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Assessing the Compressive Strength of Concrete by Utilizing Recycled Plastic as a Partial Replacement of Fine Aggregate

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Abstract **- Plastic waste has become a major problem that affects the environment because it is not easily biodegradable. The amount of plastic waste increases every year as the population grows. One solution to reduce the quantity of plastic is to recycle it and turn it into useful products. If plastic is not recycled, it ends up in landfills and littered on land. Utilizing plastic waste in concrete mixtures can not only improve the compressive strength but also offer a new method for managing plastic waste, which is a significant environmental concern. This study investigates the utilization of recycled plastic waste as a fine aggregate in concrete. The study employed a mix ratio of 1:1.5:3 for concrete and replaced a portion of the fine aggregate with recycled plastic waste at varying percentages of 2.5, 7.5, 12.5, 17.5, and 22.5. The results of the study were focused on analyzing the workability and compressive strength of the concrete to determine the most suitable percentage of recycled plastic waste to be used. It was observed that as the percentage of recycled plastic waste increased, the workability of the concrete decreased. The optimal percentage for enhancing compressive strength through the incorporation of plastic waste was determined to be 7.6% for a 2.5% plastic waste replacement. Overall, recycled plastic waste can be suggested to use with precautions due to its ability to enhance strength when used optimally.**

Keywords: Compressive Strength, Optimal, Recycled Plastic Waste, Partial Replacement, Workability.

I. INTRODUCTION

Concrete is the most widely utilized construction material globally due to its well-known beneficial qualities. It is a straightforward combination of ingredients, including cement, aggregate (coarse and fine), and water, and are economically superior and more long-lasting compared to other construction materials. However, concrete does have significant drawbacks, such as its relatively weak tensile strength, which makes it susceptible to failure under tensile stresses as well as environmental concerns associated with CO_2 emissions and the depletion of ecosystems caused by aggregate production.

To mitigate these drawbacks and generate improved and more environmentally-friendly concretes, engineers currently employ methods such as utilizing reinforced concrete, such as traditional steel-bar reinforcement or more advanced fiber reinforcement concrete, to enhance the mechanical properties of the material [1]. Another approach adopted by concrete producers involves incorporating recycled aggregates from demolition waste to diminish the depletion of quarries and subsequently decrease the adverse environmental effects [2].

Every day, a total of 3,000 tonnes of plastic waste is being generated in Bangladesh [3]. Plastic accounts for 8% of the annual waste produced, which equates to 800,000 tonnes [4]. In Dhaka city alone, an estimated 14 million polythene bags are used daily, often ending up in rivers and the ocean, posing a serious threat to marine life. Around 73,000 tonnes of plastic waste enters the sea each day through the Padma, Jamuna and Meghna rivers [3]. In the specific area of old Dhaka, approximately 250 tonnes of non-recyclable items such as straws and plastic cutlery are sold on a monthly basis [3]. The rate of bio-waste production is increasing at a rate of 5.2%, while plastic waste is growing at a rate of 7.5% [4]. In addition to domestic waste, plastic waste from neighboring countries like India, Nepal and China also flows into our water bodies, including rivers and canals [4]. The magnitude of this issue is enormous. According to Reuters, Asia is responsible for the largest production and disposal of plastic material worldwide [5]. Plastic waste has the potential to be used in concrete production for sustainable development and economic efficiency in construction industries. Currently, it is widely utilized because of its advantageous characteristics, including its low density, resistance to corrosion and wear, insulation properties, low thermal conductivity and ease of processing and molding. However, the consumption of plastic has increased, resulting in a significant amount of plastic waste being generated.

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Presently, the global production of concrete amounts to 4.4 billion tons per year [6]. Considering these figures, the utilization of plastic waste in concrete production holds immense potential. Therefore, incorporating recycled plastic waste into concrete could contribute to sustainable development and economic efficiency in the construction industry [7]. On the contrary, there have been reports stating that the use of waste plastic aggregate in concrete, ranging from 0 to 20% volume, can decrease the weight of the concrete, thus reducing the overall weight of the structure. This allows it to be used as lightweight concrete [8]. Additionally, the utilization of plastic waste offers numerous benefits, such as enhancing environmental sustainability, boosting industrial production, reducing pollution, and maximizing the use of non-renewable natural resources. This can be achieved through the reinforcement of concrete with plastic fibers and the utilization of recycled plastic waste as a substitute for aggregate in concrete. Shyam S. et al (2018) investigated the strength and durability properties of concrete with 5, 10, 15 and 20% replacement of M sand with plastic in powder form. The workability, compressive strength, flexural strength and tensile strength of concrete found reduced with increase in HDPE plastic powder. Also, the density of concrete reduced with the increasing percentage of HDPE plastic powder [9]. Shukla et al. (2019) found that replacing the sand by plastic waste (0%, 10%, 20%, 40% & 60%), compressive strength increased to increase the percentage (%) of plastic aggregate (0% to 40%) after 40% of plastic aggregate compressive strength decreases for both 14 days & 28 days cube strength [10].

Charudatta et al. (2017) investigated the use of recycled plastic waste as a replacement for natural river sand in concrete different percentages of plastic waste (20%, 40%, and 60%).The results showed that replacing up to 40% of the sand with plastic waste yielded satisfactory properties for construction purposes in the civil industry [11]. Arivalagan. S et al. (2016) found that replacing 10% of PET waste plastic as sand in concrete, the compressive strength is increased by 26% compared to sample recycled plastic waste but replacing more than 15% the compressive strength less than recycled plastic waste [12].

The aim of this study is to identify the ideal proportions of recycled plastic waste that can be incorporated into concrete to achieve the highest compressive strength possible. Various ratios of recycled plastic waste were utilized as substitutes for fine aggregate, with the assumption that they were evenly dispersed throughout the concrete. The concrete samples containing different percentages of recycled plastic waste were subsequently subjected to compression testing.

II. MATERIALS AND METHODS

This investigation used coarse aggregate, fine aggregate, ordinary portland cement (OPC) and recycled plastic waste. Properly proportioning these elements is crucial for achieving desired results in concrete, which is known as "mix-design." The experimental part of the project aims to conduct various tests.

a) Materials

i) Cement

The focus of this study was to explore the use of CEM I-Ordinary portland cement (OPC) as the primary ingredient in concrete. OPC is a substance that reacts chemically with water, and it is crucial to carefully choose the appropriate type and use it correctly in order to achieve cost-effective concrete with the desired qualities. The OPC used in this research met the requirements set by BDS EN 197-1:2003 Part-1 and had a specific gravity of 2.90. It consisted of 95-100 percent clinker. The OPC had an initial setting time of at least 45 minutes and demonstrated compressive strengths of at least 52.5 MPa after 28 days [13].

ii) Coarse Aggregate

Aggregates, like gravel or crushed stone, are materials that have an irregular and granular structure. They are commonly used in the production of concrete. These aggregates are usually found naturally and can be obtained by either blasting quarries or manually crushing them, or by using crushers. In this specific research, the goal was to use aggregates to improve the durability and ability of the concrete to absorb impacts. If the aggregates used in the concrete are uniform in size and grading, then the concrete will have good workability. The coarse aggregate chosen for this study was locally sourced stone chips that were ¾" in size and were downgraded for use in concrete preparation. This particular coarse aggregate was selected because it was readily available and had desirable properties. The fineness modulus (FM) of the coarse aggregate was determined to be 7.30.

iii) Fine Aggregate

Fine aggregate is an essential ingredient in concrete and can be either natural sand or crushed stone. To be classified as fine aggregate, the granular material must have a fine texture that allows it to pass through a sieve with a 4.75mm opening, while still retaining particles that are larger than 2.36mm. In this research, the fine aggregate used was locally sourced sand that had a particle size smaller than 4.75mm. The main reason for choosing this specific type of sand, known as Sylhet sand,

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was its availability. The fine aggregate had a fineness modulus (FM) of 2.77.

iv) Water

Water plays a crucial role in the chemical reaction of cement, making it one of the most vital ingredients in concrete. Generally, drinking water is suitable for blending with concrete. However, impurities present in the water can impact the concrete's setting time, strength, shrinkage, and may even lead to reinforcement corrosion. In this research, tap water provided by WASA (Water Supply and Sewerage Authority), with a pH level ranging from 6.5 to 9.5, was utilized for all analyses, including the casting, and curing of the cylinders. Furthermore, the water met the standards specified by BDS ISO 12439:2011 for mixing water in concrete, as outlined in BNBC-2020 [14].

v) Recycled plastic waste

This study employed Recycled Plastic Waste (RPW), sourced from a reputable company via local markets, as a fine aggregate in concrete production. The fineness modulus (FM) of the RPW was determined to be 2.9. The RPW was incorporated into concrete specimens in varying proportions by weight, specifically at 2.5%, 7.5%, 12.5%, 17.5%, and 22.5%.

Table 1: Particle size distribution of sand and RPW

Sieve Size (mm)	Cumulative passing (%)	
	Sand	RPW
4.75	100	99.8
2.36	100	97.6
1.18	98.80	76.00
0.6	90.80	49.4
0.3	26.20	9.8
0.15	4.20	0.4

Table 2: Physical and mechanical properties of plastic aggregates

Properties	RPW
Bulk density (kg/m^3)	74
Fineness Modulus	2.90
Color	Green
Youngs modulus (MPa)	2600

a) Cement **b) Sand**

c) Stone chips **d) Recycled plastic waste**

Figure 1: Materials Used

b) Methods

i) Mix proportions of concrete

Mix design was carried out by American Concrete Institute (ACI, 211.1-91) to ensure precise and high-quality results. The desired slump value, a measure of workability, ranged between 3 to 4 inches, ensuring optimal consistency. Prior to mixing, the aggregates experienced a thorough soaking process, bringing them to a saturated surface dry (SSD) state. Deliberately, a slump value of 75mm was initially chosen. With a coarse aggregate of maximum size approximately 20mm, the mix design ratio adhered to the esteemed ratio of 1:1.5:3. Additionally, a water cement ratio of 0.4 was carefully selected, ensuring the ideal balance for a superior mixture.

Table 3: Materials proportion

Materials	Proportion
Cement	1.0
Fine Aggregate	1.5
Coarse Aggregate	3.0
(RPW)	2.5%,7.5%,12.5%,17.5% & 22.5%
WC Ratio	0.4

ii) Mixing of Concrete

To ensure the success of our experiment, we took precautions to keep the cement dry and store it in a moisture-resistant container. We also prepared the fine and coarse aggregates by alternating between keeping their surfaces moist and dry. All materials for the concrete were stored at room

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temperature to maintain consistency. We used a drum mixer to thoroughly mix everything. To assess the workability of the concrete mixtures, we conducted slump tests following the guidelines of ASTM C143-90a (1990) standards [15]. We created concrete samples using molds and varied the content of RPW. These samples included RPW ranging from 0% to 22.5%. By adjusting the RPW content as a partial replacement for sand, we can examine how it impacts the properties of the concrete.

iii) Curing of Specimen

The test cylinders were cured in accordance with the guidelines outlined in ASTM C192-90a[16].After a period of 24 hours, the molded specimens were carefully taken out from the molds and placed in a water bath for the curing process. They were then kept in the water bath for durations of 7, 14, and 28 days as instructed. By adhering to these procedures, the concrete cylinders were properly prepared and cured, making them suitable for subsequent testing and analysis.

III. RESULTS AND DISCUSSIONS

a) Slump Test

The slump test is an important method for assessing the consistency and workability of newly mixed concrete. It involves filling a cone-shaped mold with concrete that has specific dimensions (8 inches at the bottom, 4 inches at the top, and 12 inches in height) and measuring the amount of settlement or slump. This assessment is critical in determining the flow and cohesion of the concrete mixture, which are essential for the successful completion of construction projects. The BNBC 2020 guidelines emphasize the importance of ensuring that the concrete mix has the right workability to achieve proper compaction and optimal performance [14].

Table 4: Result of slump test

Sl. No.	RPW (%)	Average Slump (mm)
1	0	65
2	2.5	62
3	7.5	68
4	12.5	74
5	17.5	81
6	22.5	89

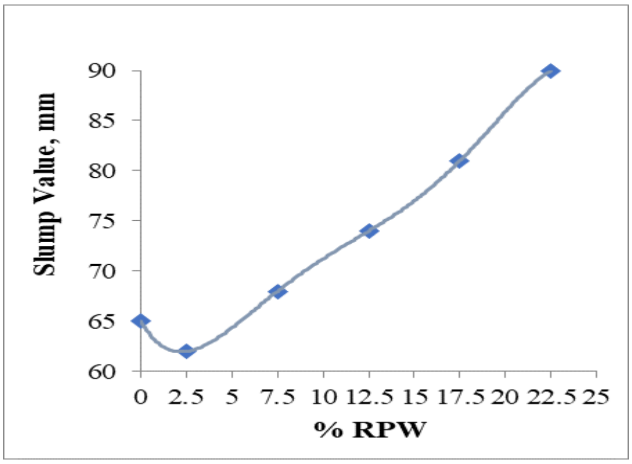

Figure 2: Slump Test Value

b) Compressive Strength of Concrete

One important characteristic of concrete that significantly impacts its overall properties is the average compressive strength at specific time intervals, such as 7, 14, and 28 days, which determines the water-cement ratio in the mixture. In Bangladesh, the assessment of concrete compressive strength is typically done through testing cylindrical samples measuring 4inch x 8inch with a mix ratio of 1:1.5:3. Compression tests were carried out on groups of three cylinders at different curing periods and levels of RPW (Recycled Plastic Waste) content to determine the necessary strength. The findings presented in Tables 5, 6 and 7 indicate that the addition of RPW to concrete can improve compressive strength, with a 7.6% enhancement at a 2.5% content. Although replacing fine aggregate with RPW can boost strength, surpassing certain RPW content does not meet the desired strength. The compressive strength of natural concrete without RPW is 18.64 N/mm^2 after 28 days, while incorporating RPW enhances strength and rigidity. Compression tests conducted over 7, 14, and 28 days of curing reveal that longer curing periods result in higher concrete strength. For example, concrete containing 2.5% RPW has a compressive strength of 13.16 N/mm^2 after 7 days and 20.07 N/mm^2 after 28 days of curing.

Table 5: Compressive strength for 7 days

Plastic Content (%)	Compressive Strength (MPa)
0	12.14
2.5	13.16
7.5	12.92
12.5	11.58
17.5	10.32
22.5	8.88

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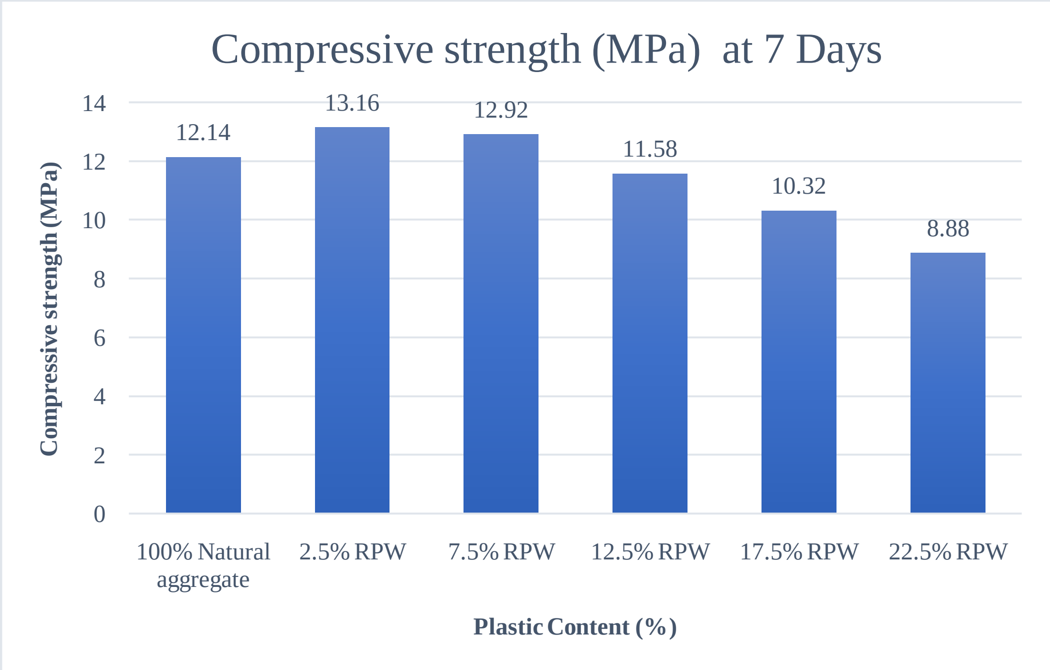

Figure 3: Compressive strength for 7 days

Table 6: Compressive strength for 14 days

Plastic Content (%)	Compressive Strength (MPa)
0	13.94
2.5	15.91
7.5	15.66
12.5	13.86
17.5	12.25
22.5	10.33

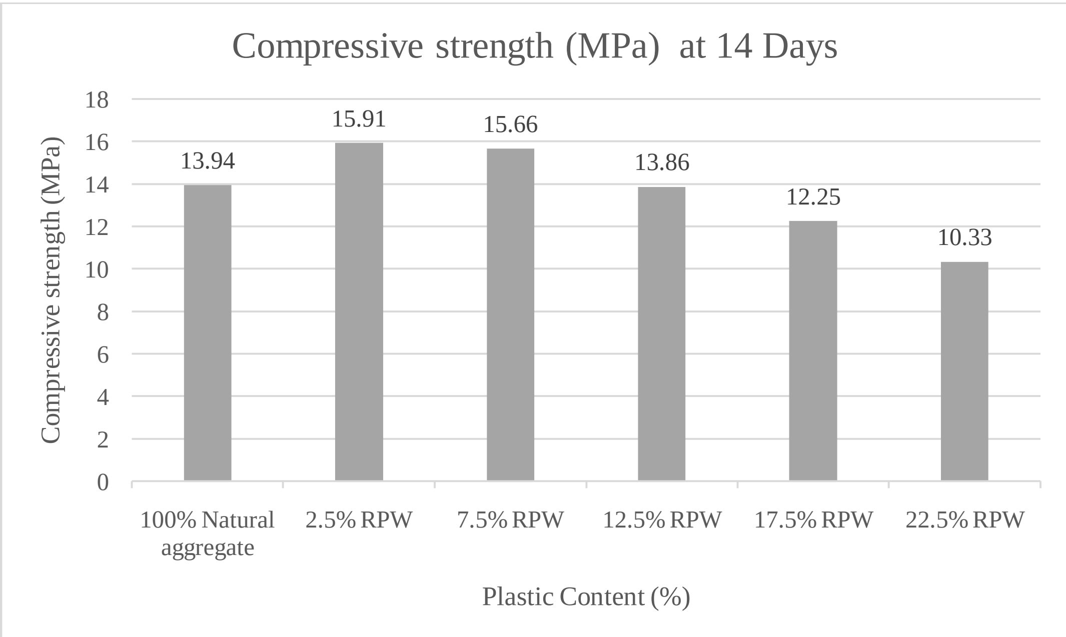

Figure 4: Compressive strength for 14 days

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Table 7: Compressive strength for 28 days

Plastic Content (%)	Compressive Strength (MPa)
0	18.64
2.5	20.07
7.5	19.01
12.5	17.06
17.5	15.08
22.5	12.97

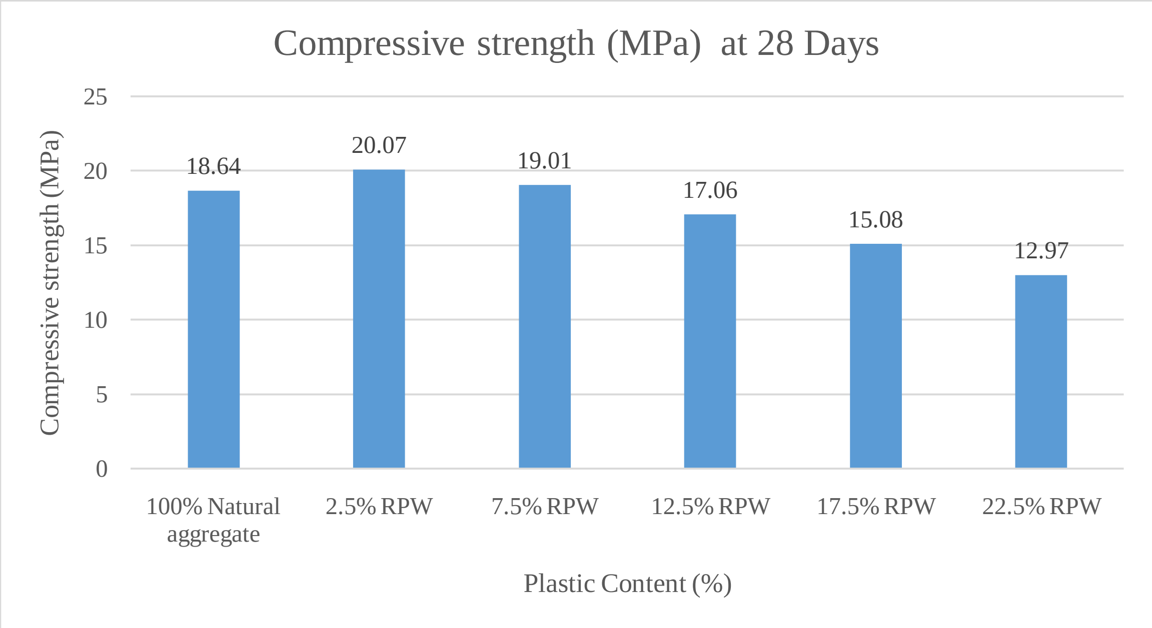

Figure 5: Compressive strength for 28 days

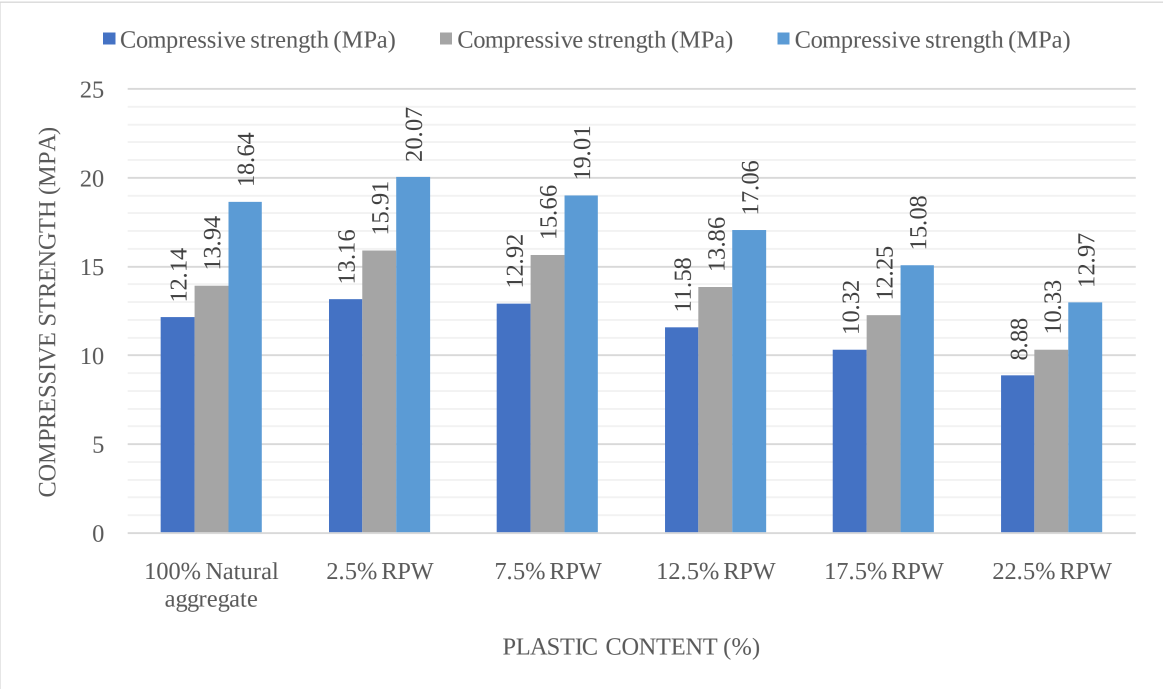

Figure 6: Compressive strength for 7, 14, 28 days

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IV. CONCLUSION

As the quantity of waste plastics increases, the overall strength decreases. Without any plastic waste, a concrete cylinder achieved the highest compressive strength of 18.64 MPa. However, as the percentage of plastic waste increased in subsequent cylinders (2.5%, 7.5%, 12.5%, 17.5%, and 22.5%), the compressive strengths increased to 20.07 MPa, 19.01 MPa and then decrease to 17.06 MPa, 15.08 MPa, and 12.97 MPa respectively. After conducting experiments, it was found that the best amount of plastic waste to replace in a mixture is 7.6% when the waste content is 2.5%. The decrease in strength is due to a lack of adhesion between the waste plastic and cement paste, indicating a weak connection between them. However, higher percentages of waste plastic led to an increase in slump, showing that the plastic does not absorb water. These lower compressive strength values suggest that waste plastic cylinders should only be used in situations where minimal workability is needed, such as in precast bricks, partition wall panels, and channel linings. To enhance strength and bond, future research should focus on grinding the waste plastic into a fine powder and determining the best ratio for maximum packing density. Alternatively, adding a plasticizer may be necessary to improve the bond between the plastic surfaces and cement particles.

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