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# EVALUATING THE PERFORMANCE OF LIGHTWEIGHT CONCRETE WITH POLYETHYLENE TEREPHTHALATE WASTE

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**Article Info**

**Keywords:** Lightweight concrete, polyethylene terephthalate (PET), recycled plastic waste, coarse aggregate, compressive strength, sustainable construction, environmental impact.

**Abstract**

Concrete is the most widely utilized building material in civil engineering structures, with its normal variant consisting of natural coarse aggregates, making it heavy and susceptible to seismic effects. To address these issues and promote sustainability, lightweight concrete has emerged as a viable alternative. Lightweight concrete not only reduces the dead load of buildings, leading to cost savings and increased flexibility but also improves seismic response, enables longer spans, and reduces the ratio of reinforcement to foundation materials. However, the production of normal concrete using natural aggregates poses significant environmental concerns and depletes precious natural resources. To mitigate these impacts and ensure ecosystem preservation for future generations, alternative materials are sought. This study explores the use of processed plastic waste, particularly polyethylene terephthalate (PET) aggregates, as a replacement for coarse aggregates in lightweight concrete production. By recycling plastic waste into lightweight aggregates, the environmental burden of plastic disposal is reduced, offering a sustainable waste management solution. The researchers employed PET plastic waste collected from used bottles, heated it to a liquid state, poured it into molds, and subsequently crushed it to obtain coarse aggregates. These PET aggregates were incorporated into the concrete mix design, comprising 25%, 50%, and 100% of the volume of coarse aggregates. Various mechanical and physical tests were conducted on the hardened lightweight concrete to assess its performance. Compressive strength, split tensile strength, water absorption, rebound hammer, and ultrasonic pulse velocity tests were carried out to evaluate the material's suitability for structural applications. Previous studies on the use of recycled waste plastics in

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concrete were also discussed for validation purposes. The results demonstrated that PET aggregate incorporation led to changes in the concrete's properties, with variations in compressive strength and split tensile strength observed based on the percentage of PET aggregate used and the water-cement ratio. The concrete's water absorption and other characteristics were also affected by the presence of PET aggregates. These findings suggest that PET waste can be effectively utilized to produce lightweight concrete, paving the way for eco-friendly construction practices that minimize environmental impact.

## 1. Introduction

The most commonly used building material in civil engineering structures, both as structural and non-structural elements, is concrete with a unit weight of 2200 kg/m3 to 2500 kg/m3, referred to as normal concrete. Natural coarse aggregate comprises about 60–75% of the volume of normal concrete, thus providing a considerable self-weight that affects the total dead load of a building [1][2]. The heavy weight of the building will make it vulnerable to the effects of earthquakes. The use of Lightweight concrete in multi-story buildings results in significant weight reduction, which increases flexibility and saves costs. Lightweight concrete also enhances the seismic response of the structure, allows for longer spans, and reduces the ratio of reinforcement to foundation materials.

Then, the use of natural coarse aggregates in the production of normal concrete can significantly attack the environment and deplete natural resources. To ensure the preservation of the ecosystem for upcoming generations, it is crucial to decrease the use of natural aggregates [4]. Processed plastic waste is one of the alternatives to coarse aggregate used in the manufacture of concrete that will produce a unit weight of less than 2200 kg/m3 since plastic has a smaller specific gravity than natural aggregate.

The majority of plastics are not biodegradable, thus they can survive for many years or even centuries in the environment. Consequently, recycling plastics into lightweight aggregates is the best way to manage plastic waste and reduce its adverse impacts on the environment [4]. As the advantages of waste management is more widely recognized, numerous studies have been done to identify natural raw materials that can be utilized as a form of coarse aggregate in the production of lightweight concrete. Waste PET (polyethylene terephthalate) is one raw resource that has garnered interest.

Researchers have looked into the potential for employing recycled waste plastic as aggregates in concrete. [5]–[7]. Rahmani et al., (2013) using polyethylene terephthalate (PET) waste to replace fine aggregate by 5%., found that compresive strength increased by 8.86% when water to cement (w/c) ratio was 0.52, and compresive strength increased by 11.97% when w/c ratio was 0.42. In this context, the validation of the use of recycled waste plastics in concrete production is discussed in detail by Almohana et al., (2022) [8].

This study was conducted to produce lightweight concrete by using aggregate from polyethylene terephthalate (PET) plastic waste as a substitute for coarse aggregate. Used bottle plastic is heated to a liquid state and poured into molds; after cooling, the plastic is crushed to obtain coarse aggregate. PET aggregates were utilized as 25%, 50%, and 100% of the volume of coarse aggregates in the concrete mix design. Compressive strength, split tensile strength, water absorption, rebound hammer, and ultrasonic pulse velocity tests were then conducted on the hardened concrete.

## 2. Literature Review

### 2.1. Lightweight Aggregate Concrete

Using lightweight aggregate concrete (LWAC) in building has a number of advantages. The self-weight of high-rise buildings is reduced, which can lead to significant cost savings [2]. LWAC is a good material for a variety of applications since it also displays outstanding performance under fire and cryogenic environments [9].

There are a lot of different types of lightweight aggregates used to produce lightweight concrete, and they can be divided into two groups according on their source: artificial and natural [9]. Pumice, volcanic cinders, and palm kernel shell are examples of natural lightweight aggregates. Expanded clay, shale, slate, waste plastic and diatomaceous earth are examples of manmade lightweight aggregates.

Based on some research, After an evaluation of the viability of using palm kernel shell in place of conventional aggregates in concrete, it has been determined that palm kernel shell is a potential replacement for coarse aggregate in the construction of mortar and concrete [10] [11]. Palm kernel shell has good mechanical qualities and can withstand compressive loads of up to 14.02 N/mm$^2$ when used as a lightweight aggregate in concrete.

According to Hasan's research, lightweight concrete developed of chunk-shaped diatomaceous earth has a density that ranges from 1121 kg/m$^3$ to 1181 kg/m$^3$, however due to its low strength, it is limited to use as insulating materials and non-structural elements. Concrete composed from river sand as the fine aggregate and diatomaceous earth pellets as the coarse aggregate has a density of 1832 kg/m$^3$ and is categorized as lightweight structural concrete based on its strength [13].

In the last 50 years, plastic production has increased dramatically, and its use has become a crucial aspect of our daily life. Because of this, there is a rise in the production of plastic-related waste, which harms the environment. This urges scientists to utilise this waste as a sustainable substance for producing concrete. The aggregate, which makes up the majority of concrete's weight and weighs 85% of it, is the biggest and heaviest component. In addition, the density of the plastic is lower than that of the aggregate. The effectiveness of thermal and sound insulation in lightweight concrete can be greatly increased by substituting plastic trash for up to 75% of the total aggregate. Plastic may also be manufactured at significantly lower costs than regular concrete, and because it is lightweight, it can be erected and used more rapidly and with less work. Plastic trash might be viewed as a typical material for making lightweight green concrete, which could be used as a non-structural element in building construction.

In general, using plastic aggregates at all curing ages, the comprehensive strength decreased as the waste plastic ratio increased. This can be explained by the weakening of the bond between waste plastic and cement paste. There seems to be a tenuous connection between the cement paste and plastic particles [14].

Based on ACI Committee 213R LWACs are classified based on their density and strength, namely [15]:

1. Low density concrete with a density of 400 kg/m$^3$ - 800 kg/m$^3$ and a compressive strength of 0.69 MPa - 6.89 MPa
2. Moderate strenght concrete a density of 800 kg/m$^3$ - 1400 kg/m$^3$ and compressive strength of 6.89 MPa - 17.24 MPa
3. Structural Lightweight Concrete with a density of 1400 kg/m$^3$ - 1900 kg/m$^3$ and compressive strength values > 17.24 MPa.

**2.2. Polyethylene Terephthalate**

J. Rex Whinfield and James T. Dickson of the Calico Printers Association created PET for the first time in England during a phthalic acid investigation that was started in 1940. Patent specifications for the new material were not immediately disclosed due to constraints imposed during the conflict. It took Imperial Chemical until 1954 to start manufacturing PET fiber under the Terylene name. In the meantime, DuPont had independently created a useful terephthalic acid preparation method by 1945, and the business started making Dacron fiber in 1953 [16]

PET is a form of plastic that is frequently used for food and beverage packaging, including containers for ketchup, salad dressing, peanut butter, and soft drinks, sports drinks, water, [17] [18]. It is advised not to be used as a hot water container and is only to be used once [4]. PET is recyclable and has received FDA approval for food contact [17]. It is a transparent, durable, and lightweight plastic that is frequently utilized to package water and convenience-sized beverages [19].

In 2015, the world produced around 6,300 metric tonnes of plastic waste. Only 9% of this waste was recycled, while 12% was incinerated. Shockingly, 79% of the plastic waste ended up in landfills or the natural environment. If we continue with the current production and waste management practices, it is estimated that by 2050, the amount of plastic waste in landfills and the natural environment will increase to approximately 12,000 metric tonnes [20].

Recycled PET can be used as a partial substitute for sand or fine natural aggregates in concrete production at certain replacement rates, resulting in eco-friendly concrete with reduced self-weight in structures. The use of recycled PET in construction materials, such as concrete, has grown in recent years. Studies have shown that PET can be used as a partial substitute for sand in concrete up to 50% [2][8] [21].

## 3. Methods

### 3.1. Materials

The study utilized Portland cement type I from PT Semen Andalas, along with fine and coarse aggregates in the form of natural sand and river gravel from Krueng Mane in North Aceh Regency. PET type A1 plastic bottle waste was obtained from a plastic waste processing warehouse in Kutablang, Bireuen Regency. The water used in the concrete mixture was sourced from the Civil Engineering Department Laboratory, Universitas Malikussaleh. **Table 1** shows the physical properties of the materials used in this study.

**Table 1**. Physical properties of concrete constituent materials

| Description | Natural sand | River gravel | PET |
|---|---|---|---|
| Nominal size (mm) | 4,75 | 19 | 19 |
| SSD | 2,59 | 2,59 | 1,28 |
| Spesific grafity OD | 2,57 | 2,56 | 1,27 |
| Absorption (%) | 1,66 | 1,28 | 0,63 |
| Moisture content (%) | 2,23 | 1,34 | 1,01 |

### 3.2. PET Aggregate Manufacturing Process

To produce PET aggregate, the process begins by melting the PET Plastic bottle cuttings and heating sand to 260°C (**Fig. 1**b). The melted PET is combined with hot sand and stirred to prevent clumping before being poured into a mold to harden. Once hardened, the mixture of PET and sand is released from the mold and left to cool for 24 hours. The hardened mixture is then crushed to create coarse aggregate. Next, the PET aggregate is screened through sieve size 19 mm and 4.75 mm, with only the portion that passed through sieve 19 mm but was retained by sieve 4,75 mm being utilized for concrete mixtures (**Fig. 1**c).

(a)

(b)

(c)

**Fig 1.** PET aggregate production processes. (a) PET Plastic bottle cuttings (b) PET melting process; (c) PET aggregate after sieving

### 3.3. Mixtures Proportion

For the purpose of testing, 40 cylinders measuring 150 mm by 300 mm were prepared. The proportion of the concrete mixture was calculated using the SNI 7656-2012 [22] method with a water-cement ratio of 0.58. The substitution of gravel with PET aggregate is calculated by the absolute volume method. The percentages of PET aggregate substituted in the concrete mix were 25%, 50%, and 100%. target compressive strength of 20 MPa and a slump of 25 mm to 100 mm. Mix design is carried out to obtain mix proportions that meet the requirements of plasticity, density, strength, durability, and economy. The mix design specifications or requirements for concrete to be produced can be based on the following provisions: a. Maximum water cement ratio;

b. Minimum cement content;
c. Air content;
d. Slump;
e. Nominal aggregate size; and
f. Targeted compressive strength

In compliance with the above provisions, the required proportion to produce 1 m$^3$ of concrete was determined and tabulated in **Table 2**.

**Table 2**. Proportion of constituent materials

The proporsion of 1 m$^3$, w/c 0,58

| Concrete type (% Substitution) | Cement (kg) | Water (kg) | Natural sand (kg) | River gravel (kg) | PET (kg) |
|---|---|---|---|---|---|
| NC (0%) | 322,41 | 181,90 | 809,03 | 997,18 | 0 |
| PET-1 (25%) | 322,41 | 181,53 | 809,03 | 758,04 | 128,77 |
| PET-2 (50%) | 322,41 | 181,27 | 809,03 | 496,64 | 244,65 |
| PET-3 (100%) | 322,41 | 180,60 | 809,03 | 0 | 497,01 |

### 3.4. Sample Preperation and Curing

A laboratory mixer is used to mix all the ingredients, which have been measured according to their proportions, from the dry mixture to the wet mixture (**Fig 2**a). This ensures that the mixture is perfectly uniform and homogeneous. A standard steel cylinder mold of 150 mm by 300 mm was used to produce 10 test specimens for each type of mixtures. Three layers were cast and each layer had 25 compaction cycles with an iron rod. A thin layer of cement paste was applied to the specimens in the final stages of casting. This was done to ensure a smooth and uniform surface. All 40 were removed from the steel mould after 24 hours and immersed in ambient water for up to 28 days.

### 3.5. Testing Procedure

The consistency of the fresh mixes was assessed using the ASTM C 143M slump test [23] as part of the physical testing. To prevent the cone from absorbing water, the inside of the cone was lightly moistened with a wet cloth. The cone was then filled with three equal layers of fresh concrete, placed on a solid impermeable base (**Fig. 2**b). In addition, ten 300mm x 150mm cylindrical samples (**Fig. 2**c) were used for the determination of density and water absorption in accordance with ASTM C 642 [24].

(a) (b) (c)

**Fig 2.** Concrete sample preperation. (a) concrete mixing process, (b) slump measurement to determine consistency,
(c) Pouring concrete into cylinder molds

The wet density or fresh unit weight ($U_w$) of concrete is determined immediately after slump testing and calculated using the following formula:

$U_w = M/V$ (kg/m$^3$) (1)

Where $M$ and $V$ are the mass and volume of the cylindrical sample, respectively.

The water absorption test was carried out right after the concrete was 28 days of age. The water absorption ($W_a$) test procedure begins with the soaking of the cylindrical sample in water for 24 hours, then wiping to obtain a saturated surface dry (SSD) sample. The SSD samples are then oven-dried at 100ºC until the weight is constant. $W_a$ is calculated based on:

$$W_a = \frac{W_{ssd} - W_d}{W_d} \times 100 \quad (\%)$$
(2)

Where $W_{ssd}$ and $W_d$ are the saturated and dry weight of specimens, respectively.

The mechanical properties of the concrete specimens were investigated by means of two destructive tests (compressive strength and tensile split strength) and two non-destructive tests (rebound hammer test and ultrasonic pulse velocity test). On the 28th day, the compressive strength and the tensile split strength were evaluated. The five 300 mm x 150 mm cylinder samples of each mix were tested for strength using an ELE ADR 1500 compression tester. The average of the results was used to determine the strength. ASTM C 496/C 496M [25] and ASTM C 39/C 39M [26] were used for tensile and compressive strength tests respectively.

The compressive strength of concrete is the maximum load per unit area, which causes the concrete test specimen to fail when loaded with a specific compressive force generated by a compression machine. The compressive strength of concrete ($f_c'$) calculted by:

$f_c' = P/A$ (MPa) (3)

Where $P$ is peak load and $A$ is area of the cylindrical sample.

Subsequently, the following equation is used to analyse the split tensile strength:

$f_{ct} = 2P / (\pi \times D \times L)$ (MPa) (4)

Where P is the maximum load applied to the specimen, D is the diameter of the cylindrical specimen, and L is the length of the specimen.

In the same way, the tests for the ultrasonic pulse velocity and the rebound hammer were carried out in accordance with ASTM C 805 [27] and C 597 [28] respectively.

## 4. Result and Discussion

### 4.1 Slump, Unit Weight and Water Absorption

Applying the slump testing procedure and using equations 1 and 2, **Table 3** shows the results of measured slump, density, and absorption for normal concrete and concrete containing PET aggregates. Based on the statistics, all data shows that the standard deviation (Sd) is less than 5, which indicates that the data values in a dataset are relatively close to the mean value with little variation or spread. From the table, it can be seen that the slump value meets the consistency requirements within the range of 25mm - 100 mm.

**Table 3**. Slump, unit weight, and absorption results

| Concrete type (% Substitution) | Slump (mm) | Fresh concrete weight (gr) | Cylinder Volume ($cm^3$) | Unit weight Density (gr/cm3) | Average density (kg/m3) | Standard deviation (Sd) | Water absorption: SSD weight (gr) | Dry weight (gr) | Water absorption (%) | Average absorption (%) | Standard deviation (Sd) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NC (0%) | 80 | 12524.0 | 5299 | 2.36 | 2300 | 0.20 | 12290 | 11825 | 3.93 | 4.02 | 0.31 |
| | | 14455.5 | 5299 | 2.73 | | | 12465 | 11940 | 4.40 | | |
| | | 12439.5 | 5299 | 2.35 | | | 12435 | 11993 | 3.69 | | |
| | | 12000.5 | 5299 | 2.26 | | | 12570 | 12115 | 3.76 | | |
| | | 12252.5 | 5299 | 2.31 | | | 12515 | 11996 | 4.33 | | |
| | | 11800.5 | 5299 | 2.23 | | | 12257 | 11792 | 3.94 | | |
| | | 10244.5 | 5299 | 1.93 | | | 12498 | 11973 | 4.38 | | |
| | | 12155.5 | 5299 | 2.29 | | | 12468 | 12026 | 3.68 | | |
| | | 11481.0 | 5299 | 2.17 | | | 12537 | 12082 | 3.77 | | |
| | | 12553.5 | 5299 | 2.37 | | | 12483 | 11962 | 4.36 | | |
| PET-1 (25%) | 83 | 11631.0 | 5299 | 2.19 | 2219 | 0.02 | 11960 | 11456 | 4.40 | 3.97 | 0.45 |
| | | 11710.5 | 5299 | 2.21 | | | 12010 | 11548 | 4.00 | | |
| | | 11605.5 | 5299 | 2.19 | | | 11900 | 11507 | 3.42 | | |
| | | 11664.0 | 5299 | 2.20 | | | 11880 | 11472 | 3.56 | | |
| | | 11840.5 | 5299 | 2.23 | | | 11850 | 11343 | 4.47 | | |
| | | 11852.5 | 5299 | 2.24 | | | 12008 | 11504 | 4.38 | | |
| | | 11955.5 | 5299 | 2.26 | | | 11962 | 11500 | 4.02 | | |
| | | 11803.5 | 5299 | 2.23 | | | 11852 | 11459 | 3.43 | | |
| | | 11739.5 | 5299 | 2.22 | | | 11832 | 11424 | 3.57 | | |
| | | 11774.0 | 5299 | 2.22 | | | 11803 | 11296 | 4.49 | | |
| PET-2 (50%) | 85 | 10992.5 | 5299 | 2.07 | 2109 | 0.03 | 11084 | 10663 | 3.95 | 3.90 | 0.21 |
| | | 11094.0 | 5299 | 2.09 | | | 11197 | 10739 | 4.26 | | |
| | | 11318.5 | 5299 | 2.14 | | | 11434 | 11023 | 3.73 | | |
| | | 11274.5 | 5299 | 2.13 | | | 11388 | 10977 | 3.74 | | |
| | | 11114.0 | 5299 | 2.10 | | | 11231 | 10820 | 3.80 | | |
| | | 11001.0 | 5299 | 2.08 | | | 11106 | 10685 | 3.94 | | |
| | | 11155.5 | 5299 | 2.11 | | | 11175 | 10717 | 4.27 | | |
| | | 11360.5 | 5299 | 2.14 | | | 11456 | 11045 | 3.72 | | |
| | | 11305.5 | 5299 | 2.13 | | | 11366 | 10955 | 3.75 | | |
| | | 11150.5 | 5299 | 2.10 | | | 11210 | 10799 | 3.81 | | |
| PET-3 | 90 | 9852.5 | 5299 | 1.86 | 1855 | 0.02 | 9998 | 9712 | 2.94 | 2.73 | 0.16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 9894.0 | 5299 | 1.87 | 9731 | 9473 | 2.72 |
| | 9905.5 | 5299 | 1.87 | 9830 | 9590 | 2.50 |
| (100%) | 9903.5 | 5299 | 1.87 | 9906 / 10016 | 9652 | 2.63 |
| | 9945.5 | 5299 | 1.88 | | 9739 | 2.84 |
| | 9781.0 | 5299 | 1.84 | 9981 | 9695 | 2.95 |
| 2.84 | 9650.5 | 5299 | 1.82 | 9748 | 9490 | 2.72 |
| | 9789.5 | 5299 | 1.84 | 9813 | 9573 | 2.51 |
| | 9824.0 | 5299 | 1.85 | | 9669 | 2.63 |

9800.5 5299 1.85 9923 / 10033 9756

Morover, slump increases as the amount of PET aggregate in the mix

| Concrete type (% Substitution) | Compressive strength, $f_c'$: Peak load (N) | Cylinder area ($mm^2$) | $f_c'$ (MPa) | Average $f_c'$ (MPa) | Standard deviation (Sd) | Splitting tensile strength, $f_{ct}$: Peak load (N) | $\pi$ x D x L ($mm^2$) | $f_{ct}$ (MPa) | Average $f_{ct}$ (MPa) | Standard deviation (Sd) |
|---|---|---|---|---|---|---|---|---|---|---|
| NC (0%) | 399500 | 17662.5 | 22.62 | 23.01 | 0.78 | 185200 | 141371.7 | 2.62 | 2.66 | 0.10 |
| | 386200 | 17662.5 | 21.87 | | | 194900 | 141371.7 | 2.76 | | |
| | 409900 | 17662.5 | 23.21 | | | 185500 | 141371.7 | 2.62 | | |
| | 416500 | 17662.5 | 23.58 | | | 178500 | 141371.7 | 2.53 | | |
| | 420200 | 17662.5 | 23.79 | | | 195500 | 141371.7 | 2.77 | | |
| PET-1 (25%) | 334300 | 17662.5 | 18.93 | 17.23 | 1.20 | 168200 | 141371.7 | 2.38 | 2.42 | 0.08 |
| | 284900 | 17662.5 | 16.13 | | | 161700 | 141371.7 | 2.29 | | |
| | 283900 | 17662.5 | 16.07 | | | 173100 | 141371.7 | 2.45 | | |
| | 313700 | 17662.5 | 17.76 | | | 176200 | 141371.7 | 2.49 | | |
| | 305000 | 17662.5 | 17.27 | | | 174500 | 141371.7 | 2.47 | | |
| PET-2 (50%) | 235300 | 17662.5 | 13.32 | 15.54 | 1.91 | 151700 | 141371.7 | 2.15 | 2.21 | 0.04 |
| | 292300 | 17662.5 | 16.55 | | | 157000 | 141371.7 | 2.22 | | |
| | 310400 | 17662.5 | 17.57 | | | 157700 | 141371.7 | 2.23 | | |
| | 293000 | 17662.5 | 16.59 | | | 157100 | 141371.7 | 2.22 | | |
| | 241400 | 17662.5 | 13.67 | | | 158800 | 141371.7 | 2.25 | | |
| PET-3 (100%) | 250300 | 17662.5 | 14.17 | 14.15 | 0.64 | 93300 | 141371.7 | 1.32 | 1.34 | 0.03 |
| | 253700 | 17662.5 | 14.36 | | | 98900 | 141371.7 | 1.40 | | |
| | 258600 | 17662.5 | 14.64 | | | 94600 | 141371.7 | 1.34 | | |
| | 256800 | 17662.5 | 14.54 | | | 93000 | 141371.7 | 1.32 | | |
| | 230700 | 17662.5 | 13.06 | | | 94500 | 141371.7 | 1.34 | | |

increases. In contrast to the slump, there is a decrease in unit weight as the amount of PET aggregate in the mix increases. The increase in slump can be attributed to the slippery surface of the PET aggregates, which allows the cement paste to separate slightly from the PET aggregates. Meanwhile, the lower specific gravity of PET aggregates compared with river gravel affects the decrease in concrete unit weight. As indicated in **Table 3**, PET-3 concrete with 100% PET aggregates and densities below 1900 kg/$m^3$ meets lightweight aggregate concrete requirements.

Water absorption in concrete refers to the amount of water that is absorbed by the pores of the concrete material. The water absorption of concrete can be influenced by a number of factors, including the type of aggregate used in the concrete. Controlling water absorption in concrete is important for guaranteeing its long-term performance and durability. The use of PET aggregates significantly reduces the water absorption percentage of concrete. Reduction in water absorption of concrete with PET aggregates by 2%-32% of normal concrete.

**4.2 Compressive and Splitting Tensile Strength**

The compressive and the splitting tensile strength of each concrete type after 28 days of testing is shown in **Table 4**. The data from the results of the compression and the split tensile test shown in the table have been calculated on the basis of the equations (3) and (4) given above. Concrete compressive strength is the ability of concrete to withstand compressive loads and it is the most commonly used measure of concrete quality. The splitting tensile strength is used to measure the tensile strength of concrete. It is determined by compressing a cylindrical concrete specimen along its axis and measuring the tensile strength of the specimen when diametrically split. The splitting tensile strength of concrete is influenced by a number of factors such as the water-cement ratio, the proportions of the mix, the age of the concrete, the curing conditions and the properties of the aggregates. The tensile strength of concrete is an important parameter for assessing the durability and performance of concrete structures, although it is generally lower than its compressive strength.

**Table 4**.

Compressive and splitting tensile strength results

A compressive strength of 23.01 MPa is obtained for normal concrete (NC) with coarse aggregate of river gravel and a bulk density of 2300 kg/m$^3$. Replacing 25% of the gravel with PET aggregate reduced the compressive strength to 17.23 MPa (PET-1). When the PET content was increased by 50% (PET-2) and 100% (PET-3), the compressive strength decreased further to 15.54 MPa and 14.15 MPa, respectively. These results indicate that the adhesion of PET aggregates to the cement paste is not as good as that of river gravel. As a result, the compressive strength is dependent on the percentage of PET aggregates in the concrete mix, and there is a decrease in compressive strength of 26%–39% from the compressive strength of normal concrete. In line with the compressive strength, the split tensile strength also decreased as the amount of PET aggregates in the concrete mix was increased.

The relationship between compressive and tensile strength is not direct. ACI 318M-14 [1] provides a formula for estimating the split tensile strength of normal concrete based on its compressive strength as $f_{ct} = 0,56\sqrt{f_c'}$. For PET-1 and PET-2 concrete, this empirical formula is still valid, but for PET-3 concrete, the $f_{ct}$ value will be quite high. For PET-3 concrete, the empirical $f_{ct}$ value is $0.35\sqrt{f_c'}$.

**4.4 Rebound Number and Ultrasonic Pulse Velocity**

A rebound hammer, also known as a Schmidt hammer, is a non-destructive testing device that is used to assess the strength of concrete by measuring the rebound of a spring-loaded hammer as it strikes the surface of the concrete. The rebound hammer operates on the principle that the rebound of a spring-loaded mass is proportional to the hardness of the surface it strikes. As the hammer strikes the concrete surface, the rebound distance is measured by a scale. This is used to determine the surface hardness of the concrete.

Ultrasonic pulse velocity (UPV) testing places an ultrasonic transducer on one side of the concrete and a receiver on the other (**Fig. 3**). A short pulse of high frequency sound is transmitted through the concrete and the time it takes for the sound waves to travel through the concrete is measured. The UPV is calculated by dividing the distance between the transducer and receiver by the time taken for the pulse to travel.

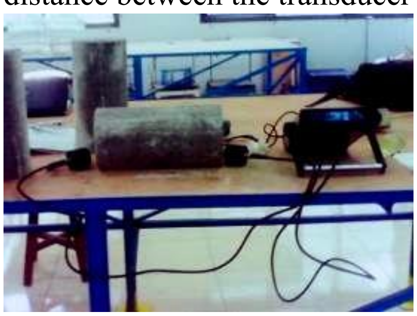

**Fig 3.** Ultrasonic pulse velocity setup

**Table 5**. Pulse velocity and rebound number results

| Concrete type | Pulse velocity (*PV*) | | Rebound number (*RN*) | |
|---|---|---|---|---|
| | Average | Standard | | Standard |

| (% Sub-stitution) | *PV* (km/s) | *PV* (km/s) | deviation (Sd) | *RN* | Average *RN* | deviation (Sd) |
|---|---|---|---|---|---|---|
| NC (0%) | 4.7 | 4.72 | 0.05 | 24.7 | 24.57 | 0.08 |
| | 4.6 | | | 24.6 | | |
| | 4.7 | | | 24.5 | | |
| | 4.8 | | | 24.6 | | |
| | 4.8 | | | 24.5 | | |
| PET-1 (25%) | 4.6 | 4.58 | 0.05 | 19.8 | 19.16 | 0.53 |
| | 4.6 | | | 18.5 | | |
| | 4.6 | | | 18.8 | | |
| | 4.6 | | | 19.2 | | |
| | 4.5 | | | 19.5 | | |
| PET-2 (50%) | 4.4 | 4.33 | 0.10 | 18.4 | 18.26 | 0.76 |
| | 4.3 | | | 19.4 | | |
| | 4.4 | | | 17.7 | | |
| | 4.3 | | | 17.5 | | |
| | 4.2 | | | 18.3 | | |
| PET-3 (100%) | 3.6 | 3.67 | 0.04 | 17.6 | 16.93 | 0.63 |
| | 3.7 | | | 17.6 | | |
| | 3.7 | | | 16.8 | | |
| | 3.6 | | | 16.3 | | |
| | 3.6 | | | 16.4 | | |

Based on **Table 5**, the pulve velocity and rebound values decrease from 4,72 km/s and 24.57 respectively in normal concrete to 3.67 km/s and 16.93 in PET-3 concrete. This decrease is consistent with the decrease in compressive strength. The decrease in UPV values as the amount of PET in the concrete mix increases indicates that the concrete becomes less dense, leading to a decrease in its strength and rebound number. PET-1 has the closest UPV value to normal concrete, which suggests that it has a similar quality to normal concrete, but the presence of PET still affects its strength.The pulse velocity at a certain speed through the concrete and the rebound value is affected by the density and homogeneity of the concrete.

## 5. Conclusion

The PET aggregate's slippery surface makes the paste and aggregate's adhesion or bond less strong which decreases the compressive strength value. The use of PET aggregate as a substitute for coarse aggregate in lightweight concrete reduced the hammer test by 22% - 31% and the split strength of concrete by 9% - 50% compared to normal concrete. The percentage of PET aggregate used in the concrete was found to be inversely proportional to the pulse velocity value and directly proportional to the time obtained in the UPV test. Moreover, the higher the percentage of PET aggregate used, the lower the results of the rebound strength and split strength obtained. Concrete made with 100% PET aggregate is categorized as medium-strength structural lightweight aggregate concrete based on the compressive strength test.

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