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ORIGINAL CONTRIBUTION

Production of Structural and Nonstructural Lightweight Concrete Using Slate and Plastic Waste

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Abstract— **Concrete is a construction material that is widely used in the world. In the design of concrete structures, lightweight concrete plays a vital role to decrease the density or a dead load of structural elements. This paper investigates the utilization of slate aggregate as a coarse aggregate replacement and the replacement of plastic waste with fine aggregate for the production of lightweight concrete. The research aims to get the structural and nonstructural lightweight concrete by replacing the lightweight aggregate and evaluate their effects on compressive strength, density, and acidic attack. Before the preparation of concrete for the experiment, different tests were conducted to find out the physical properties of the materials. A concrete mix ratio of 1:1:2 and 0.45 w/c ratio was used for our experiment. Coarse aggregate is replaced by slate aggregate from 80% to 100% replacement and sand is replaced by plastic waste from 50 to 60%. By conducting a compressive strength test, the observed optimum value for structural lightweight concrete was 3105 psi in the case of replacing slate 100% with coarse aggregate and plastic waste 50% with fine aggregate. By replacing 80% of slate with coarse aggregate and 60% of plastic waste with fine aggregate, the optimum value for non-structural lightweight concrete was 2841 psi.**

Index Terms— **Lightweight Concrete, Structural and Nonstructural Concrete, Slate Aggregate, Plastic Waste, Compressive Strength, Cost Estimation**

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I. INTRODUCTION

Researchers and college students in several developing nations have focused their findings on the exploration of alternative materials for the production of inexpensive lightweight concrete. The current trend in concrete development is lightweight concrete, which aims to make concrete lighter than normal concrete. Utilizing lightweight concrete in construction could reduce the cost of development in terms of transporting goods and shorten the duration of the development work [1]. Bond, fine aggregate, coarse aggregate, and water are combined to create concrete. To make the lighter concrete, a ton of additional material was selected. To produce lighter concrete, additional elements like blown slate, plastic debris, sawdust, silica fume, fly ash, papercrete, electronic waste, and so forth can be replaced for the coarse aggregate. Concrete can be used to support a healthier and more sustainable environment by employing them as a substitute for cement, fine aggregate, or coarse aggregate [2]. In addition to the enormous need for concrete, the necessity for Lightweight Concrete for Construction (LWC) is rising daily because of the rise of smart infrastructure [3].

The global structural LWC market was valued at USD 37.2 billion in 2018 and is projected to reach USD 56.7 billion by the year 2026, according to the most recent analysis by Reports and Data of Globe Newswire (2020). It demonstrates the rising global demand for structural LWC. Several new methods of producing structural LWC must be developed to meet this infrastructure requirement, which may result in a rise in the use of cement and natural aggregates [4]. FAC is a hollowed, lightweight, inert material that is packed with air or another inert gas. Because of its unique qualities, including high workability, thermal resistance, low conductivity, and low bulk density, it is utilized in a variety of sectors [5]. FAC incorporation is a viable first step towards the creation of more environmentally friendly lightweight materials [6]. The development of sustainable structural LWC is also done using FAC as the fine aggregate [7]. Scientists have started developing artificial LWA focusing on multiple wastes like agricultural waste, inorganic polymer waste, clay waste for reducing CO_2 emission, industrial by-products, such as fly ash and blast boiler slag, and eco-friendly Capsule Aggregate (CA) with core-shell structured by encapsulating sodium alginate. This is due to the lack of availability of natural lightweight materials to meet the demand for infrastructure. It is important to keep in mind that other materials do exist, but their ecological impact is far lower than that of industrial waste. As a result, research into novel strategies to use large amounts of fly ash in LWC has focused on the LWA made from fly ash [8, 9, 10, 11, 12, 13, 14].

Research on the impact of brick aggregate type is still in its early stages. Bricks come in a variety of raw materials, origins, and characteristics. The majority of studies examine how red brick aggregate affects

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concrete. Red clay brick concrete has been shown to have minimal relative strengths (up to 18% with 30% by weight after 7 days); the strength was increased with curing time, reaching 89% after 28 days. The red brick aggregate's porosity and pozzolanic activity may be the key drivers of this enhancement. It has been discovered that crushed brick aggregate is a low-cost component that can be used to lessen concrete weight and the depletion of natural aggregate. Few studies examined the impact of crushed brick aggregate type or color. To manufacture lightweight concrete with acceptable strength, this research compares two different types of CCB aggregate (yellow and red) with various percentage replacements for coarse and fine aggregate. Those varieties have great workability and require less water when employed in hot or dry environments [15].

EPS concrete is a type of concrete that uses EPS beads as its aggregate. EPS beads can either entirely or in part replace the conventional aggregates [16, 17, 18]. The qualities, sizes, and composition of the EPS beads affect their characteristics. EPS concrete quickly separates and bonds poorly because of its extremely low density and the hydrophobicity of its EPS particles [19]. The addition of EPS beads makes things less workable [20]. Once the content is increased, the workability dramatically declines. Increased strength is provided by the smaller-sized EPS beads. Moreover, when the EPS content rises, the strength and density of concrete decline [21, 22]. Lightweight aggregate concrete has various comparative advantages over regular concrete, such as fire resistance, thermal insulation, moisture resistance, and soundproof structures. Lightweight aggregate concrete is utilized worldwide to minimize the dead load in bridges, dams, and high-rise buildings. To gather samples for this study, two routes—Kaka Sahib to Akora Khattak (N33°55'56" E 072°02'38") and Attock to Peshawar (N33°53'55.5" E072°17'08.8")—were taken from various sites. The northern slopes of the Attock-Cherat Range in Punjab and Khyber Pakhtunkhwa are where you may find the Attock slates. Chemical and physical testing has been done on these slates to determine whether they may be used as aggregate in structural lightweight concrete. Several of the samples had somewhat greater iron and ignition loss values, according to XRF studies, but they were still within acceptable limits. In a rotary kiln, samples were inflated. Following bloating, physical tests were performed following the requirements of the American Standards for Testing Materials (ASTM). Iron staining, bulk density, specific gravity, water absorption, organic impurities, freezing and thawing, and alkali-aggregate reactivity were among the physical tests carried out. After that, concrete cubes, cylinders, and blocks were cast, and their compressive, flexural, and splitting tensile strengths were evaluated per ACI 2112-98 and ASTM 330. When the results of all these tests were compared to the ASTM standard values, it was clear that these slates could be used as structural lightweight concrete aggregate [23].

The main aims and objectives of this project work are as follows;

- To produce structural and non-structural lightweight concrete to enhance development in concrete material with the combination of two locally available lightweight materials.
- To make the concrete with locally available lightweight aggregate material to produce lightweight concrete most economically.

II. MATERIALS AND METHOD

A. Materials

After reading the research papers and fulfilling the research gap, we decided to make lightweight concrete by using a combination of waste plastic and bloated slate. The following materials for the research are used that are mixed according to our proportions for lightweight concrete production.

1) *Cementation material*

Fauji brand of ordinary Portland cement was used in all-out experiments which are easily available at nearby material stores. This cement should be met the standard set by the ASTM C150 which was checked thoroughly and was considered appropriate for the research work as this is a popular cement brand in Pakistan and is used in different mega projects [24].

2) *Physical characteristics of cement*

For the physical characteristic of cement, we decided to the done following test.

- Consistency test
- Density of cement
- Fineness of cement

B. Consistency Test

TABLE I
RESULTS OF STANDARD CONSISTENCY TEST

Serial No.	Consistency Value (%)	Average Value (%)
1	32%	
2	32%	32%
3	32%	

1) *Density of cement*

The density of cement can be achieved with the help of a cement bag. One cement bag contains 50 kg of cement having a volume of 0.0347m3. So its density will be 1440 Kg/m3.

2) *Fineness of cement*

TABLE II
RESULTS OF THE FINESSE OF THE CEMENT TEST

Serial No.	The Fineness of Cement (%)	Average Value (%)
1	96%	
2	95%	95.5%
3	95.5%	

3) *Gradation Analysis of fine aggregates*

Following is the graphical representation of the sieve analysis of fine aggregate.

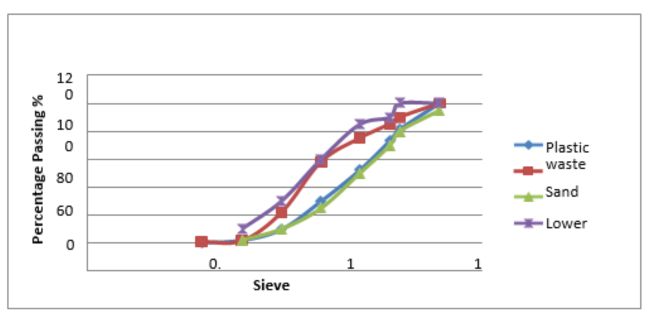

Fig. 1. Sieve Analysis of Fine Aggregate

4) *Course aggregate of coarse aggregates*

Following is the graphical representation of the sieve analysis of coarse aggregate.

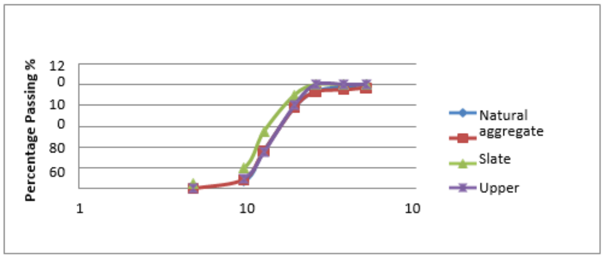

Fig. 2. Gradation of Coarse Aggregate with Upper-Lower Limits

5) Impact value test

Following are the results of the impact value test.

TABLE III
IMPACT VALUE TEST RESULTS

Sample No.	Natural Aggregate Value (%)	Average Value (%)	Slate Aggregate Value (%)	Average Value (%)
1	23.5		33	
2	21.5	22	30.1	31
3	21		29.9	

III. METHODOLOGY

A. Concrete Mixing Proportions

We use an M25 grade of concrete having 1:1:2 ratios of concrete mix design with a 0.45 W/C ratio. Replacement values of fine and coarse aggregates for the concrete are given below.

TABLE IV
MIX PROPORTION

Sample No.	Sample Code	Coarse Aggregate		Fine Aggregate	
		Coarse Aggregate Slate	Natural Aggregate	Plastic Waste	Sand
1	CS	0%	100%	0%	100%
2	C80F50	80%	20%	50%	50%
3	C80F55	80%	20%	55%	45%
4	C80F60	80%	20%	60%	40%
5	C90F50	90%	10%	50%	50%
6	C90F55	90%	10%	55%	45%
7	C90F60	90%	10%	60%	40%
8	C100F50	100%	0%	50%	50%
9	C100F55	100%	0%	55%	45%
10	C100F60	100%	0%	60%	40%

B. Preparation of Hardened Concrete and Test Specimen

We use an M25 grade of concrete having 1:1:2 ratios of concrete mix design with a 0.45 W/C ratio. Replacement values of fine aggregates and coarse aggregates according to our mix proportions. We make four cubes of 6x6x6 inches with each sample proportion. Then we allow them for curing at 28 days. After 28 days, we perform different tests on hardened concrete to find out the different properties of hardened concrete. For the preparation of the concrete mixture, prepare the concrete mix according to the proportions suggested in our experiments. For mixing the concrete, we used hand-mixing methods with hand-mixing equipment such as a spatula. Mix the cement and fine aggregate in a steel tray, then added the coarse aggregate until the mixture is thoroughly mixed and gets uniform color. After that water of measured quantity is added and mixed it properly and thoroughly. For sampling the cubes for the test, molds are cleaned and lightly oiled on the surface. Concrete is filled with three compacted layers with a compacting rod. After sampling in mold, remove the specimens from the molds after 24 hours in the air and then leaving for curing in the water tanks for curing for 28 days. Before performing the test, make dry the specimen in the air.

C. Density of Hardened Concrete

The density could be defined as the relationship between the mass of the substance and the volume of the substance that it takes up during the placing is called density. So, density is a characteristic property of any substance. By calculating the density of cubes, we can compare them to check how much our specimens are lightweight. To find out the density of cubes, weigh all the cubes separately. To find out the average weight of four samples for each proportion, divide the weight of the sample by the volume of the cube. Finally, a graph is plotted between sample names (x-axis) and the water Density of the cube (y-axis), and compare the results.

The density of structural lightweight concrete varies between 1440-1840 kg per m3 and the density of normal concrete varies between 2240-2400 kg per m3.

D. Water Absorption of Hardened Concrete

To find out the rate of absorption of water for hydraulic cement concrete, this test method is used by measuring the increment of mass of the specimen due to the absorption of water as an interval of time when only one surface of the specimen is exposed to water. In this method presence of water in the concrete samples after immersion water is measured.

Limits for water absorption vary between 0.3-2.5 percent and are different for different purposes.

E. Compressive Strength Test

Compressive strength is the capability of a material or structure to bear the loads on its surface area without any creak, break, or deflection. A material under compression leads to reduce the size of the material, while if in tension, it tends to size elongate. For M25 concrete, the Normal strength of concrete is 3600 psi.

F. Durability Test Resistance against Acid Attack

To check the chemical attack on concrete, the durability of the specimen is checked. Durability is the ability to resist abrasion, weathering action, or any other process of deterioration while maintaining its desired engineering properties. Hence it is necessary to test the durability of concrete specimens. For the acid attack test, we pick one sample of each proportion of a concrete cube of known weight after curing. We make the sulphuric acid (H_2SO_4) solution where 5% acid is used in water and immersed the sample into the solution for the test. According to the standard, maintain the pH value at 0.3. After 28 days of immersing in an acid solution, the specimens are taken out and washed with running water, and kept in the open air for 24 hours. Then the weight of specimens is taken again and calculates the weight loss for the different specimens. Also, the compressive test is conducted on affected specimens and compared with normal compressive test results.

IV. RESULTS AND DISCUSSION

Following are the results of the different experiments done for this research work.

A. Slump Test on Fresh Concrete

TABLE V
SLUMP TEST

Serial No.	Sample Code	W/C Ratio	Slump
1	CS	0.55	5”
2	S80F50	0.50	4.5”
3	S80F55	0.48	4.3”
4	S80F60	0.45	4”
5	S90F50	0.45	3.5”
6	S90F55	0.45	3.7”
7	S90F60	0.45	3.8”
8	S100F50	0.45	2.7”
9	S100F55	0.45	3”
10	S100F60	0.45	3”

B. Hardened Concrete Test

Average Density of specimen Result

TABLE VI
AVERAGE DENSITY OF THE SPECIMENS

Serial No.	Sample Code	Average Weight	Density (Kg/m3)
1	CS	8.43	2381
2	C80F50	6.74	1903
3	C80F55	6.72	1898
4	C80F60	6.70	1892
5	C90F50	6.68	1887
6	C90F55	6.64	1875
7	C90F60	6.61	1867
8	C100F50	6.56	1853
9	C100F55	6.35	1793
10	C100F60	6.31	1782

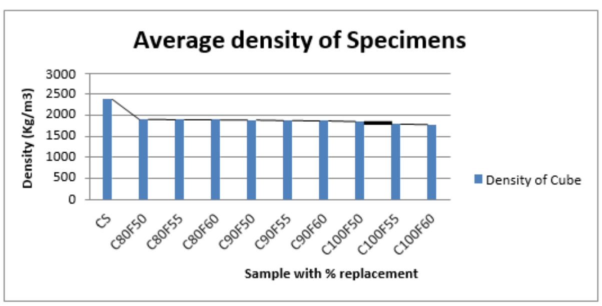

Fig. 3. Average Density of Samples

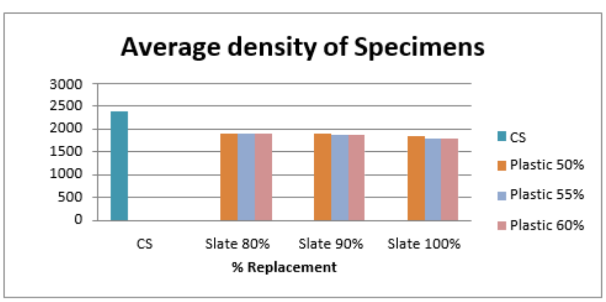

Fig. 4. Average Density of a Sample with Constant Slate Replacement

C. Water Absorption Test

TABLE VII
WATER ABSORPTION TEST RESULT

Serial No.	Sample Code	Water Absorption (%)
1	CS	1.16
2	C8050	1.46
3	C8055	1.45
4	C8060	1.44
5	C9050	1.47
6	C9055	1.46
7	C9060	1.46
8	C10050	1.53
9	C10055	1.5
10	C10060	1.49

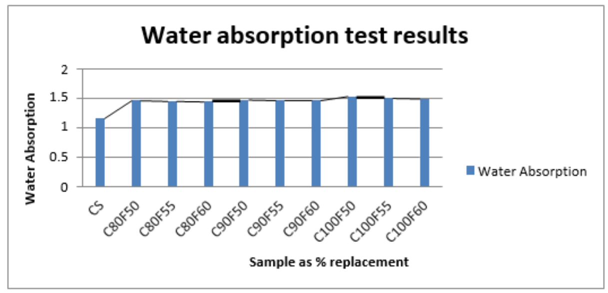

Fig. 5. Water Absorption of the Sample

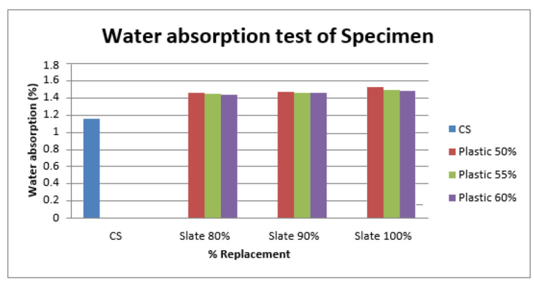

Fig. 6. Water Absorption of the Sample with Constant Slate Replacement

D. Compressive Strength Test

TABLE VIII
COMPRESSIVE STRENGTH TEST RESULTS

Serial No.	Sample Code	Compressive Strength (N/mm2)	Compressive Strength (PSI)
1	CS	36.74153	5327
2	C8050	19.44479	2819
3	C80F55	18.90659	2741
4	C80F60	18.19618	2638
5	C90F50	19.5309	2832
6	C90F55	19.51841	2830
7	C90F60	19.33198	2803
8	C100F50	21.41329	3105
9	C100F55	19.86587	2881
10	C100F60	19.59548	2841

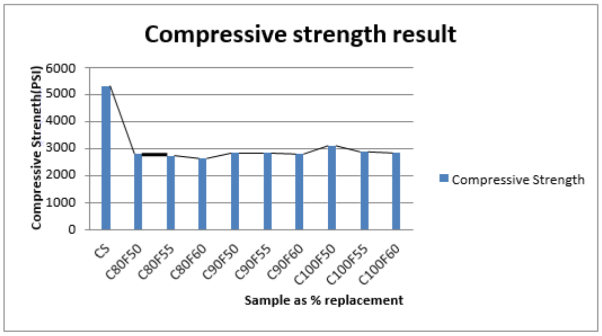

Fig. 7. Compressive Strength Test Result Comparison

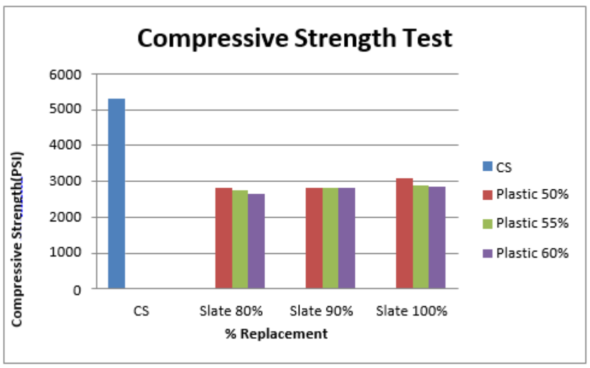

Fig. 8. Compressive Strength Test Result at Constant Slate Replacement

E. Durability Test Resistance against Acid Attack at 28 days

Following is the graphical representation of this investigation.

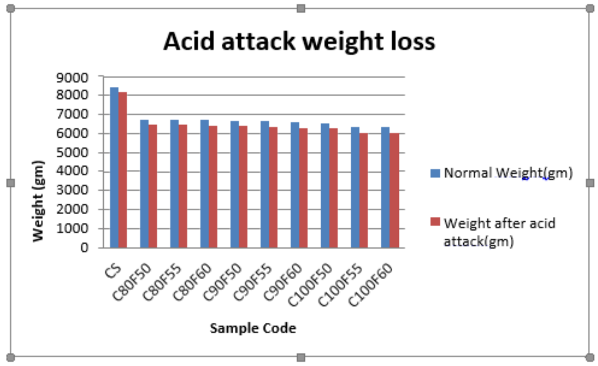

Fig. 9. Weight Loss Due to Acid Attack

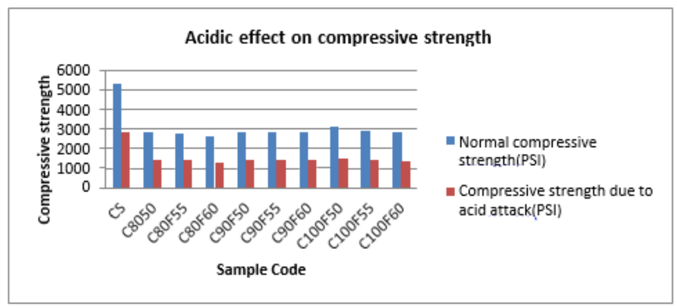

Fig. 10. Acidic Effect Results in Compressive Strength of Concrete

TABLE IX
EFFECT OF ACID ON COMPRESSIVE STRENGTH OF CONCRETE

Sample Code	Normal Compressive Strength (Psi)	Compressive Strength After Acid Attack (Psi)	Compressive Strength Difference (Psi)	Strength Loss in Percentage (%)
CS	5327	2805	2522	47.34%
C8050	2819	1444	1375	48.77%
C80F55	2741	1404	1337	48.77%
C80F60	2638	1302	1336	50.64%
C90F50	2831	1398	1433	50.61%
C90F55	2830	1403	1427	50.42%
C90F60	2803	1400	1403	50.05%
C100F50	3104	1502	1602	51.61%
C100F55	2880	1399	1481	51.42%
C100F60	2841	1344	1497	52.69%

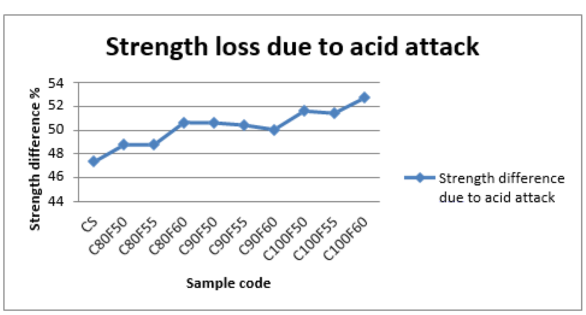

Fig. 11. Strength Losses in Percentage due to Acid Attack

V. CONCLUSION

From the research carried out on the usage of slate aggregate and plastic waste as the replacement of coarse aggregate and fine aggregate, the following were deduced from the results and observations of the test:

- The density of plastic waste and slate is lower than the density of sand and natural coarse aggregate. So these materials could be used as lightweight aggregate by replacement with sand and natural coarse aggregate. We get 25% lighter concrete with compare to normal concrete.
- Plastic waste is lighter compared to slate aggregate.
- Plastic waste and slate aggregate reduce the unit weight of concrete due to their low density as compared to sand and natural coarse ag-

gregate

- We also note that increasing the slate aggregate replacement percentage resulted in to decrease in slump values due to angular and non-uniform shapes. And increasing the plastic waste replacement percentage resulted in to increase in the workability values due to frictionless plastic partials.
- The water absorption rate of lightweight concrete is more than that of normal concrete due to the porous properties of slate aggregate but by increasing the plastic waste, the water absorption value is reduced a little bit. There is a small difference in the water absorption values of lightweight concrete and normal concrete. So water absorption values are within limits and have weatherproofing capabilities.
- By conducting the compressive tests on samples, we realize that the compressive strength of concrete increase by increasing the replacement percentage of slate aggregate but decrease by increasing the replacement percentage of plastic waste.
- At our suggested proportions, we get the structural concrete. We can produce nonstructural concrete by changing the grade of concrete.
- The acid attack test at 28 days, resulted in a loss of weight and strength of lightweight concrete due to acid attack being a little bit greater value as compared to normal concrete but there is not a big difference.
- Crush plastic waste can be successfully used for the production of structural and nonstructural lightweight concrete, which is a great sign of environmental impacts.
- Finally, it was revealed during the study that plastic waste is not a good material for increasing the compressive strength of concrete but good for the production of lightweight concrete. And slate aggregate is good for both lightweight concrete and compressive strength concrete.

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