DEGREE PROJECT

Utilization of Rubber and Plastic Waste as A Partial Replacement of Aggregate for Improved Sound Insulation

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Technology Candidate, Architecture

In Partial Fulfillment of the Requirements for bachelor's degree in Technology, Major Area of Architecture

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Abstract

Globally, billions of tons of rubber and plastic waste are produced annually, and because these wastes degrade so slowly (about 450 years for plastic bottles and 80 years for tire rubbers), they are extremely difficult to dispose of. As a result, utilizing these wastes directly in building materials can significantly reduce the environmental load while also increasing the sustainability of the building material. This study compares the roles and effects of using recycled plastic and rubber as aggregates on the properties as well as the performance of concrete. This research focuses on sound insulation properties in particular. Each artificial polymer material of rubber and plastic has a special structure but consists of the same essential components. Plastic and rubber wastes, replacing fine/coarse aggregates are determined by their sort, size, replacement content, and shape. Plastic-based aggregates generally reduce the concrete's workability, but the impact of rubber-based aggregates is mostly influenced by their size and replacement amount.

The main objective of this study is to review the evaluation of the sound insulating properties of concrete containing particles of plastic and rubber wastes based on their size, replacement amount, shape, and other factors. **For the recycled PET**, the results showed that the best percentage of recycled PET fibers mixed with ordinary concrete was in the range of 0.5 – 1.5% compared with other percentages. Low values in the range of 0.5 - 2%, especially 0.5%, of recycled PET mixed with concrete demonstrated the best value in terms of compressive strength compared with ordinary concrete. **For the recycled rubber aggregate**, the improved sound loss transmission for coarse crumb rubber was higher than the sound loss when using the same percentage of fine crumb. This could belong to that the coarse aggregate caused the voids to appear and increased the porosity in the system compared with the fine aggregate. When these aggregates were included the sound absorption can be improved drastically. The compressive strength of the samples containing fine crumbs of rubber was decreased compared to the control concrete sample without added rubber.

Many previous studies found a clear drop in compressive strength when using a fine rubber aggregate compared with coarse rubber aggregate. Generally, when adding a higher percentage of rubber, the sound absorption coefficient increased, while the compressive strength decreased.

Many researchers found that the thermal insulation increased when adding higher percentages of plastic and rubber waste to concrete. The degree of thermal insulation improvement for mixing concrete with plastic and rubber is also determined by the shape of the pieces. The density of concrete decreased as the percentage of plastic and rubber particles in the mixture increased.

Table of Contents

List of Tables

List of Figures

1. Introduction

Due to their low degradability, polymeric wastes such as plastic and rubber need for their decomposition 450 years (Globle Averda, 2022) and more than 80 years (Playground Professionals, 2014) respectively. These materials make up a significant portion of solid waste and pose a significant load on the environment. Every year, approximately 6.5 billion tons of plastic and rubber waste are created (Li et al., 2022).

Currently, burning, recycling, and disposal sites are used to treat these materials. However, landfilling is the most commonly used technique. According to statistics, only twenty-two percent of plastic waste is recycled for reuse, while 51% is buried and 27% is burned. Waste in landfills leads to several pollution issues, which may later create health issues. Research has already been done on these wastes' potential applications in composite materials, for example, adding plastic to wood-based materials and rubber to asphalt. One application for producing environmentally friendly concrete is the use of plastic and rubber waste as aggregates in concrete. This type of concrete has many advantageous properties such as lightweight, flexibility, chemical inertia, and so on. Researchers have found that using recycled rubber as a partial replacement for mineral aggregates in concrete is an effective solution. This type of replacement has a double benefit: it reduces the depletion of natural resources while also protecting the environment from the harmful effects of rubber waste (Saikia and Brito, 2012).

Rubber waste is most commonly used as fine or coarse aggregate to produce what will be hereafter so-called “rubberized concrete”, but there are also certain uses for it as fiber and binder (Gupta et al., 2016), Waste plastic, on the other hand, is commonly utilized as fiber, fine aggregates, and coarse aggregates. It has been investigated if recycled plastic and rubber may be used to effectively enhance certain characteristics of concrete and mortar (Saikia and Brito, 2012). For instance, post-fire mechanical performance was improved in concrete that used recycled polyolefin (PO) waste as aggregate (Colangelo et al., 2016; Correia and Lima, 2014). Moreover, Yin et al., 2015 demonstrated outstanding post-crack ductility and flexural toughness when plastic fiber was added. Despite the reduction in workability and compressive strength, mixed concrete with rubber aggregates can be used in secondary parts of structures (Siddique and Naik, 2004). Additionally, plastic and rubber have proven to perform well in terms of thermal insulation, waterproofing, and noise reduction qualities, as well as reducing the density and brittleness of concrete and mortar (Rashad, 2016). Rubberized concrete is used to produce structural or nonstructural members that contribute to improving the sound insulation of buildings.

Sound pollution is a potential risk for residents and the environment due to the ever-increasing expansion of transportation means, urban centers, airports, and highways. Despite technological advancements, excessive sound exposure within legal limits remains one of the health issues that pose the greatest harm to urban dwellers and industrial employees worldwide (Chalangaran et al., 2021). In addition to reflecting and absorbing sound, a solid hardboard also allows sound waves to travel through, which may be harmful to nearby occupants' health. The life of people is now impacted by the great rise in noise levels in both urban and rural areas. In addition to being unpleasant for people, noise from various sources, such as machinery, industries, and traffic, is harmful to their health (Tiwari et al., 2004).

Since the world population increases and villages and cities are compelled to migrate closer to highways as well as more roads are being built noise problems will worsen. In the United States, 15% of the population is exposed to noise levels over 85 dBA, while 50% of the population is subjected to disturbance sound levels above 70 dBA. The maximum measured noise level was 96 dBA in residential zones, while the minimum noise level was 52 dBA in commercial zones. Looking at sound levels values called L10 and L90 are important. L10 and L90 are defined as the sound levels that exceeded 10% and 90% respectively at the measurement period (t) (US Department of Transportation Federal Highway Administration, 2017). The highest and lowest noise level of L10 was 96 dBA in commercial zones and 56 dBA in residential zones. The maximum value of L90 was 77 dBA in commercial zones, whilst the minimum value of L90 was 44 dBA in residential zones (Oyedepo et al., 2019).

Generally, according to (Irwan et al., 2013; Juki et al., 2016), the number of different types of consumed plastic is continuously increasing around the world. Among the most often used consumer polymers worldwide, especially in the manufacture of drink bottles as well as other consumer goods, is polyethylene terephthalate (PET) (Frigione, 2010; Fraternali et al., 2014). Due to recent increases in demand in China and India, PET manufacturing in the Asian region, which is already over 6.7 million tons annually, has been rapidly growing (Kim et al., 2010).

With an increase in PET fiber concentration, PET aerogels' absorption coefficient rises (Phan-Thien et al., 2018), where PET aerogels are ultralight, porous materials made from recycled plastic bottle waste (Material District, 2022). Cao et al. (2018) found when using PET aerogels of 2.0% by weight, that the sound absorption was improved by 20% to 30% compared to PET aerogels of 1.0%. The acoustic effect of the concrete matrix will be reduced in concrete that has a higher content of aerogels PET.

In order to manage noise inside buildings, items that minimize the transition of sound from one space to another need to be used (Chalangaran et al., 2021). Concrete is commonly used because it has strong compressive strength, making it ideal for use in various structural applications. Under certain environmental circumstances, concrete and other materials can lose their resistance, which leads to, e.g., appearing cracks and deterioration of the structure. To further improve the ability of concrete that it can endure severe environmental conditions, various products are used such as active additives, fibers, and rubber crumbs in various forms (Hosseini, 2020; Fayed and Mansour, 2020). These should help concrete to develop mechanical characteristics such as desired durability and resistance (Farzampour, 2017). Furthermore, more study is necessary to improve concrete performance to prevent the spread of environment degradation. Similar to how there is limit usage of additives, there is a need for ways of improvement for use in broad applications and to lessen the difficult circumstances endangering urban health (Mansouri & co., 2020 The high levels of environmental noise present in the residential and manufacturing industries can be reduced by using a variety of helpful materials in concrete applications(2016) Forouharmajd and Mohammadi.

Sound transmission loss was calculated using limited methods by adding various materials to concrete. It was proved that the impedance tube test (among other tests) can exactly evaluate sound transmission loss (Yousefzadeh et al., 2008). Many researchers, including (Asdrubali, 2008; Collings, Stewart, 2011; and Sukontasukkul, 2009), have measured the amount of sound transmission reduction in a space made of concrete containing high-porosity materials. In this test, a microphone was placed inside and outside the rectangular room, as well as an acoustic source, to measure the microphones' internal and external amounts of sound absorption and loss. According to the findings, adding more porous materials to concrete could reduce sound transmission (Uthaichotirat et al., 2020).

1.1 Aims of study

This literature study aims to evaluate the sound insulating properties of concrete after mixing with recycling waste consisting of plastic and rubber with different percentages, sizes, and shapes. Moreover, an assessment of some important properties like workability, density, and compressive strength is included based on the amount of added plastic and rubber waste.

2. Polyethylene Terephthalate PET

2.1 Properties of Polyethylene Terephthalate PET

The term PET is abbreviated for polyethylene terephthalate and is considered the most common polymer used by consumers around the world. PET bottles used for drinking water are shown in **Figure 1**.

Figure 1. Recycled plastic bottles of drinking water are made from polyethylene terephthalate PET (Loong et al., 2020).

PET is a polymer that is usually used as a raw substance in plastic bottles for drinking and different plastic boxes for saving various types of food like fruit, and vegetables (Frigione, 2010). Because of their lightweight as well as easy handling and storage, PET bottles have widely replaced glass bottles as a container for keeping beverages. The exponential rise in packaging-related plastic trash sparked a hunt for substitute recycling methods (Marzouket al., 2007). The PET waste has often been sorted, crushed, and compacted into bales before selling it to companies for recycling. Recycling companies apply many processes to PET waste to cut it into tiny pieces. For a variety of goods, PET flakes are employed as raw materials.

Polyethylene Terephthalate is a material that is typically suitable to be filled with different liquids and can contain numerous food products. It is tough, stiff, strong, and stable in dimension. Its solid-state ranges from highly crystalline to amorphous. Although wider parts of polyethylene terephthalate polyester PETP are often opaque and off-white, thinner sections can be exceedingly transparent and colorless. Dimethyl terephthalate and ethylene glycol reacted to create polyethylene terephthalate (John Wiley & Sons, 2016).

PET is made from ethylene terephthalate monomers that have been polymerized with a formula of $C_{10}H_8O_4$ (**Figure 2**) (Muhamad, 2012).

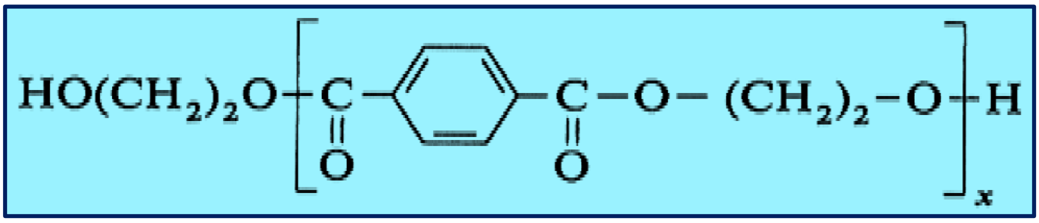

Figure 2. The chemical formula of polyethylene terephthalate
(Modified after John Wiley & Sons, 2016).

According to Loong et al. (2020), the mechanical and physical properties can be seen in **Figure 3**.

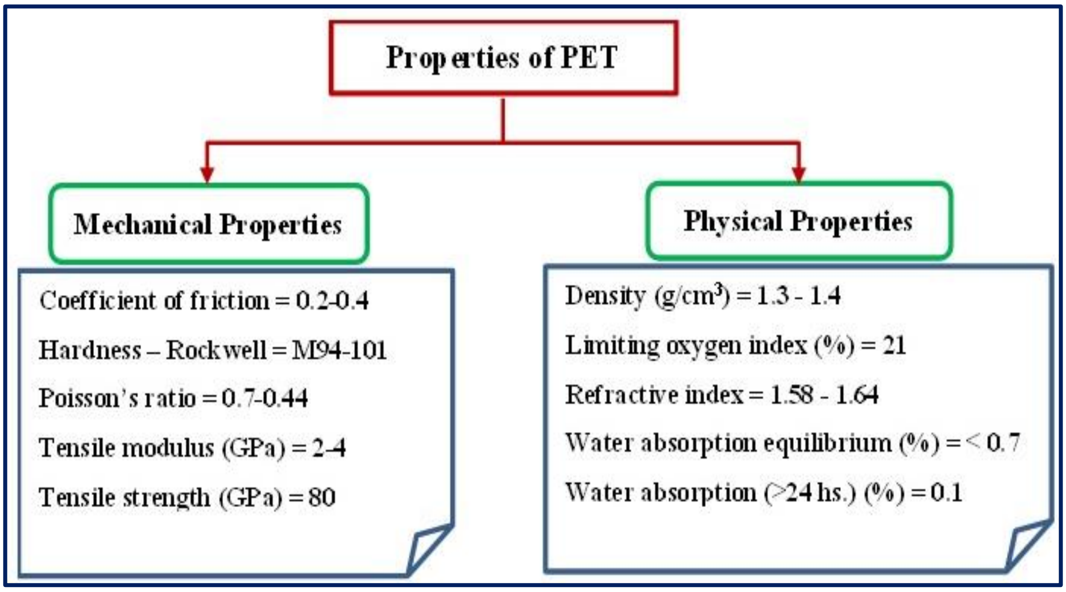

Figure 3. Mechanical and physical properties of PTE (Modified after Muhamad, 2012).

2.2 Creating aggregates from plastic waste

The primary materials used to make plastic aggregates are polypropylene PP and polyethylene terephthalate PET (Yang et al., 2015). One of the thermoplastics that are most frequently used worldwide is PP. Plastic containers, plastic components for machinery and equipment, and even fibers and textiles are only a few applications for polypropylene. Today, it is widely employed in a variety of residential and industrial applications. It is a hard, semi-crystalline thermoplastic. With its slick, tactile surface, polypropylene is perfect for low-friction applications like a gear in machines and automobiles as well as plastic furniture. Because of its exceptional resistance to chemical corrosion, it is a great option for packaging cleaning materials, bleach, and first aid items (Adreco Plastics, 2022).

Before being able to add these reclaimed materials as aggregates to the concrete mix, these materials typically need to go through three phases of processing (Hopewell et al., 2009). First, it is necessary to wash them using disinfectants and detergents to get rid of contaminants like labels and adhesives. This stage is crucial for ensuring that the final product will be of high quality. The second phase is shredding, where the plastic is cut up into very small pieces or chips of plastic waste. In the third step, it is melted and then extrusion-formed into granules. Extrusion and extrusion moulding are the two popular techniques (Awaja and Pavel, 2005). Plastic waste, therefore, has a low density and absorbs a lot of water. Because the PET particles have smooth surfaces, the binding connection between them and the cement matrix is weak. To make up for the reduction of mechanical properties resulting from this weak interface bond, pozzolanic materials and plasticizers are often added (Sadrmomtazi et al., 2016).

Additionally, by granulating or foaming the plastic aggregate's surface layer, it is possible to significantly boost the performance. Due to the creation of a rougher and more porous surface, modified expanded polystyrene EPS, and plastic grains displayed superior bonding (Madandoust et al., 2011).

According to Loong et al. (2020), plastic bottles made of PET can be cut into fibers as well. Also, here the PET plastic bottles were cleaned and dried to remove any contaminants. Recycled pieces of PET were finally shaped with a specific dimension (e.g., 2.5 cm (long) × 0.5 cm (wide)).

Loong et al. (2020), used a total of 60 specimens. For the compression test, 30 of them were cubes, while the remaining cylinders were used for the impedance tube test. Five different sorts of mixtures were created for this study. Control specimens made with zero% by volume of fibers came first. Then, other specimens were prepared by adding recycled PET fibers with different percentages by volume of 0.5, 1.0, 1.5, and 2.0% to the mixture. The concrete samples were tested after seven and twenty-eight days of curing. The recycled PET fiber's length and width were 2.5 cm and 0.5 cm, respectively. For all ranges, a W/C ratio of 0.45 proved suitable.

2.3 Evaluation of sound transmission loss of plastic aggregate

There are few studies on concrete/mortar with plastic aggregate's ability to absorb sound. According to Murugan et al. (2006), expanded polystyrene (EPS) with micro-voids performs better than the original polyethylene in absorbing sound at all frequencies. They tested the sound absorption coefficient in a traveling wave tube device designed of acrylic that was 1 m long and 100 mm in diameter (ASTM E1050. This device is suitable for frequencies between 100 and 2000 Hz. Humans can hear frequencies ranging from 20 to 20,000 Hertz on average. Specifically, the frequency range between 500 and 4000 Hertz. An HP15MHz frequency measurement was performed with a waveform generator, sound amplifier, millivoltmeter, microphone, and the test object making up the data acquisition equipment. Through the use of an amplifier, the sound level within the tube was calibrated to be approximately 20 to 30 dB louder than the ambient sound levels. The frequency of the function generator has been determined to be 100 Hz. To obtain the minimum and maximal sound pressure measurements, the microphone was moved from one of the tube's ends to the other. This process has been carried out at various times. Sinusoidal sound waves were used for testing.

According to Branco and Godinho et al. (2013), lightweight mortar mixed with granules of polystyrene plastic performed better than mortars made with other types of traditional sound absorption materials when it came to absorbing sound. Lower rigidity and more closed pores in the polystyrene granules may be the reason for the sound reduction.

The tests of compression and impedance tube are among the tests that were carried out by (Loong et al., (2020). Following the mixing of the concrete with the recycled PET fibers, selected samples were analyzed for seven days and then again for twenty-eight days at frequency ranges of 250, 500, 750, 1000, 1250, 1500, and 1750. After 28 days of curing, the compressive strength of ordinary concrete was 48.2 MPa, while the compressive strengths of concrete containing PET were 50.9, 49.8, 47.9, and 46.6 MPa, with percentages by volume of 0.5, 1.0, 1.5, and 2.0, respectively. When compared to other percentages, the best % of recycled PET fibers mixed with ordinary concrete was 0.5%. This value of 0.5% demonstrated the best in terms of compressive strength, and sound absorption coefficient. The impedance tube device can be seen in Figure 4.

Figure 4. Impedance tube device (Loong et al., 2020).

The impedance tube has to be straight and have an inner wall that is smooth and impermeable. The tube must be formed of a hard material, and the wall thickness must be thick enough to avoid vibrations within the tube's operational frequency range. A wall thickness of 5% of the inner tube diameter is the suggested standard. The tube's design must make sure that the interest frequency's upper limitation frequency is less than the tube's lowest cut-off frequency. Only waves that travel in planes are able to form inside the tube under these circumstances.

A sound wave cannot travel in one direction without changing when it encounters an absorbent substance or, more generally, a change in impedance. The most useful wave phenomenon for impedance tube testing is reflection, which is one of several that could happen in this situation. The incoming and reflected sound wave elements are layered in space though an impedance tube with a sample at one end and an acoustic driver at the other. As a result, the only wave that can be measured is the resultant wave, which is formed by superimposing the incident and reflected waves. Often, the measurement is only permitted to measure sound pressure levels. As a result, only the resulting sound pressure level in space can be measured. A reconstruction of the pressure loss in space could give a measurement of the sample's impedance because the resulting acoustic pressure wave, which is a combination of the absorbed and reflected sound waves, is caused through a change in the medium's impedance. One to three microphones can be set up for the experimental test to transmit the signal and then receive it after determining a specific digital frequency **Figure 5** (Chalangaran et al. 2021). The great sound loss accuracy, adaptability of the approach to tiny specimens, and precise calibration capability are the main advantages of impedance tube tests compared with other methods. However, this process requires an extremely accurate mold design, which could raise the cost of the preparations.

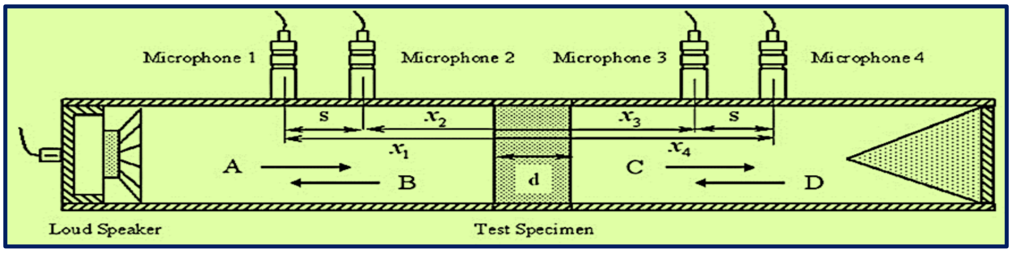

Figure 5. Impedance tube test schematic (using four microphones) for sound transmission loss (Modified after Collings and Stewart, 2011; Zhao et al., 2014).

The energy of sound can be assessed by measuring it for each side of the separator. The coefficients of separator transfer are computed using Equations (1) and (2) (Kimura et al., 2014).

$$\tau = \frac{W_t}{W_i} \tag{1}$$

$$\mathrm{STL} = 10\log_{10}\frac{W_i}{W_t} = 10\log_{10}\left(\frac{1}{\tau}\right) \tag{2}$$

where: W_i is the audio power entering separator, W_t is the audio power leaving the separator, τ is the coefficient of separator transfer, and STL is the sound transmission loss.

After 7 and 28 days of impedance tube testing, the sound absorption coefficient of ordinary concrete was 0.14 and 0.13, respectively. After 7 days of curing, the concrete mixed with PET aggregates at percentages of 0.5 and 1.5 had a maximum sound absorption coefficient of 0.16 in the impedance tube test. Furthermore, after 28 days of curing, the sound absorption coefficient was 0.17 at PET added to concrete with percentages of 0.5 and 1.5, and these values demonstrated good sound absorption. All percentages of mixing PET with concrete had the highest sound absorption coefficient at a frequency of 250 hertz. In their study, 1750 Hz was the frequency at which both the normal concrete specimen and the concrete specimen mixed with PET had the highest sound absorbing coefficients. For all frequencies between 250 and 1750 Hz, mixing samples of concrete with PET have a higher coefficient of sound absorption than ordinary concrete samples. This is because of the higher concrete density (Loong et al., 2020).

Arenas et al. (2015) found that porous concrete greatly improves sound quality by increasing the reflection of sound waves in the structural concrete on its own and converting sound energy into thermal energy because of its porosity.

Figure 6 shows the relationship between the compressive strength at 28 days and the sound absorbing coefficient. The mixed concrete sample with PET 0.5% gave the highest value of sound absorption coefficient and compressive strength among other samples. When increasing the PET content further, the compressive strength decreases (Loong et al., 2020).

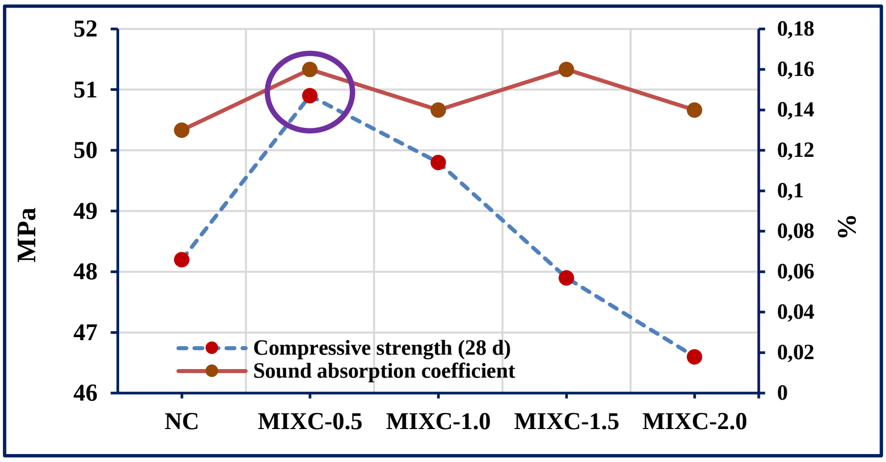

Figure 6. The relationship between sound absorption coefficient and compressive strength on 28 days for different samples.

3. Rubber

3.1 Properties of rubber-containing concrete

Chalangaran et al. (2021) compared three samples of concrete containing rubber crumb waste as fine grain aggregates with sizes ranging from 1 mm to 3 mm to a control sample in which 5, 10, and 15% by weight of the sand were replaced by rubber crumb waste only. Three samples of concrete, each measuring 150 mm by 150 mm and cured for 7, 14, and 28 days, were prepared to test the compressive strength of the samples. A w/c ratio of 0.29 was used.

The crumb rubber pieces made from car tire waste. The crumbs were divided into two sizes. The chemical components of rubber adopted in this study are natural rubber, styrene-butadiene rubber SBR, butadiene rubber, and butyl/halogenated butyl rubber, and their weight proportion respectively are 40%, 30%, 20%, and 10%. Crushed rubber products made from fine and coarse aggregates are referred to as PR and CR, respectively. The used gravel aggregate had a maximum size of 12.5 mm and a dry density of 1620 kg/m3. The largest size of the almond coarse gravel was 19 mm, and its dry density is estimated to be 1600 kg/m3 The concrete was spread uniformly and kept from clumping once more by the use of a superplasticizer. Furthermore, the mixing water was reduced by reaching 30% to increase the overall strength of the concrete. The water-cement ratio should be adopted at ≥ 0.4 when utilizing additives in the mix design of concrete to consider the high absorption of water by additives.

3.2 Creating aggregates from rubber waste

One of the key items produced from rubber is tires for various automobiles **Figure 7**. After the EoL the used tires are recycled by sorting them as rubber-based products and they will be typically crushed into powder or microscopic particles (Thomas et al., 2016; Li et al., 2020).

Figure 7. Tire Dump in Spanish Countryside Mountains (yahoo news photos).

Three main steps make up the bulk of the recycling process of waste tires. These steps are crushing, shredding, and grinding (Torretta et al., 2015; Isayev and Khait, 2005). Rubber particles ≥ 4.75 mm were commonly produced in this process using a rolling mill (grinding process). By using a rolling mill (crushing process), the particles of coarse rubber are transformed into fine particles of crumb rubber that have sizes ranging from 75 µm to 4.75 mm. To produce finer rubber powder with a size of 75 µm or smaller, a rotating colloid mill is used for grinding the rubber.

The so-called cryogenic grinding process is typically the primary procedure used to create crumb rubber and its grains are smoother than the grains resulting from using an ambient grinding process that has a spongy texture (Kim et al., 2018) **Figures 8a, 8b**.

There are two kinds of ambient grinding processes: air impact and water jet. Vulcanized rubbers are pushed through the nip gap of a shear mill or 2 mills at room temperature to decrease the particle size. When employing this grinding method, the milling temperature may increase to 130 °C, consequently, processing at room temperature cannot be indicated by ambient grinding. As there are more paths through the nip zone, the particle size gets smaller. The basic idea behind particle fragmentation is to build up enough kinetic energy so that they can collide with other particles and various instrument elements before finally breaking up into smaller pieces. By speeding the particles through the air jet in the ambient grinding process, kinetic energy is produced. Particles might also become separated by turbulence inside the mill. The system generates heat due to the overall effects of turbulence, an air circulation that is upside-down, and the energy stored by rubber particles; consequently, cooling of the system is required (Adhikari et al., 2018).

The fundamental idea for cryogenic grinding is to use liquid gases to turn rubbery, elastic chips into brittle materials. Typically, the rubbery substance under the glass transitional zone is cooled with nitrogen gas, and then the frozen, brittle material is crushed using a hammer mill to apply impact force. The rubber chips can be cooled either before or during the grinding process. Cryogenic grinding has a high output rate and low energy consumption. For cryogenically ground material, a pre-grinding and drying procedure is necessary, which raises the cost of processing overall. Nitrogen, an inert gas, aids in lowering the level of rubber chip surface oxidation (Adhikari et al., 2018).

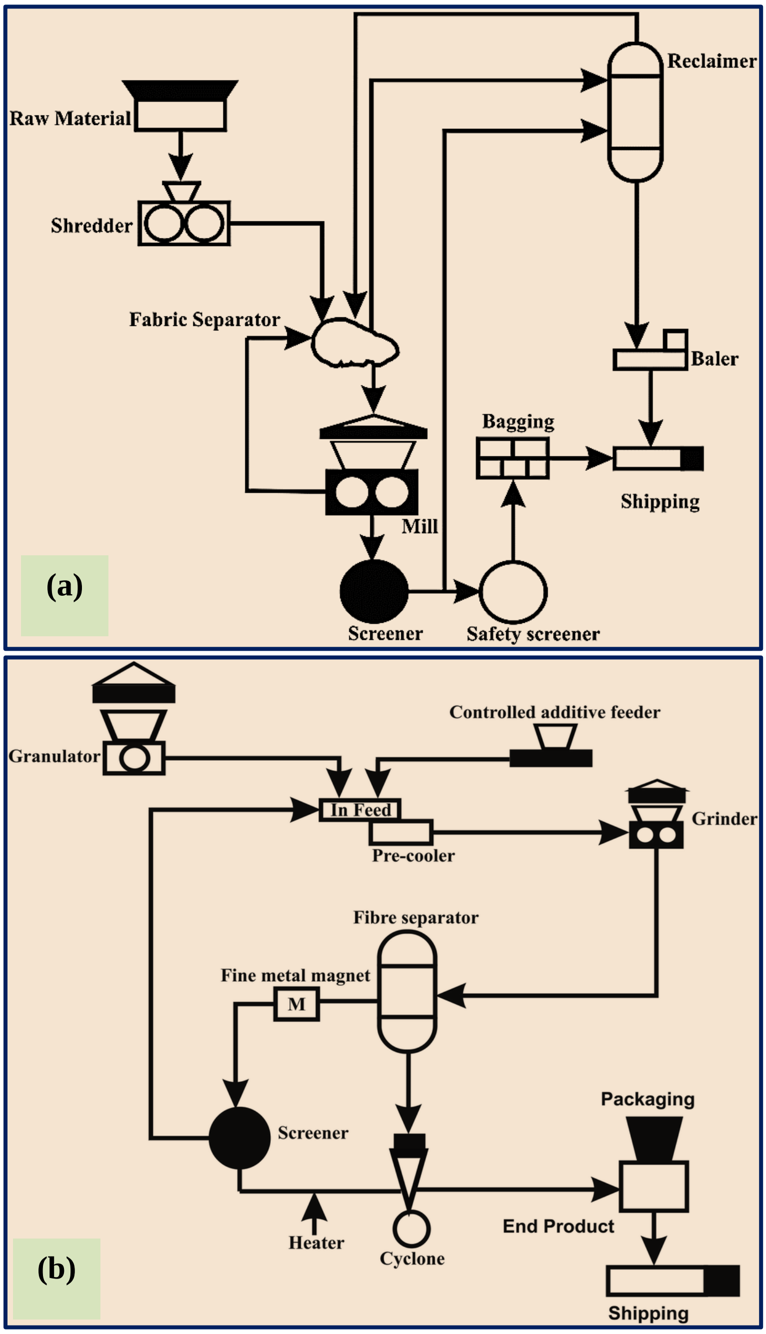

Figure 8. Graphic illustration of (a): ambient grinding; (b): cryogenic grinding (Modified after Isayev and Khait, 2005).

Chalangaran et al. (2021) evaluated several designs to lower the transmission of sound through concrete, where they used one sample of concrete as a reference sample. Then, they selected three samples of concrete mixed with fine aggregate of recycled rubber **Figure 9a** and another three samples mixed with coarse aggregate of recycled rubber **Figure 9b**. Recycled rubbers with percentages of 5, 10, and 15 replaced the fine and coarse aggregates in the mixture of concrete. The strengths of concrete on 7, 14, and 28 days were determined.

Figure 9. Crumb rubbers with grains of (a): fine; (b): coarse (Chalangaran et al. 2021).

Sukontasukkul (2009) studied many properties of concrete containing local crumb rubber of recycled tires. The properties were such as sound absorption, thermal resistivity, heat transfer, and so on. To prepare a lightweight mixture of crumb rubber with concrete CRC, Crumb rubber was used instead of the fine aggregates in percentages of 10, 20, and 30 by weight. This analysis was done using sieve No. 6 (3,35 mm in diameter) **Figure 10a**, sieve No. 26 (0,70 mm in diameter) **Figure 10b**, and sieve No. 6 + 26. The mix ratio of materials was determined at 1.00 cement: 0.47 water: 1.64 fine aggregate: 1.55 coarse aggregate for the control sample, which did not contain crumb rubber.

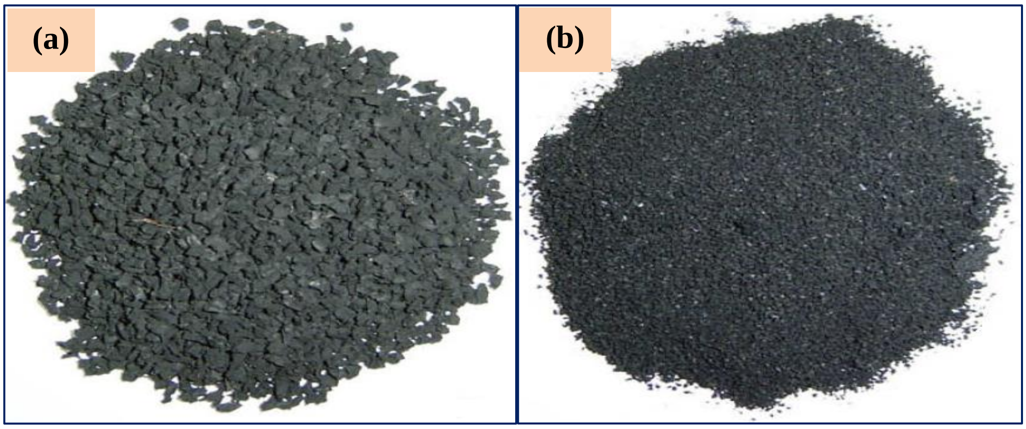

Figure 10. (a): Crumb rubber No. 6; (b): Crumb rubber No. 26.

Rubber waste has low density, and it is used therefore as lightweight aggregate. Nevertheless, its hydrophobic property leads to restrictions. The rubber particles are like plastic aggregates and have surfaces that are flexible and smooth. These properties contributed to the deterioration of the interface bonding of the cement paste with the rubber particles. Pretreating rubber aggregates using a chemical approach has been recommended to overcome this problem. The most popular treatment method is the treatment using NaOH solution because it can create a high alkaline environment surrounding the particles of rubber that helps increase the following: hydraulic conductivity, the transfer rate of water between cement and rubber, interface-hydration, all of which increase the adhesion between the rubber and cement (Youssf et al., 2016).

Additionally, this process improves the rubber aggregate's hydrophilicity, resulted in a thin water layer and increased the porosity of the Interfacial Transition

Zone ITZ between rubber particles and cement paste (Guo et al., 2017). Similar results were also observed when the rubber particles were treated with a hydrochloric acid solution (Tian and Zhang, 2011). Other studies, however, found that, while NaOH treatment increased the compressive strength significantly. The rubber's hydrophobic properties were unchanged, with the hydrophilic nature of rubber surface being higher than 90°. (Mohammadi et al., 2016). For generating a great strong chemical interaction between rubber and cement. He et al. (2016) proposed using a more advanced pretreatment method to introduce strong polarity groups to the rubber surface to strengthen the chemical connection between rubber and cement. According to the Fourier-transform infrared spectroscopy FTIR results, the pretreatment significantly decreased the thickness of the water film and contact angle, improving the adhesion strength.

3.3 Evaluation of sound transmission loss of rubber aggregate

Generally, two common measurement techniques are used to evaluate the loss of sound transmission through concrete. The first approach involves determining the sound transmission class, while the second method involves using an impedance tube to compute the transmission loss (Gholami et al., 2014).

There are currently just a few primary ways for determining how much sound is absorbed by different materials. They found that the transfer impedance tube test can provide a more accurate estimation of the sound transmission loss when compared to other methods (Yousefzadeh et al., 2008).

The methods and materials adopted in this research are intended to reduce sound transmission loss through concrete without significantly affecting its mechanical qualities. Sound-absorbing materials can be efficiently developed to prevent the harmful effects of noise, e.g. by reducing noise transmission from public roads to residential communities.

According to Chalangaran et al. (2021), the results showed that samples with 15 percent fine crumb rubber had a reduction in sound transmission up to 190%, while samples with 15% coarse crumb rubber had a reduction in sound transmission up to 228%. In comparison with 15% of fine rubber crumbs, 15% of coarse rubber crumbs improved the sound loss by 18% on average. This proved that coarse aggregates were successful in reducing sound transmission loss even though having a detrimental impact on compressive strength. Using the same test, samples with 5% and 10% crumb rubber have significant effects on improving so-called environmental noise absorption. The studies used frequencies ranging from 63 and 6300 Hz, although the most harmful impacts of noise pollution on the human body occur between 4000 and 20,000 Hz, where concrete containing rubber crumbs significantly reduces sound transmissions (Farzampour, 2017).

According to Chalangaran et al. (2021), the sound transmission loss increases when more fine-grained rubbers are used. The frequency from 2000Hz to 6300Hz is significantly reduced in the sample with 15 percent more coarse-grained rubber than in the other samples. The sound transmission loss is then increased by approximately 8%

generally at frequencies from 63Hz to 1400Hz by adding additional 5% of fine rubber crumbs as a replacement for the sand particles in the concrete mixture.

However, the compressive strength of the samples containing fine rubber crumbs CRC decreased compared to the control concrete CC sample without adding rubber **Table 1**.

Table 1. Compressive strength of control sample and samples with different content of fine crumb rubber (Modified after Chalangaran et al., 2021).

Sample	Compressive Strength (MPa)		
	7 days	14 days	28 days
CC	47	48	51
CRC5	38	41	41
CRC10	29	34	34
CRC15	24	26	26

The sound transmission loss STL values for control concrete CC and the mixture of concrete with crumb rubber CRC using various percentages at a range of frequencies from 63 to 6300 by applying different methods to obtain STL values can be seen in **Figure 11** (Loong et al., 2020).

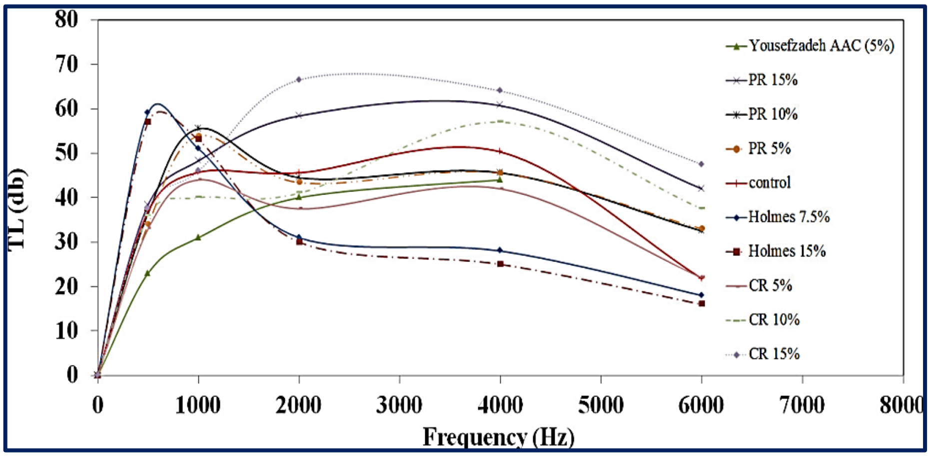

Figure 11. Sound transmission loss values for different samples of CC and CRC with various percentages of crumb rubber, applied various methods to obtain STL (Loong et al., 2020).

Chalangaran et al. (2021) found that the sound transmission test utilizing an impedance tube has various disadvantages, moreover, some restrictions when using two rooms or impedance tubes for testing. Because of the tube's physical length restriction, the results from the low-frequency side of an impedance tube did not give accurate results from the high-frequency side.

Additionally, researchers found that adding recycled rubber crumbs to concrete might significantly increase its ability to absorb outside noise. In addition, because this sort of concrete works well at a higher frequency, it can be used in structural applications close to motorways, such as airport waiting areas, to decrease STL without compromising the concrete's strength properties.

Sukontasukkul (2009) measured the sound absorption and coefficient of sound absorption, using an impedance tube device (ISO 10534-1:1996), with the mixture of concrete with crumb rubber using two different ranges of frequency. The first frequency was low to mid with frequency values of 125, 250, and 500 Hz, while the second frequency was high with frequency values of 1000, 2000, and 4000 Hz.

The crumb rubber with concrete (CRC lightweight concrete) seemed to have the best sound absorption properties to that of the control sample of Portland concrete CPC, although our results were inconclusive at the lower frequency range. Both samples of control concrete and CRC had similar sound absorption at the low frequency of 125 and 250 Hz. However, the CRC started to exhibit slightly higher sound absorption at the mid-frequency of 500 Hz. At frequencies over 1000, 2000, and 4000 Hz, respectively, the samples of CRC had significantly higher sound absorption than the sample of CPC, Table 2 (Sukontasukkul, 2009). The highest values of the sound absorption for samples among all frequencies were at a frequency of 1000 Hz.

Table 2. Mean coefficient of sound absorption (Modified after Sukontasukkul, 2009)

Samples	**Freq. (125 Hz)**	**Freq. (250 Hz)**	**Freq. (500 Hz)**	**Freq. (1000 Hz)**	**Freq. (2000 Hz)**	**Freq. (4000 Hz)**
CPC	23	11.5	6.8	24.5	9.1	20.1
6CRC**10**	23	12	12.1	31.5	17	25
6CRC**20**	23.5	11.3	9.5	37	15.1	24
26CRC**10**	24.5	11	10	26.5	16	27.5
26CRC**20**	24.5	11.3	9.3	29	23.5	27.1
6+26CRC**10**	25.1	11.5	9.5	29	15.1	24.8
6+26CRC**20**	25.5	12.2	13.5	30.1	20.3	30

According to Sukontasukkul (2009), **Figure 12** showed the coefficients of noise reduction values for a mixture of crumb rubber samples with concrete CRC compared with the sample of control Portland concrete CPC.

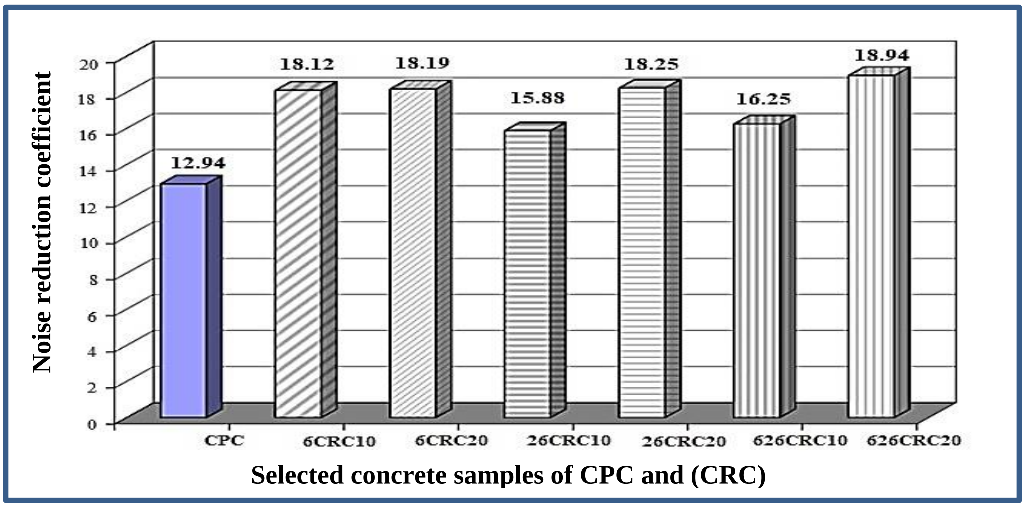

Figure 12. Coefficients of noise reduction for the selected samples (Modified after Sukontasukkul, 2009).

Moreover, the time of the traveling wave was studied by Issa and Salem (2013) to determine a material's sound absorption capacity. They found the best sound absorption was achieved by a longer travel time value. It was discovered that adding more rubber to concrete improved its capacity for sound absorption. According to the test conducted by Grdic et al. (2014), concrete containing 20% and 30% rubber aggregate each saw a wave velocity reduction of 14% and 21%, respectively, and these results corresponded with Khaloo et al. (2008).

Zhang and Poon (2018) replaced all fine furnace bottom ash FBA as a part of a lightweight aggregate concrete mixture with a recycled rubber aggregate, where the lightweight control mixture contained coarse aggregate (expanded clay) and fine aggregate (furnace bottom ash). According to the findings, a total level of 32.5 dBA sound reduction was determined, which is much more than the 15.5 dBA level attained by the control mixture without rubber aggregates. The surface of the recycled rubber aggregate was then modified by developing a technique of cement slurry coating pretreatment. When FBA was substituted with percentages of 50 and 75 by the modified rubber aggregates, respectively, a further reduction of noise of 10.9 dBA and 14.8 dBA was obtained. According to the finding, the pretreatment process resulted in the formation of a weak bond between the cement paste and the rubber aggregates, which increased the vibration absorption capacity and improved the noise insulation properties of the concrete.

4. Further properties of Plastic and rubber aggregate

4.1 Thermal insulation

Thermal insulation is considered very important in the construction of buildings in different regions especially in cold and hot regions to provide a suitable environment for residents. Using recycled waste material can even lead here to a reduction in cost.

Yesilata et al. (2009) conducted an experimental study to determine how adding polymeric waste material affected the insulating properties of ordinary concrete. Shredded polyethylene PET bottles as well as vehicle tire fragments, which are easily and inexpensively obtained were mixed with ordinary concrete to study specimens' heat insulation characteristics. Five separate samples of concrete were studied. The first sample included just ordinary concrete, the second sample consisted of mixing concrete with rubber waste pieces, and the three other samples had PET bottle pieces (square, strip, and irregular) in varying configurations with concrete. The selected rubber pieces were double as thick 2 mm as PET pieces. The effect of the additions on the concrete samples for thermal transmittance was compared using the adiabatic hot-box method. The results showed improvements in insulation properties brought by the addition of waste polymeric components to normal concrete. The insulation improvement of square rubber pieces was 18.52%, while the insulation improvement for pieces of PET square, PET Strip, and PET Irregular were 10.27%, 17.11%, and 17.16% respectively.

4.2 Workability

4.2.1 Plastic aggregate

The major conclusions of many previous tests showed that the friction between the irregular shapes of plastic particles determined the workability of the concrete-plastic aggregate mix, where the workability was affected highly by the shape and amount of the aggregates (Li et al., 2020). Rahmani et al. (2013) discovered that the flaky shape of PET waste affected the fluidity of concrete and reduced the workability of mixing concrete with PET waste.

As the amount of plastic waste in the mixture increased, the decrease in workability became more pronounced. When the amount of plastic was increased to 15%, there was a 42% loss in workability. Using plastic crumbs of various shapes, Rai et al. (2012) achieved a comparable effect. The impact of recycled plastic particles on workability was covered well by Silva et al. (2013). They found that the loss of workability can be compensated for by adding a small number of additives to the concrete before mixing it with plastic particles.

When differently shaped aggregates made of PET were mixed with concrete the results indicated that spherical and regular shaped aggregates improved the workability whereas angulate and lamellar shapes led to the resulting concrete having lower workability. The interpretation for the case above is related to the variance in internal friction between the binder material (cement) and the plastic aggregate in various shapes. According to Ferreira et al. (2012) and Coppola et al. (2016), the higher porosity of the concrete due to increased particle size and roughness - led to further hampering the workability of the concrete. Ismail and Al-Hashmi (2008) noted that the addition of plastic-based aggregates of 10 and 25 weight % of concrete led to reducing the workability of the mixture to approximately 13% and 27%, respectively.

4.2.2 Rubber aggregate

According to earlier research, adding rubber aggregates to concrete reduced its workability, which was again mainly affected by the amount of rubber and the size of rubber particles (Li et al., 2020). Bisht and Ramana (2017) found that even by using a low crumb rubber aggregate percentage of less than 5% (size 0.6 mm), the workability of the concrete was decreased. A higher percentage of crumb rubber aggregate from 0 to 20 mm-sized particles led to a greater decrease in workability. The workability could be reduced by 34% for concrete with 100% of the aggregates being rubber-based (Raffoul et al., 2017).

However, if only 30% of the sand were replaced by rubber aggregate, the mixture would still be adequately workable for casting, mixing, and vibrating fresh concrete (Youssf et al., 2014; Angelin et al., 2017). However, different research presented conflicting results. As an example, Mendis et al. (2017) tested the workability of many mixtures for various ratios of rubber with concrete and they found the workability increased when the rubber content was in the range of 5 - 25%.

4.3 Density

4.3.1 Plastic aggregate

The density decreased by 23% when concrete contained 35% of plastic aggregates in contrast to the normal concrete sample's density, which was 2156kg.m^{-3}. When the concrete was blended with 50% PET fine aggregate the density decreased by 37.5%, reached a value of 1500 kg/m^3 (Safi and Saidi, 2013). Moreover, the density decreased to the range of 4 - 10% when natural coarse aggregates were replaced by PET coarse aggregates at a volume ratio of 20 to 50%. (Islam et al., 2016). This is because the plastic aggregate's density being around 70% lower than sand's. Compared to 2.61 for sand, the specific gravity for plastic aggregate ranged between 0.9 to 1.34, significantly.

4.3.2 Rubber aggregate

The density of concrete was reduced by approximately 28% when crumb rubber was replaced with fine aggregate at percentages of 10 to 30% by weight (Asutkar et al., 2017). Compared to the density of concrete mixed with crumb rubber samples, which was reduced from 2130 to 1900 kg/m3, the density of normal concrete was 20% lower (Gesoglu et al., 2017). The densities decreased by approximately 17, 18, 21, and 28% when crumb rubber was replaced with fine aggregate sand in the mixture with concrete at percentages of 10, 20, 30, and 40, respectively (Gisbert et al., 2014). The reduction was primarily due to the rubber aggregate's lower density about 0.51 to 1.2 g/cm3 relative to sand because it has a density almost twice as high (Li et al., 2020).

4.4 Compressive strength

4.4.1 Plastic aggregate

According to Li et al. (2020), many properties such as size, form, and composition of the plastic aggregate, together with its hydrophobic and non-hydrating qualities, have given a significant impact on the compressive strength. Generally, with an increase in the percentage of PET aggregate, the concrete's compressive strength decreases. Concrete's decreased strength was related to the development of honeycombs and the kind of failure (Albano, 2009).

The inclusion of plastic-based aggregate also decreased the formation of hydration products in the transition zone between interfacial areas., which in turn reduced the compressive strength and the bonding between plastic particles and the cement matrix (Gesoglu et al., 2017). Finer plastic aggregate with sizes ranging from 0.18 to 2 mm contained fewer voids, which could decrease the loss of compressive strength (Coppola et al., 2016).

Yang et al. (2015) found that the compressive strength of a mixture of plastic particles with a length of 1.5 - 4 mm less than 20% with self-compacting concrete that was used in casting short columns, was somewhat increased because some holes in concrete could be filled by the plastic particles that have a small volume. Therefore, to avoid a significant reduction in compressive strength, the percentage of plastic waste that mixes with concrete should be less than 20%. In addition, as the plastic aggregate volume got bigger, the interface bond of the aggregate matrix was weaker, which has a detrimental impact on the compressive strength.

Many researchers studied mixing PET with other materials. The compressive strength of mixing clay-fired bricks with PET at different percentages of 0, 5, 10, 15, and 20 were tested. The results showed that adding 5% PET increased the compressive strength to 2.30 MPa, but adding 10% PET reduced the compressive strength to 0.85 MPa (Akinyele et al., 2020). Melted PET in percentages of 20, 30, and 40% were mixed with recycled crushed glass to make masonry bricks. Clay bricks had compressive strengths of 14 MPa, 33.45 MPa at 20%, 43.14 MPa at 30%, and 38.25 MPa at 40%. (Ikechukwo and Shabangu, 2021). Azhdarpour et al. (2016) found the compressive strength for mixing fragments of plastic waste of 5% after 3 days, 14 days, and 28 days of curing increased to 21 MPa, while it decreased when using percentages of >5%. Hameed and Fatah Ahmed (2019) using flakes of PET with percentages of 1, 3, 5, 7, and 10, found that only the percentage of 1 had the best compressive strength of 20.72 MPa compared with other percentages **Figure 13**. At 1wt.% of PET, the value of compressive strength for the mixture increased but decreased when further increasing the content of waste plastic aggregate. This phenomenon may be because of poor adhesive strength between the surface of the plastic and the cement paste.

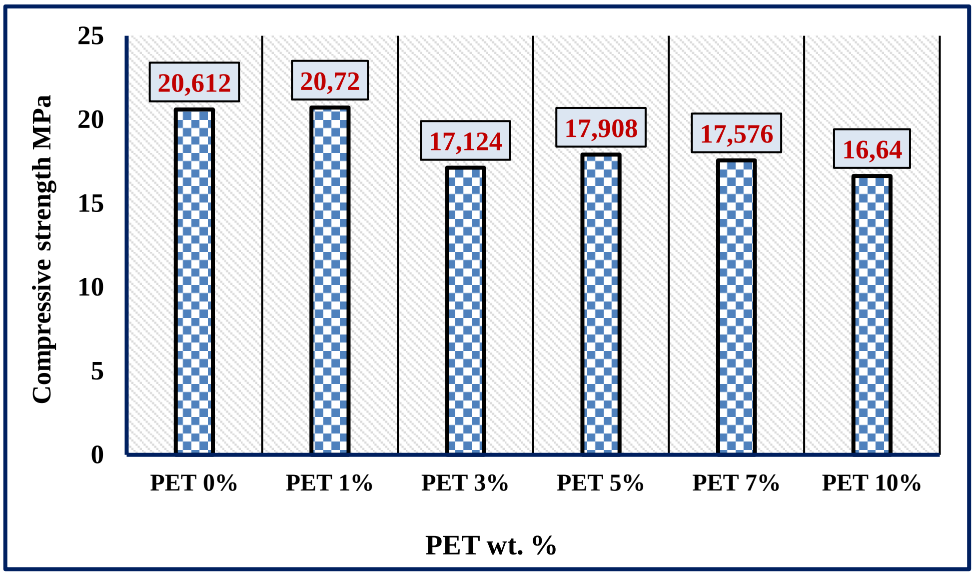

Figure 13. Change in compressive strength with different percentages of plastic aggregates (Hameed and Fatah Ahmed, 2019).

4.2.2 Rubber aggregate

The major cause of the strength drop in the compressive strength of crumb rubber is thought to be the weak stiffness of the rubber (Li et al., 2020). Many physical properties of crumb rubber mixed with cement have a significant impact on the strength of the concrete. The rubber aggregate's deformation has the behavior like soft aggregate, so, Aiello and Leuzzi, 2010 found that using a coarse aggregate with the size of 12.5 - 20 mm led to a higher drop in compressive strength compared to employing fine aggregate with a size of 10 to 12.5 mm. (Aiello and Leuzzi, 2010). The largest reduction in 7 days' compressive strength of nearly 74% was noticed when using 100% of rubber aggregate (Reda et al., 2008). Additionally, it was noted that because the size of the rubber aggregate (chip) was bigger than the crumbed rubber, there was dropped in compressive strength when using chipped rubber compared with using crumbed rubber.

Pretreatment can be used to reduce the negative effects through the increase of the hydrophilicity of the rubber aggregate, creating a surface that is comparatively rough and porous to strengthen the bonding between the matrix of the cement and the rubber particles (Tian et al., 2011). The impact of several treatment methods was investigated by Guo et al. in 2017. They discovered samples of rubber with NaOH-treated rubber and also rubber that had been treated with Na_2SiO_3 and covered by cement displayed lower compressive strength compared with rubber samples that had not been treated. He and colleagues (2016) have shown how crumb rubber's surface properties using solutions of $NaHSO_3$ and $KMnO_4$ could decrease the negative impact on the compressive strength of concrete. They demonstrated that modified rubber of 4% mixed with concrete had a compressive strength that was 48.7% more than the concrete mixed with untreated rubber. Furthermore, the addition of an increased quantity of 10 to 50% of NaOH-treated crumb rubber aggregate resulted in a 17.7 to 72.2% reduction in the 7-day compressive strength. (Youssf et al., 2017).

5. Conclusions, Discussion, and Recommendations.

Many researchers studied the properties of concrete after replacing the whole or part of the coarse or fine aggregates with plastic and rubber pieces. This study dealt with sound insulation as the main objective through reviewing previous studies in this field. Moreover, reviewing also some other properties such as thermal insulation, the density of concrete, compressive strength, and workability.

The sound insulation of adding plastic PET with 0.5, 1.0, 1.5, and 2.0% by volume showed that after 28 days of curing, the samples of mixed concrete with PET 0.5 and 1.5% had the highest value of a sound absorption coefficient of 0.17% at the frequency of 1750 Hz. The optimum value of the sample for mixing concrete with PET was 0.5%. This value achieved the highest value of sound absorption coefficient and compressive strength compared to other samples. The compressive strength decreased when increasing the percentages of PET **Figure 6**.

All percentages of mixing PET with concrete at 7-day showed the highest sound absorption coefficient at a low sound frequency of 250 Hz due to concrete's sound absorption coefficient being frequency-dependent. When compared to PET concrete, normal concrete had the lowest sound absorption coefficient. Comparing the combination to normal concrete, there wasn't any noticeable change. Therefore, this suggests that PET fiber has some sound absorption capacity (Loong et al., 2020).

For all frequencies, the coefficients of sound absorption for mixing PET with concrete were higher than that of normal concrete. This is because of the reduced density of the concrete, where porous concrete considerably improves acoustic performance by increasing the waves of sound reflection in the concrete structure and due to porosity converting the energy of sound into heat.

When three rubber samples of 5, 10, and 15% were used to test sound insulation, the coarse rubber crumbs sample of 15% improved sound transmission loss by about 18% when compared to the same percentage of fine crumbs rubber (Chalangaran et al., 2021). This means that adding more rubber to concrete improved its sound absorption capacity, which was confirmed by many researchers in their studies.

At high frequencies of 1000, 2000, and 4000 Hz, especially frequency of 1000 Hz, the samples with different contents of crumb rubber with concrete had significantly more sound absorption than the sample of control Portland cement concrete **Figure** 14 (Sukontasukkul, 2009).

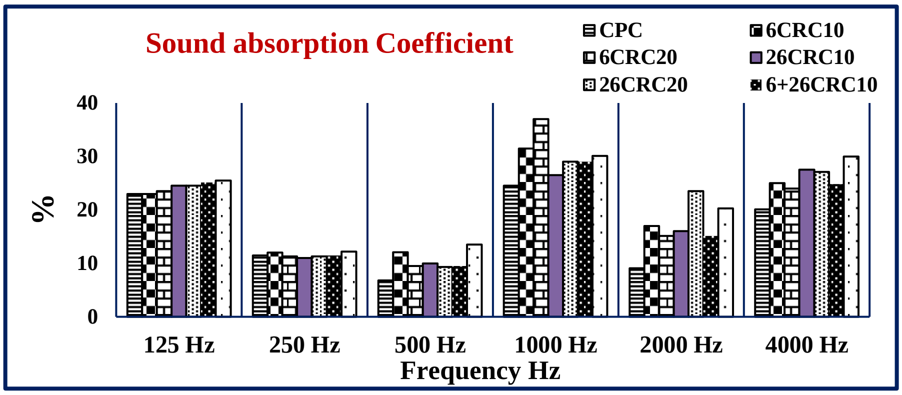

Figure 14. Sound absorption coefficients for the samples with different contents of crumb rubber at various frequencies (Modified after Sukontasukkul, 2009).

The coefficients of noise reduction values for a mixture of crumb rubber samples with concrete CRC increased compared with the sample of control Portland concrete (Sukontasukkul, 2009).

Table 3. Noise reduction coefficients for the samples with different contents of crumb rubber (Modified after Sukontasukkul, 2009).

Sample	Noise reduction coefficient
CPC control Portland concrete	12.94
6CRC10 coarse crumb rubber concrete with 10%	18.12
6CRC20 coarse crumb rubber concrete with 20%	18.19
26CRC10 fine crumb rubber concrete with 10%	15.88
26CRC20 fine crumb rubber concrete with 20%	18.25
6+26CRC10 mix crumb rubber concrete with 10%	16.25
6+26CRC20 mix crumb rubber concrete with 20%	18.94

For compressive strength, the mixing of rubber aggregate with concrete led to a decrease in compressive strength. This was essential because the cement matrix and the rubber with a smooth surface had a weak bond, moreover, the rubber itself had a low strength, and there were voids in the mixture.

The compressive strength of the samples containing fine rubber crumbs with concrete CRC was lower than the control concrete CC sample. When a high amount of rubber crumbs mixed with concrete was used, the compressive strength decreased **Figure 15** (Chalangaran et al., 2021).

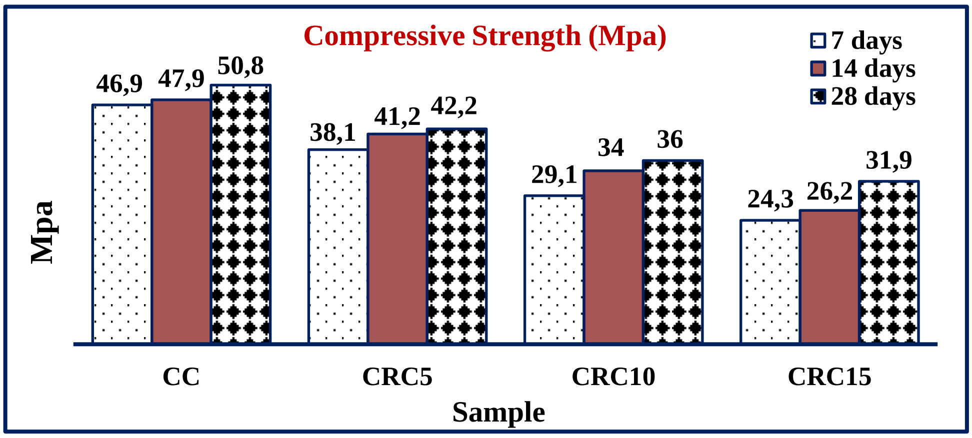

Figure 15. The compressive strength of the samples containing **fine** rubber crumb with control concrete (CC) sample (Modified after Chalangaran et al., 2021).

The compressive strength values of concrete containing PET with percentages of 0.5, 1.0, 1.5, and 2.0 % by volume were improved slightly compared with ordinary concrete after 7 and 28 days of curing. **Figure 16** showed that after using percentages higher than 0.5 of PET, the concrete's compressive strength trended to decrease due to reducing the adhesive strength between the cement and PET's surface (Loong et al., 2020). In contrast, the compressive strength for the mixture sample of cement and PET that has a length of up to 3 cm was improved when compared to PET with a length of 1 cm and 2 cm.

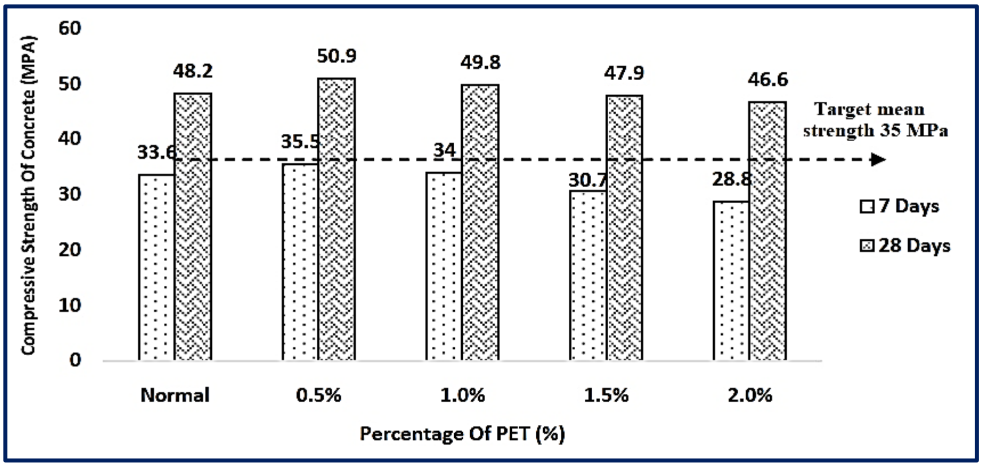

Figure 16. The compressive strength values of concrete containing different percentages of PET after 7 and 28 days of curing (Loong et al., 2020).

Depending on the kind and amount of the fine aggregate-crumb rubber used, the density of the concrete with crumb rubber decreased when the crumb rubber amount increased that was included in the mix (Sukontasukkul, 2009). Concrete containing rubber or plastic aggregate produces relatively similar densities as a consequence, and the density is linearly reduced as the amount of plastic or rubber aggregate increases. The density of plastic and rubber aggregate had been lower compared to sand, ranging from 0.51 to 1.2 g/cm3 and 0.9 to 1.34 g/cm3 respectively, as compared to 2.61 g/cm3 for sand. (Li et al., 2020).

Thermal conductivity coefficient values for a mixture of crumb rubber samples with concrete were higher than the value of the control Portland concrete sample (Sukontasukkul, 2009). Thermal insulation improved when higher amounts of rubber with square pieces were added. The thermal insulation was improved by increasing PET pieces. Irregular PET pieces improved the thermal insulation when mixed with concrete compared with square PET, and stripe PET respectively.

According to the literature, the workability has the same effect when adding the rubber and plastic aggregate to cement or concrete, whereas when adding a higher percentage of rubber and plastic aggregate to concrete the workability decreased highly and quickly. The workability of plastic aggregates was more affected by the shape and size of the particle. the rubber aggregate would show better workability than the plastic aggregate at the same replacement percentage. The pretreatment process and selecting the suitable amount added to concrete can be contributed to improving the workability of concrete.

Overall, the most common methods for disposing of non-biodegradable rubber and plastic waste are recycling and reusing. Although the addition of rubber and plastic to concrete reduced its compressive strength and workability, it decreased its density and improved the concrete's thermal conductivities, sound absorption coefficient, and sound transmission loss. Based on that, this type of concrete can be used in a variety of applications due to its superior sound and thermal insulation properties, while also containing materials such as rubber and plastic that would otherwise end up in landfills. The mechanical strength loss of concrete as a result of partial replacement of the aggregate with rubber or plastic can compensate by using pre-treatment with chemicals that enhance the bonding between the aggregate and cement paste.

5.1 Recommendations

Based on the literature, many suggestions can be considered for future studies that can give acceptable results when adding plastic and rubber to concrete. These suggestions are as follows:

1. Precast concrete structures built from these wastes are one the feasible applications, due to the mechanical strength and workability constraints.
2. Due to superior sound and thermal insulation, it can be used in residential, commercial, or educational buildings when sound insulation is significantly in demand.
3. The mixing of plastic and rubber waste aggregate with concrete could be employed in the parts of structures that require high sound and thermal insulating properties such as outside and inside concrete walls that need low loads or without loads on them, precast panels, concrete pavement, and concrete floors.
4. The recycled waste plastic and rubber, which have low cost, can be utilized to create lightweight concrete by adding recycled plastic and rubber instead of normal aggregate.

5. To improve the weak properties of concrete compressive strength and workability that resulted from mixing plastic and rubber aggregate with concrete, the chemical pretreating for plastic and rubber aggregate is an option NaOH, Na_2SiO_3, $NaHSO_3$ $KMnO_4$. Furthermore, silica fume can be used to enhance the mechanical and durability properties of concrete. It may be added directly to concrete as an individual ingredient or in a blend of Portland cement and silica fume. Silica fume is a highly pozzolanic material and the by-product of the ferrosilicon industry.
6. Future studies could focus on combining plastic and rubber waste with other materials to produce composite materials. Examples could be plastic-rubber wood fiber composites or mixing melted PET with recycled crushed glass to use in the building of bricks.
7. Investigating concrete properties especially sound insulation by using other percentages of recycled waste plastic and rubber to mix with concrete regardless of the percentages which were adopted to review in this study.
8. Studying comprehensive evaluation of the effects of recycling and reusing plastic and rubber waste as substitute materials on the environment with considering the economic side.

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