Journal of Advanced College of Engineering and Management, Vol. 10, 2025, Advanced College of Engineering and Management

EXPERIMENTAL ANALYSIS OF MECHANICAL AND PHYSICAL PROPERTIES OF HEXAGONAL PAVER BLOCK USING PLASTIC POLYMER AS A BINDER

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ABSTRACT

Nepal faces significant challenges in solid waste management, especially with non-biodegradable plastic waste. Recycling and reusing plastic waste as construction material can help reduce its impact significantly. This study evaluates the mechanical and physical properties of paver blocks bonded with waste polymer, specifically Polyethylene Terephthalate (PET), by varying the PET-to-sand proportions. Fifty-four hexagonal block samples were made by applying 100 bars of pressure in a hydraulic press machine. PET and sand were mixed in the following proportions: 15:85, 20:80, 25:75, 30:70, 35:65, and 40%. The compressive strength after 7 days and 14 days varied between 15.51 MPa to 33.47 MPa and 15.72 MPa to 35.54 MPa, respectively. And the compressive strength ranged between 18.27 MPa and 33.73 MPa after 14 days, with the temperature effect. With increasing PET proportion, the bulk density varied from 1886.772 kg/m^3 to 2144.974 kg/m^3. And the water absorption varied from 1.42 to 4.46. The outcome shows that the compressive strength of paver blocks rises with an increase in PET percentage up to 25%, after which the compressive strength decreases. When the proportion of PET rises, bulk density and water absorption both falls.

Keywords: Paver Blocks, Polyethylene Terephthalate (PET), Compressive Test, Bulk Density, Water absorption

1. Introduction

Solid waste management is a serious environmental concern in many developing nations, including Nepal. Solid waste management concerns are evolving with urbanization, and dealing with non-biodegradable polymeric waste is a big difficulty because of its inertness for an incredibly long time [1, 2]. The dumping and buildup in the landfill degrade soil fertility, disrupts the ecosystem, and threatens public health due to surface or groundwater pollution [3, 4]. As a result of surface and groundwater contamination, the dumping and building in the landfill reduce soil fertility, disturbs the ecosystem, and endangers public health. A critical and unprecedented crisis has arisen as a result of the accumulation of plastic waste over time and the lack of appropriate disposal techniques. Around 100 million tonnes of plastic is consumed yearly globally, up from 5 million tonnes in the 1950s; this means that 20 times as much plastic is produced now as it was fifty years ago. This implies that even while resources are being used more extensively to meet the rising need for plastic, additional plastic waste is simultaneously being produced [5].

One of plastic's best features, longevity, also poses a risk to the material's proper disposal. In actuality, plastic materials break down over hundreds of years into tiny bits rather than entirely degrading. Other than being lightweight, water-resistant, strong, durable, and corrosion-resistant, plastics are also very valuable materials because of their beneficial qualities. These include ease of transportation, affordability, and lifespan. But the real problem causing mayhem is the overuse of plastic. Since plastics are now a necessary part of contemporary life, increasing plastic reuse and recycling is the only long-term solution to reduce plastic pollution and environmental protection [6, 7].

SWM is still quite difficult, especially in low- and middle-income nations when it comes to metropolitan areas. Plastic garbage is one category of solid waste that is an issue on a national and international level. One approach to waste management is to recycle and reuse polymeric waste into construction materials. Significant environmental issues arising from plastic trash have garnered global attention in recent times, prompting the implementation of novel initiatives aimed at recycling plastic waste into building materials [8]. Using plastic waste like PET, High-Density Polyethylene (HDPE), Polystyrene (PS), Polypropylene (PP), and Low-Density Polyethylene (LDPE), as the binding components to create construction materials that resemble concrete or mortar is one of the efforts with great potential. Yet, it is unknown how the composition and curing conditions of melted plastic used as the only binder in concrete and mortar-like materials affect critical technical features.

The longevity of roads built in developing countries is being impacted by a continual rise in traffic levels. Because road degradation causes significant disruptions to the transportation sector and ultimately hinders the future economic growth of these countries, improved road conditions are imperative. On the other hand, as a result of accelerated global warming and climate change, there is a large variance in daily and seasonal temperatures. The combined solution to the aforementioned issue can be a green road made of plastic waste, which offers an affordable and sustainable way to dispose of plastic waste while also committing to infrastructure development and making a positive contribution to society. Using plastic waste material in transportation projects implies environmentally friendly construction of roads using alternative materials rather than conventional materials [9, 10].

Some scholars have come up with solutions that offer social, environmental, and economic benefits by recognizing waste as a resource instead of as a problem that needs to be resolved. One entails making building materials such as mortar or concrete from plastic garbage, whether it's melted or not [11].

Based on the per capita waste generation, in the context of Nepal 2011, the total Municipal Solid Waste (MSW) generation from the 58 municipalities was estimated at 1,435 tons/day and 524,000 tons/year. When all three major sources of waste- household, institutional, and commercial are combined, plastic waste covers 16 percent of the total MSW [1].

Global plastic production is continuously increasing, and by 2030, the globe might manufacture around 619 million tons of plastic per year. According to the World-Wide Fund (WWF), eliminating single-use plastics has the potential to cut plastic consumption by up to 40 percent by 2030. As a result, the current scenario necessitates a more sustainable way of recycling this trash, which, if not fulfilled, will worsen the environmental imbalance due to its non-biodegradability in nature. The growing demand for eco-friendly products has prompted various investigations into alternate strategies for reusing waste in construction materials [12].

In the research conducted by [13], where the author melted and mixed the PET/sand aggregate thoroughly with portland cement slurry, they found that adding PET fillers up to 20 percent significantly improves the mechanical capabilities of composite materials, whereas adding PET fillers over 20 percent causes these qualities to diminish. Nevertheless, when the quantity of PET fillers rises, the specimen's density and water absorption decrease.

In the research conducted by [3], Polyethylene waste was used as a substitute for cement in making paving block. The sample with 1:4 mixing ratio resulted in the highest compressive strength, with the plastic-aggregate block having the lowest water absorption rate. The plastic-aggregate block's water absorption values were 0.1350% and 1.8861%, respectively, indicating excellent water absorption within the maximum 5% for quality paving blocks.

In the research conducted by [14], Paving blocks were made using LDPE and shredded waste concrete mortar. It determined that blocks having 30% and 40% plastic content outperformed standard concrete paving blocks. The plastic paving stones (40%, 30%, and 20% plastic content) demonstrated great impact strength, ans were able to endure several hits without failure. Each plastic paving block absorbed 34.9 J of energy. In comparison, the standard concrete paving block crumbled after a single hit with an energy of 6.98 J.

In the research conducted by [15], coarse and fine sand and HDPE plastic were used as the raw materials with the mixing ratio 3:2 and 1:1. The study determined that a mix design ratio of 3:1 between plastic and coarse sand yields a higher compressive strength of 13.2 MPa when compared to other ratios. Additionally, the plastic paver block exhibits a water absorption of 1.8%.

In the research conducted by [16], plastic wastes HDPE and PP were segregated, shredded, melted, and molded in steel molds. It concluded that as the percentage of plastic components rises, so does the compressive strength and limited capability of absorbing water. Abrasion testing revealed little surface wear, demonstrating excellent durability with a wear maximum of 2.56%. However, its strength decreases by 31.17% under extremely high temperatures.

Polyethylene terephthalate is a common material for plastic-bound paver blocks due to its strength, adaptability, and possibility for recycling [17]. The paver blocks' compressive and tensile strength may be increased by PET's robust molecular structure, which makes them resistant to wear and severe loads over time. Because PET has strong thermal stability, it may be used in outdoor settings where paver blocks might be subjected to temperature fluctuations. PET is a sustainable option since it may be found in large quantities from recycled materials like plastic bottles. PET is an eco-friendly choice as it can usually be sourced from recycled material, such as plastic bottles. In other words, PET in paver blocks will assist by shielding uneducated or unaware consumers from the menace that plastic is creating for the environment. PET easily bonds to other materials which is why it is also mixed with sand. This ability helps in block formation with particular characteristics and enhances the quality of product paver blocks. These advantages make PET the ideal choice for manufacturing eco and budget-friendly paver blocks that are strong and durable.

In the research conducted by [18], the study was done by grinding the PET soda bottles into flakes and adding them to the concrete, and research conducted by [19], studied the properties of sand-based pavement tiles by plastic binding. PET was used as a binding material. PET bottle pallets and sand were mixed uniformly while heating and then placed in the mold. Previous studies have been conducted to integrate different plastics into concrete using various methods. Until now, the heating and mixing process of sand and PET or adding PET flakes directly into concrete has been done, but preparation of pavement block using the compaction method has not been done yet. It is well known that the compaction procedure increases strength and density. So, research has to be done to determine the optimal process. Pavement blocks' strength and durability can be significantly impacted by the kind and dose of plastic used. This research focuses on determining the mechanical attributes of paver block made with PET by compaction method and also tends to determine the optimized proportions of the plastic content. This study aims to evaluate the mechanical and physical properties of paver blocks with different proportions of waste PET used as a binding agent. The evaluation includes the compressive strength test, compressive strength test with temperature effect, bulk density test, and water absorption test.

2. Materials and Methods

2.1 Materials

In this proposed study, Polyethylene Terephthalate (PET) and naturally occurring river sand were used to make the hexagonal paving block samples. Fine natural river sand from Melamchi that passes through a 4.75 mm sieve size was used for this experiment, and PET, a binding agent, is a thermoplastic substance. PET is known for its transparency, strength, durability, and recyclability [17]. PET was sourced from PET bottle-making industries in Patan Industrial State. A hexagonal mold of each side 115 mm and height 55 mm size was used to prepare the sample.

2.2 Properties of Paver Block

Compressive Strength

Compressive strength is the greatest compressive stress that a particular solid material can withstand under a progressively imposed load without yielding. Compressive strength, which is widely utilized for specifications as well as quality control of various types of blocks, is a crucial characteristic that establishes its application. According to IS 15658.2006, paving blocks must have a minimum compressive strength of 30 MPa and a thickness of 50 mm for non-traffic circumstances (building premises, walkways), and a minimum compressive strength of 35 MPa and a thickness of 60 mm for light traffic situations like pedestrian plazas, retail centres [20].

Water Absorption

The ability of a substance to absorb water when exposed to water is referred to as water absorption. The water-absorption ratio is used to describe it. Water absorption ratio is a crucial factor to take into account while creating blocks. A reduced capacity for water absorption is desirable in order to produce higher quality blocks. The water absorption being the average of three units shall not be more than 6% by mass and in individual sample, the water absorption is restricted to 7 % [20].

Bulk Density

Mass per unit volume is the definition of density for a material. When pressure applies, an object's density increases and its volume decreases. A substance's density decreases as its volume grows as temperature rises, with very few exceptions. Block density is the weight of a block relative to its volume.

2.3 Test Preparation

Initially, fine waste PET polymers were melted on a pan at around 250-280 °C. Then sand was added to the mixture and mixed uniformly for around 10-15 min depending on the amount of plastic used. The mixed materials were then placed into molds. The molds were cleaned and lubricated. After that, hydraulic pressure was used on the slurry to shape it into a paver block shape. Before use to ensure easy release of the blocks, 100 bar of pressure was applied, and it was held there for three minutes to prevent expansion, and the blocks were de-molded and left for curing for 7 days and 14 days. There was a total of 90 samples needed, of which the bulk density and water absorption tests were nondestructive at first, followed by the destructive compressive tests. Fifty-four hexagonal block samples were created by combining varying amounts of PET with sand.

Table 1: Composition of PET to Sand ratio

Sample Type	PET %	Sand %
A	15	85
B	20	80
C	25	75
D	30	70
E	35	65
F	40	60

Table 2: Sampling Matrix

S.N	(PET) % by volume	Number of samples		
		Compressive Strength	Bulk Density	Water Absorption
1	15	9	3	3
2	20	9	3	3
3	25	9	3	3
4	30	9	3	3
5	35	9	3	3
6	40	9	3	3

In this study, sample types A1, A2, and A3 were tested for compression strength using a 15% PET proportion. Testing three units in tests ensures accuracy and reliability by minimizing variability, confirming consistency, identifying outliers, and increasing statistical confidence in the results. This approach provides a more dependable measure of material quality than testing just one unit.

2.4 Types of Tests

Compressive strength test

After 7 days and 14 days of curing, the compressive strength of the pavement block was evaluated using Compression testing equipment. For this test, digital display-type compression testing equipment with a 2000kN capacity was utilized. The load was applied uniformly throughout its surface until a crack was visible and the peak load was recorded.

$$\text{Compressive strength} = \frac{Maximum\ load}{Cross-sectional\ area\ of\ the\ specimen} \quad (1)$$

Figure 1: Compression Testing Machine

Water Absorption Test

Paver blocks from each sample were oven-dried for 24 hours and then they were weighed and submerged in clean water for 24 hours, then brought out and weighed. Water absorption was then calculated using the following expression:

Water absorption (%) = $\frac{w2-w1}{w1} * 100\%$ (2)

where,

W1 = Dry weight of block samples (kg)

W2 = Wet weight of block samples after 24 hrs (kg)

Bulk Density Test

The block sample is dried in a vented oven at 105°C until it reaches a noticeable constant mass. The concrete brick samples are then cooled to room temperature, and their mass, denoted by M, is recorded. After that, the dimension of the block is measured and the volume is calculated.

Bulk Density = $\frac{Weight}{Volume}$ (3)

Temperature effect

Compared to conventional concrete or clay paver blocks, plastic paver blocks, also known as sand and plastic paver blocks, have distinct properties linked to temperature. At elevated temperatures, plastic paver blocks may soften or distort, which may lower their compressive strength. Under large loads, this softening may cause them to become prone to indentation or distortion, and extended exposure to high temperatures can cause plastic components' structural integrity to deteriorate, which increases the risk of fractures, deformation, and a reduction in compressive strength [16].

3. Experimental Result and Analysis

3.1 Result of Compressive Test

A compression testing machine is used for testing the compressive strength of the test specimen. The result of compressive strength after 7 days is shown below:

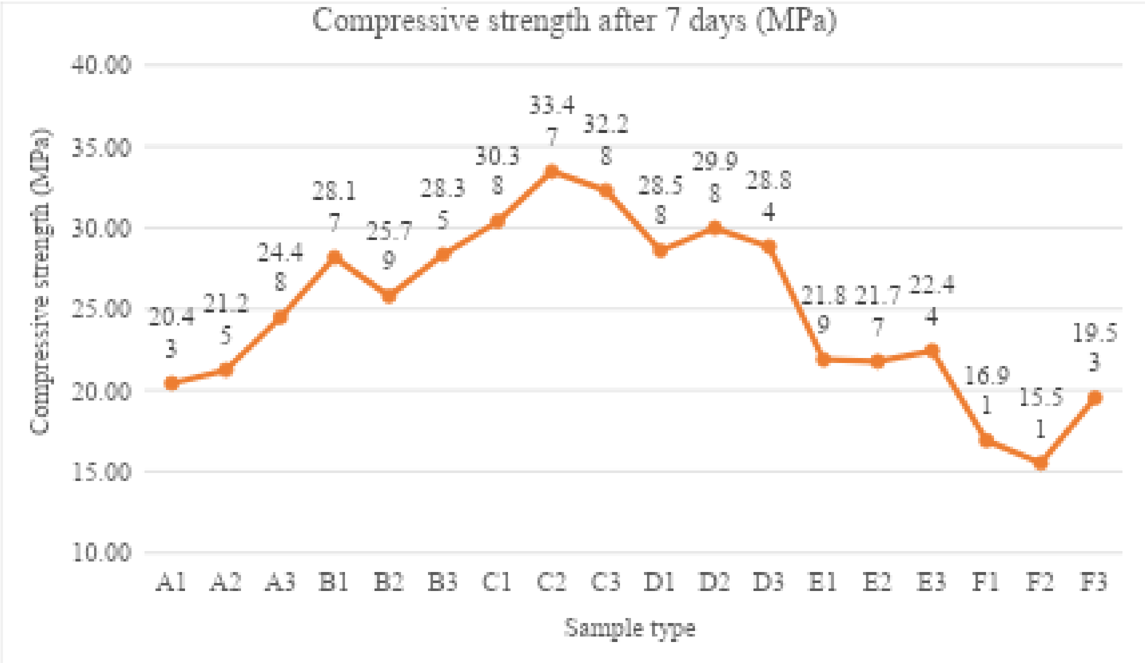

Figure 2: Variation of compressive strength after 7 days with different sample types

Figure 2 illustrates the compressive strength of the plastic paver block after 7 days. It shows that the sample C type, which is 25% PET compressive strength was found to be higher at 33.5 MPa, whereas sample F type's compressive strength was found to be the lowest at 15.5 MPa among all sample types.

The result of compressive strength after 14 days is shown below:

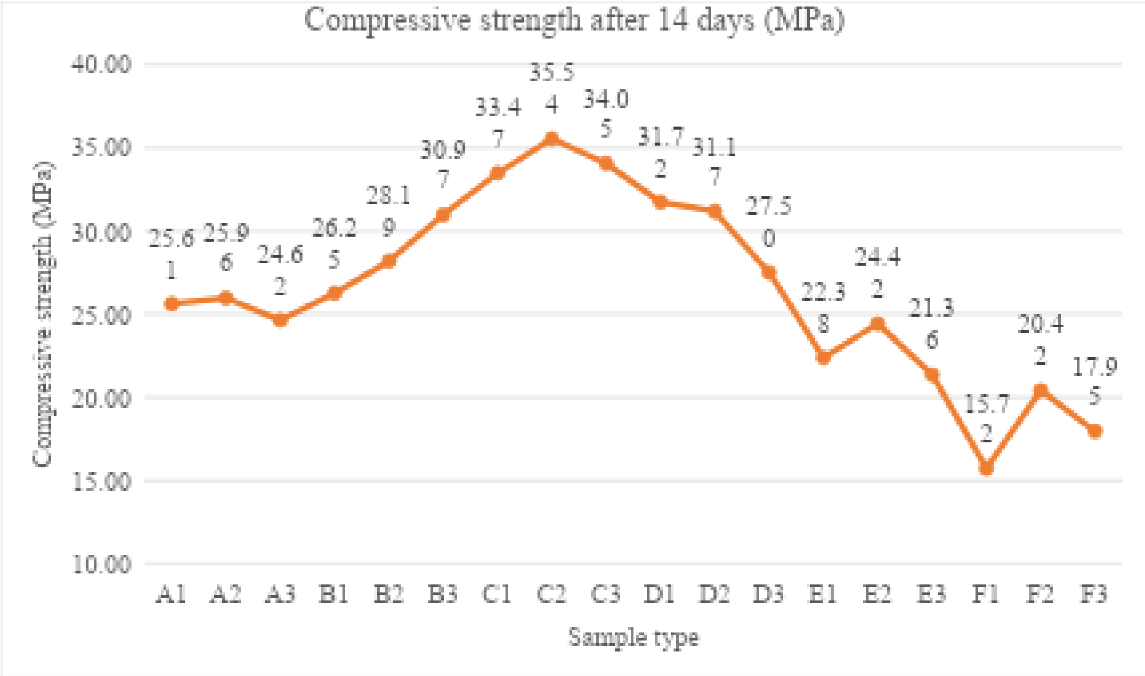

Figure 3: Variation of compressive strength after 14 days with different sample types

Figure 3 illustrates the compressive strength of the plastic paver block after 14 days. It shows that sample C 's compressive strength was found to be higher with 35.5 MPa. The notable increase in compressive strength from 7 days to 14 days suggests the curing process continues to enhance the structural integrity of plastic paver blocks. Compressive strength progressively rises to a maximum of 25% PET; however, the impact of increasing PET percentage ceases to exist after that point and begins to fall. In the beginning, the inclusion of PET particles may serve as a kind of strengthening in the mixture, increasing the paver blocks' compressive strength. It suggests that the maximum percentage of PET in the sand/PET combination appears to be 25% by volume. Some author also concluded with the increase in proportion of PET the compressive strength decreases [8, 18].The compressive strength 35.5 MPa is found to be higher as compared to various compressive strength between 4.79 MPa – 33.24 MPa reported by many authors [8, 16, 18, 19, 21, 22]. The compressive strength obtained plastic bound paver block falls within the Indian standard of compressive strength of 30 MPa non traffic and 35 MPa light traffic [20]. Therefore, this paver block can be used in light traffic roads and pedestrian walkways, plazas.

Comparison of compressive strength after 7 days' vs 14 days

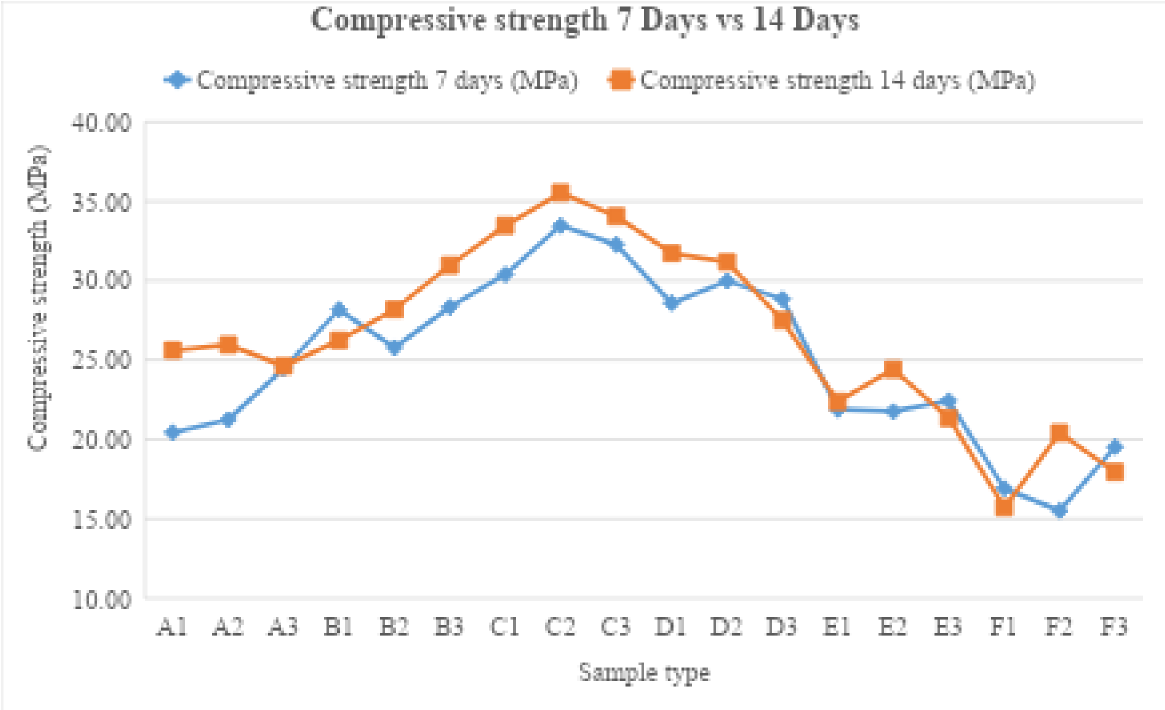

Figure 4: Compressive strength after 7 days vs 14 days

Figure 4 illustrates the comparison of compressive strength after 7 days' vs 14 days.

3.2 Temperature Effect

Sample blocks were kept in a laboratory oven at 50 °C for a day and then a compression testing machine was used to evaluate the compressive strength of the sample block with temperature effect.

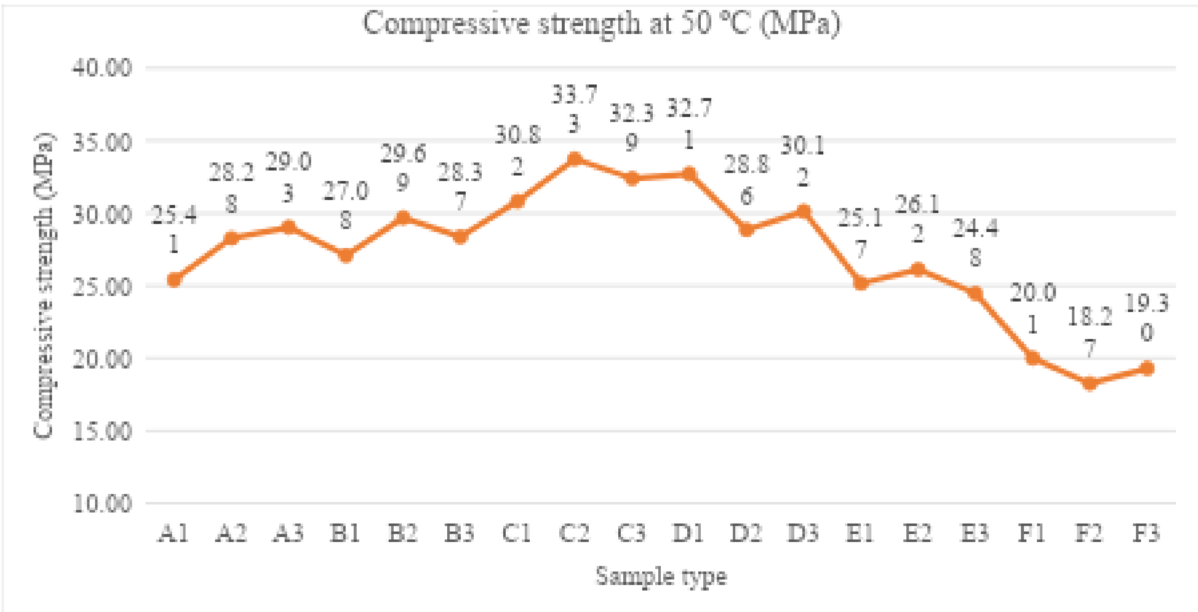

Figure 5: Variation of compressive strength at 50 ºC with different sample types

Figure 5 illustrates the compressive strength at 50 °C of plastic paver block. It shows sample type C's compressive strength was found to be higher with 33.73 MPa. The compressive strength varies by 1-2 MPa, which is a relatively small difference when compared to the compressive strength without temperature effect. The compressive strength 33.73 MPa found to be higher as compared 22.37 MPa which was done 35 ºC for 12 hours reported by [22]. Author [22] also draws similar pattern with small decrement in compressive strength with temperature effect. These paving blocks are also suitable for usage in locations with highs of up to 50 ºC.

3.3 Result of Bulk Density

The bulk density test results for plastic-bound paver blocks with varying sand and PET fractions are displayed in Figure, respectively. Measurements were made after these test specimens were dried for a day at 110 °C in a lab oven.

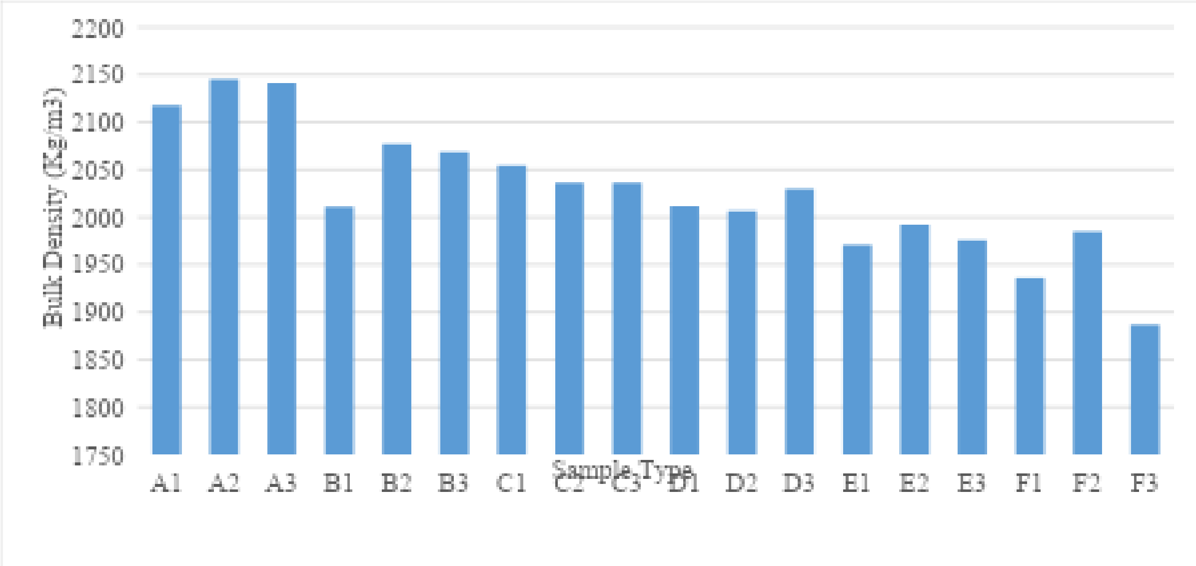

Figure 6: Graphical representation of Bulk Density

Figure 6 illustrates the bulk density of plastic paver blocks. It shows that the bulk density for Sample A type, which is a 15% proportion of PET and 85% sand, was found to be higher at 2144.974 kg/m^3 than for other proportions. The graphical representation shows bulk density of the paver block was found to decline with an increase in PET plastic percentage increment.

Compared to sand, PET is a low-density, lightweight substance. A decrease in bulk density results from the displacement of heavier materials in the mixture caused by an increase in the fraction of PET. That explains why the bulk density decreased as PET percentage increased.

3.4 Result of Water Absorption Test

Paver blocks from each sample were oven-dried for 24 hrs and then they were weighed and submerged in clean water for 24 hours. After which they were brought out and weighed.

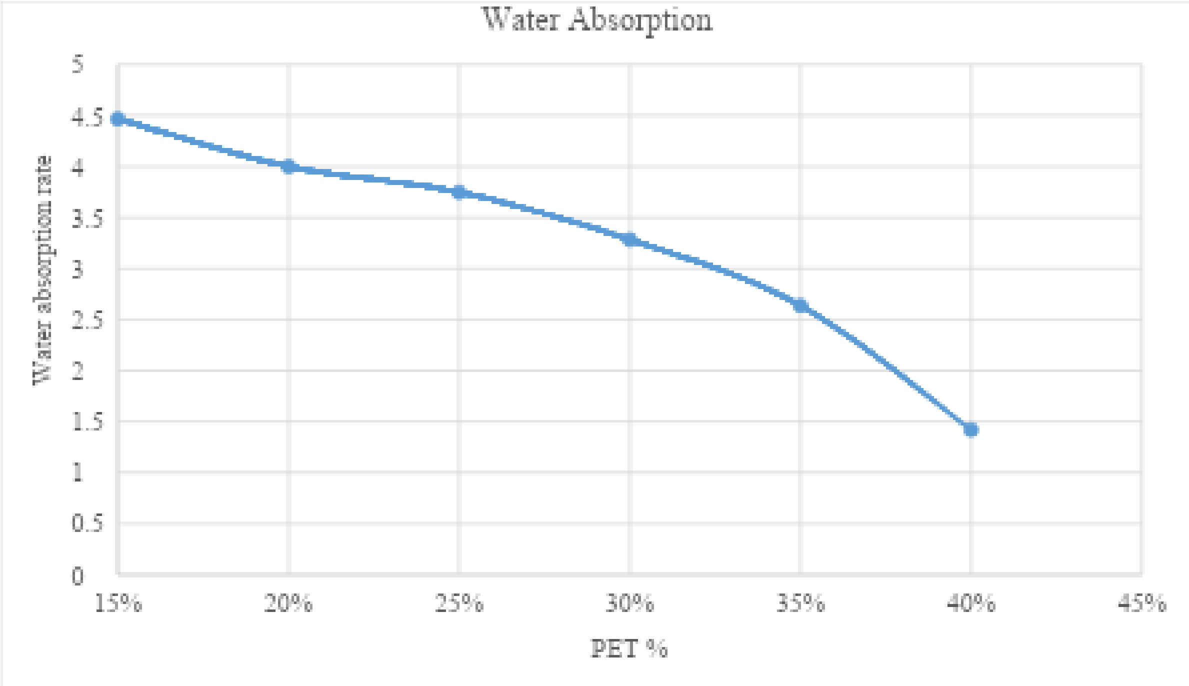

Figure 7: Graphical Representation of Water Absorption

Figure 7 shows the water absorption rate of different proportions of the PET. It was observed that the water absorption test for Sample A type was found to be higher (4.468), which is within the range of standard whereas least water absorption was found to be of Sample Type F. Many researchers obtained the water absorption value between 1-5% for different mix proportions similar to the results from this study. [23, 24]

According to IS 15658:2006 [20] average absorption rate should be less than 6 percent being the average of three units. The graphical representation of water absorption shows that increasing the PET proportion in the samples, decreases the water absorption rate.

Water tends to reject PET rather than absorb it because of its natural water resistance. The PET plastic's hydrophobic qualities lessen the paver block's capacity to absorb water. This explains the inverse relationship between the rate of water absorption and PET fraction.

4. **Conclusions**

In this research, plastic-bound paver blocks were prepared via compaction. Various testing was conducted, including bulk density, compressive, and water absorption tests. The compressive strength after 7 days and 14 days varied between 15.51 MPa to 33.47 MPa and 15.72 MPa to 35.54 MPa, respectively. The compressive strength of the proportion 25% PET plastic and 75% sand was found to be higher with 33.47 MPa and 35.54 MPa after 7 days and 14 days, respectively which is comparable with a concrete block with a strength of 30-35 MPa. The compressive strength was found to be higher with 33.73 MPa after 14 days, with the temperature effect. The study concluded that the compressive strength of paver blocks rises with an increase in PET percentage up to 25%, after which the compressive strength decreases.

And the bulk density varied between 1886.772 kg/m^3 to 2144.974 kg/m^3, with the highest average density of 2134.392 kg/m^3. This study concluded that with the rise in the proportion of PET plastic, bulk density falls.

And the water absorption varied between 4.468 to 1.421. This study concluded that the rate of water absorption decreases with increasing the PET due to its water-resistant qualities.

5. **Recommendations**

Further studies can be done with the appropriate mixing process which may provide accuracy in the data. Further studies can be done to prepare plastic paver blocks using other common polymeric waste like LDPE and HPDE as a binder in place of PET.

6. Acknowledgment

This work was conducted under the funding of the University Grants Commission (UGC) Nepal, Award number: SRDIG-78/79-ENGG-01. The authors sincerely thank all of the faculty members at Tribhuvan University's Institute of Engineering, Thapathali Campus as well as other instructors for their continual help and recommendations.

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