difference, which can decrease the binder to aggregate ratio. Soft rubber particles may behave like voids in concrete. The decrease in strength is also a result of the weak adhesion between the cement paste and rubber particles. This weakness caused by the air trapped in the gap, as shown in Figure 3, partially reduces the bonding force in the concrete matrix. The rubber particles are not completely bonded to the cement matrix, but are more strongly bonded to the fine aggregate (FA) and coarse aggregate (CA) surfaces. While the load is applied to the crumb rubber concrete during testing, micro cracks begin to form at the weak interface between cement paste and crumb rubber (CR) due to the stress concentration, eventually leading to failure with continuous loading [22].

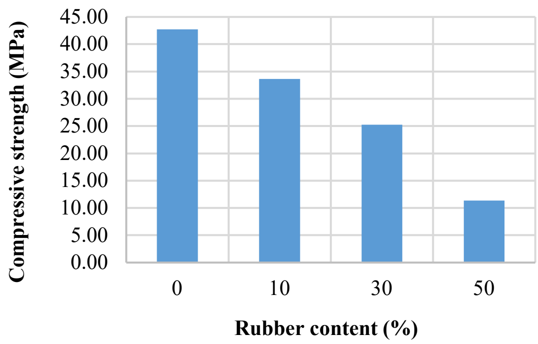

Figure 6 Compressive strength of crumb rubber concrete

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3.3 Stress-strain relationship

Results of uniaxial compressive tests according to ASTM C39 [29] for cylindrical samples of 15x30cm with UTM under different sample mixes at 0%, 10%, 30%, and 50%, stress-strain are shown in Figure 7. The stress-strain relationship showed that the compressive strength varied with an increase in the rubber content. This will also affect the mechanical properties of the concrete. The increased rubber content will cause the concrete to have a lower compressive strength, but will result in an improvement of the deformability of the concrete

The trends and characteristics of stress-strain curves are similar in all proportions. That is, there will be a linear portion from the bottom to approximately 35-45% of the maximum stress, after which would follow a nonlinear form which corresponds to Charles et al. [30], who introduced the properties of this relationship into a structural design. The elastic properties of the rubber crumb greatly affect the deformation of the concrete. This makes the rubber concrete many times more flexible than normal concrete. Crumb rubber concrete with 50% rubber content is 7.67 times more elastic than normal concrete at the same stress value. Because the rubber is a soft material, it is easily deformed when stress is applied, as shown in Figure 8(a). On the other hand, reducing the stress in the soft rubber material produces rebound stress and fills the voids between the solid particles (natural aggregates), as shown in Figure 8(b) [31]. For this reason, rubber concrete is more flexible than normal concrete.

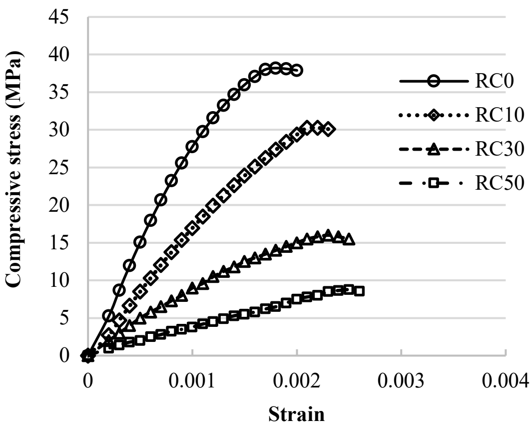
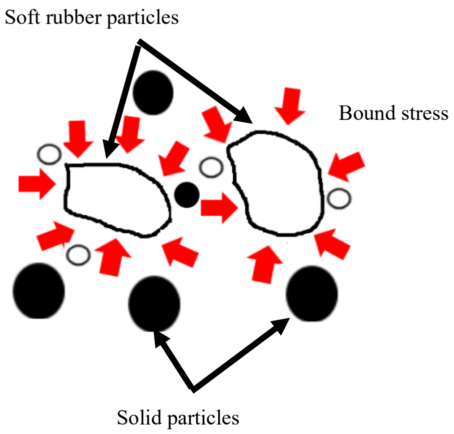
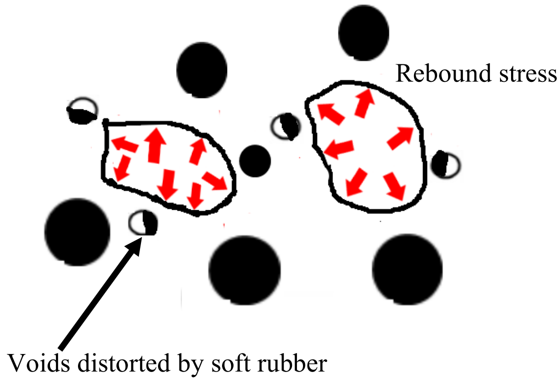


Figure 7 Stress-strain relationship of crumb rubber concrete



(a) Under compaction stress



(b) Once released from the stress

Figure 8 Mechanism behavior of soft rubber and solid particles

However, the maximum compressive strength of concrete with 50% rubber content is lower than normal concrete by 77%. Due to the effect of low-strength rubber materials and micro-cracks between the rubber aggregates and the concrete matrix, this will cause a significant loss of strength, as shown in Figure 9. Therefore, such concrete is not suitable for heavy load designs. However, when considering concrete with 10% rubber content, it is found that the maximum compressive strength is 30.27 MPa, 20% less than normal concrete, which is a strong factor within the range that can be used. Its elasticity is 1.3 times higher than normal concrete, resulting in the concrete having higher elasticity. It is advantageous for application in seismic design [10] and also suitable for high impact loads because crumb rubber concrete can absorb energy very well [8],[9]. Therefore, it is suitable for further design application in these structures.

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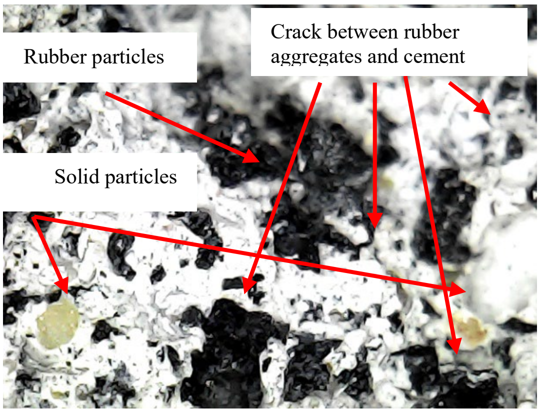

Figure 9 Observation of undisturbed facture surface resulting from a compression test

3.4 Stress-strain relationship

The elastic modulus is shown in Table 3. The modulus decreases with an increase in the rubber content. The modulus of rubber concrete in mixtures of 0%, 10%, 30%, and 50% were equal to 30.40, 24.00, 11.88, and 4.63 GPa, respectively, where 50% has a maximum reduction of modulus of 84.7%. As a result of the experiment, it can be observed that the modulus decreases with a decrease in the compressive strength and also depends on the unit weight of concrete [32]. It according to Rattanachu et.al [33] was found that cement place or mortar attached to the rubber crumb surface had high porosity as the previous reason. On the other hand, rubber crumbs cause concrete to be easily deformed when weight is applied to the aggregate. Therefore, this is the reason why concrete has a lower modulus when rubber crumbs are added to the mix.

Table 3 Compressive strength, weight unit, and elastic modulus of crumb rubber concrete

Sample ID	Compressive strength (MPa)	Unit weight (kg/m^3)	Elastic modulus (GPa)
RC0	42.73	2,381.33	30.43
RC10	33.64	2,266.96	24.12
RC30	25.23	1,953.19	18.45
RC50	11.35	1,764.74	9.32

Considering the relationship between the elastic modulus and square root of the compressive strength of the manufactured limestone dust concrete, it was found that the modulus of concrete was higher as concrete strength increased and tended to be linear. However, comparing the modulus of normal concrete in accordance with ACI 318 [34], ACI 363 [35] and proposed by Rattanachu et al. [33] revealed that the modulus of concrete with crumb rubber replacement of sand was close to ACI 318 standards (as shown in Figure 10). Further, it tends in a linear line in the same direction. This is because the equation of the standard considers the unit weight of concrete resulting in concrete strength and the modulus decreased. The equations in accordance with ACI 363 [35] and proposed by Rattanachu et al. [33] are for calculating the modulus with constant units weight of concrete. The reduced unit weight is not taken into account, resulting in low compressive strength (low units weight) will have a large deviation from the experimental results and the ACI 318 standard. Therefore, when considering the modulus of lightweight concrete, it is necessary to consider in terms of weight unit.

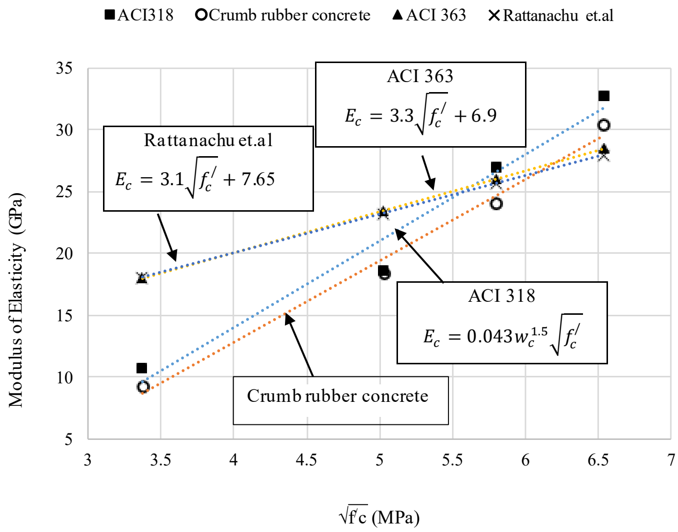

Figure 10 Relationship between modulus of elasticity and square roots of compressive strength

4. Conclusion

A study of the basic properties of crumb rubber concrete was carried out to better understand the influence of crumb rubber on the various properties of concrete when used as an admixture. Highlights included lightweight unit and higher flexibility compared to normal concrete. Therefore, it would be beneficial to further research and develop it for high impact loading of building materials. However, a disadvantage is that it bears less strength than normal concrete. Therefore, this research presents the behavior and basic properties for crumb rubber concrete, which can be expressed as follows:

The unit weight of crumb rubber concrete were equal to 2,381.33 2,266.96 1,953.19 and 1,764.74 kg/m3 respectively. The the porosity were equal to 15.15% 16.49% 19.34% and 20.64% respectively and the water absorption were equal to

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6.25% 7.17% 9.57% and 11.70% respectively. The compressive strength were equal to 42.73, 33.64, 25.23, and 11.35 MPa, respectively. The modulus of rubber concrete in mixtures of 0%, 10%, 30%, and 50% were equal to 30.40, 24.00, 11.88, and 4.63 GPa, respectively, where 50% has a maximum reduction of modulus of 84.7%.

The rubber content affect the compressive strength. The increasing rubber content result in decreased compressive strength. An increase in the rubber content affects the amount of void or porosity and water absorption. The increased amount of rubber results in the percentage of porosity and higher water absorption. On the other hand, the unit weight will be decreased because of the influence of the void. The added rubber content results in highly elastic concrete and low elastic modulus, which is caused by the flexibility of the rubber particles inside. The elastic modulus will decrease as the rubber content increases. The modulus of elasticity depends mainly on the compressive strength. Likewise, the unit weight also affects the elastic modulus besides compressive strength.Therefore, the elastic modulus must considered the unit weight term in the calculation. If only the compressive strength is considered, the modulus of elasticity has a high tolerance.

From the results, it can be concluded that rubber concrete is suitable for further development as an innovation in building materials, which would also be useful in commercial development as well as for developing construction engineering materials in the future.

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