

# Experimental Investigation of Partial Replacement of Coarse Aggregate with Aluminium Cap in Concrete

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**Abstract**—The accumulation of aluminum waste, particularly discarded bottle caps, presents environmental challenges and encourages the exploration of sustainable construction materials. This study investigates the feasibility of using waste aluminum bottle caps as a partial replacement for coarse aggregate in concrete. The aluminum caps were collected, cleaned, and processed before being incorporated into concrete mixes at various replacement percentages of coarse aggregate. Standard tests were conducted to evaluate workability, density, and compressive strength of the concrete, and the results were compared with conventional concrete. The findings indicate that partial replacement of coarse aggregate with aluminum caps can reduce concrete weight and promote recycling of waste materials. An optimum replacement level was identified where acceptable mechanical performance and sustainability benefits were achieved. The study concludes that aluminum bottle caps can be effectively utilized in concrete for lightweight and non-structural applications, contributing to environmentally friendly construction practices and waste reduction.

**Index Terms**— Waste soft drink (aluminium) caps, M sand, Coarse aggregate, Cement, and Water.

## I. INTRODUCTION

Concrete is one of the most widely used construction materials in the world due to its strength, durability, and versatility. It is primarily composed of cement, fine aggregate, coarse aggregate, and water. Among these components, coarse aggregate plays a significant role in providing strength and stability to concrete. However, the continuous extraction of natural aggregates leads to environmental degradation and depletion of natural resources. In recent years, there has been a growing interest in utilizing waste materials

in concrete production as a sustainable alternative. Aluminium bottle caps, which are commonly discarded as waste, pose environmental challenges due to their non-biodegradable nature. Recycling or reusing such waste materials in construction can help reduce landfill waste and promote eco-friendly practices.

This study focuses on the partial replacement of coarse aggregate with aluminium caps in concrete. The use of aluminium caps not only helps in waste management but also has the potential to influence the mechanical properties of concrete, such as compressive strength, tensile strength, and workability. The main objective of this experimental investigation is to evaluate the performance of concrete when coarse aggregate is partially replaced with aluminium caps at different percentages. By analyzing the results, the study aims to determine the feasibility of using aluminium caps as an alternative material in concrete production, thereby c

## II. LITERATURE REVIEW

The benefits of using waste materials like fly ash and plastic waste are considerable reduction in the use of natural raw materials, responsible for industrial sustainability, solves the disposal problems of wastes as these are utilized in construction activities, plastic improves some properties of bituminous mixes used for paving roads (Mishra & Gupta, 2017). In order to withstand tyre and weather, pavement surface layers contain the strongest and most expensive materials in road structures. Characteristics they exhibit like friction, strength, noise and ability to drain off surface water are essential to vehicles' safety and riding quality (Huang, Bird, & Heidrich, 2007) on tributing to sustainable construction practices.

### III. METHODOLOGY

The methodology for this experimental study involves the preparation and testing of concrete by partially replacing coarse aggregate with aluminium caps. Initially, the required materials such as cement, fine aggregate, coarse aggregate, aluminium caps, and water are collected. The aluminium soft drink bottle caps are cleaned properly to remove impurities and are cut or crushed into suitable sizes similar to coarse aggregate. A concrete mix design (such as M 30 grade) is prepared according to standard guidelines. A control mix is first prepared without aluminium caps, and then coarse aggregate is partially replaced with aluminium caps at different percentages (for example 8%, 12%, and 16%). The materials are weighed accurately as per the mix design.

Dry mixing of cement, fine aggregate, and coarse aggregate is carried out first, after which aluminium caps are added according to the required replacement percentage. Water is then added gradually and mixed thoroughly to obtain a uniform concrete mix. The fresh concrete is placed into standard moulds such as cubes (for compressive strength) and cylinders (for split tensile strength). Proper compaction is done using a tamping rod or vibrator to remove air voids, and the surface is finished smoothly.

After 24 hours, the specimens are removed from the moulds and cured in water for 7, 14, and 28 days. After curing, the specimens are tested using a compression testing machine and tensile testing setup. Finally, the results obtained from different replacement levels are compared with conventional concrete to evaluate the performance and determine the optimum percentage of aluminium cap replacement.

### IV. MATERIALS AND METHODS

In this experimental study, Ordinary Portland Cement (OPC) of grade 43 or 53 is used as the binding material. Fine aggregate such as natural river sand or manufactured sand (M-sand) is used, which conforms to standard specifications. Coarse aggregate of size 20 mm is used to provide strength and stability to the concrete. Waste aluminium soft drink bottle caps are collected and used as a partial replacement for coarse aggregate. These caps are properly cleaned to remove impurities and are cut or crushed to obtain a suitable size. Clean potable water is used for mixing and curing

the concrete. The concrete mix is designed for a required grade, such as M30, according to standard guidelines. A control mix is prepared without aluminium caps, and then coarse aggregate is partially replaced with aluminium caps at different percentages such as 5%, 10%, and 15%. All materials are properly prepared before mixing. The aluminium caps are cleaned and sized, and aggregates are sieved if necessary. The required quantities of cement, fine aggregate, coarse aggregate, and aluminium caps are weighed accurately.

The mixing process is carried out by first dry mixing the cement, fine aggregate, and coarse aggregate. Aluminium caps are then added according to the replacement percentage, and water is added gradually to obtain a uniform concrete mix. The prepared concrete is poured into moulds of cubes, cylinders, and beams. Proper compaction is done using a tamping rod or vibrator to remove air voids, and the surface is finished smoothly. After 24 hours, the specimens are removed from the moulds and placed in water for curing. The curing is carried out for 7, 14, and 28 days. Finally, tests such as slump test for workability, compressive strength test, split tensile strength test, and flexural strength test are conducted. The results are compared with conventional concrete to evaluate the performance and determine the optimum percentage of aluminium cap replacement.

#### 4.1. Physical properties of material

The physical properties of concrete are influenced when coarse aggregate is partially replaced with aluminium caps due to their different shape, texture, and density. Aluminium caps have a lower density compared to natural coarse aggregates, which results in a reduction in the overall weight of concrete. This makes the concrete lighter, which can be beneficial for reducing dead load in structures. The shape and surface texture of aluminium caps are generally smooth and irregular compared to crushed stone aggregates. Because of this, the bonding between cement paste and aluminium caps is weaker, which may affect the strength and durability of the concrete. The water absorption of aluminium caps is very low compared to natural aggregates. This leads to less water being absorbed during mixing, which can slightly improve the workability of concrete. In terms of workability, the presence of aluminium caps may increase or decrease it depending on their size and

percentage. Due to their smooth surface, the mix may become more workable at lower replacement levels. The bulk density of concrete decreases as the percentage of aluminium caps increases. This is due to the lightweight nature of aluminium material.

The void content in concrete may increase because aluminium caps do not pack as efficiently as natural aggregates. This can lead to more air gaps within the concrete matrix. The thermal conductivity of concrete with aluminium caps may slightly change, as aluminium is a good conductor of heat, but due to its small quantity, the overall effect is limited. Overall, the physical properties indicate that aluminium caps can be used as a lightweight replacement material, but only up to a certain percentage to maintain proper concrete performance.



Table 1 Physical properties of Aluminium caps

Density	2.7 g/cm <sup>3</sup>
Melting point	660°C
Boiling point	2519°C

#### Durability

Corrosion resistant (forms oxide layer naturally)  
Does not absorb water → improves resistance to moisture damage

#### Workability Impact

Improves workability due to smooth surface  
May cause segregation if used in higher percentages

#### Mechanical Properties

Low strength: Aluminium caps are weaker than stone aggregates  
High ductility: They can deform instead of breaking

under load

Low stiffness: Reduces overall rigidity of concrete

#### 1. Coarse aggregate



#### 2. Cement



#### 3. Water



#### 4. Fine aggregate



The cube is then placed in a Compression Testing Machine (CTM) such that the load is applied uniformly on opposite faces of the cube. The load is applied gradually without shock at a constant rate until the cube fails or cracks. The maximum load applied at the time of failure is recorded. The compressive strength of the concrete is calculated using the formula:

$$f_c = \frac{P}{A}$$

Where:

(c) = Compressive strength (N/mm<sup>2</sup>)

P = Maximum load at failure (N)

A = Cross-sectional area of the cube (mm<sup>2</sup>)

The result is expressed in N/mm<sup>2</sup> (MPa). Usually, the average strength of three cubes is taken as the final result. This test helps in determining whether the concrete has achieved the required strength and is suitable for construction purposes.

#### 4.2. Compression Test on Concrete Cube

The compressive strength test is conducted to determine the strength of concrete. It is one of the most important tests in concrete technology. In this test, concrete cubes of standard size (usually 150 mm × 150 mm × 150 mm) are prepared using the required mix. After casting, the cubes are kept in moulds for 24 hours and then removed and cured in water for 7, 14, or 28 days. Before testing, the cubes are taken out from the curing tank and wiped to remove excess water. The dimensions of the cube are checked to ensure accuracy.

Table 2 Quantities of concrete for Normal Mix and 4%, 8%, 12%, 16% replacement of coarse aggregate.

% Replacement	Cement (Kg/m <sup>3</sup> )	Fine aggregate (Kg/m <sup>3</sup> )	Natural Coarse Aggregate (Kg/m <sup>3</sup> )	Recycled Aluminium Cap (Kg/m <sup>3</sup> )	Water (Kg/m <sup>3</sup> )
0%	492.5	614.65	1200	-	197
4%	492.5	614.65	1152	48	197
8%	492.5	614.65	1104	96	197
12%	492.5	614.65	1056	144	197
16%	492.5	614.65	1008	192	197

#### 4.3. Split Tensile Strength Test in Cylinder

The split tensile strength test is used to determine the tensile strength of concrete indirectly. Since concrete is weak in direct tension, this test provides a simple and reliable method to evaluate its tensile behavior. In this test, a concrete cylinder (usually 150 mm in diameter and 300 mm in height) is placed horizontally in a Compression Testing Machine (CTM). The load is applied along the length of the cylinder, which creates tensile stress perpendicular to the direction of the applied load. As the load increases gradually, the cylinder develops cracks and finally splits into two halves along its vertical diameter. The maximum load applied at the time of failure is recorded. The split tensile strength is calculated using the formula:

$$f_t = \frac{2P}{\pi DL}$$

Where:

f<sub>t</sub> = Split tensile strength (N/mm<sup>2</sup>) P = Maximum load at failure (N) D = Diameter of the cylinder (mm) L = Length of the cylinder (mm)

This test helps in understanding the cracking behavior and tensile performance of concrete, which is important for structural design.

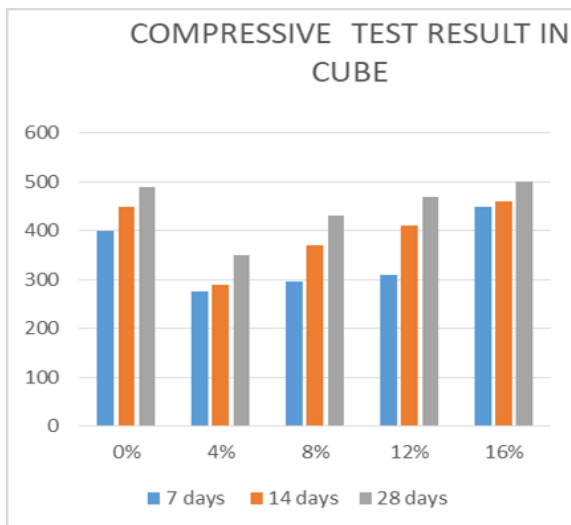
## V. RESULTS AND DISCUSSION

From the compressive strength test, it is observed that the strength of concrete increases with increase in the percentage of aluminium caps at 8%, 12%, and 16%. Among these, the maximum compressive strength is achieved at 16% replacement. This improvement may be due to better particle distribution and internal confinement provided by the aluminium caps within the concrete matrix. Similarly, the split tensile strength test results also show an increasing trend with higher percentages of aluminium cap replacement.

The tensile strength is enhanced at 8%, 12%, and 16%, indicating that the presence of aluminium caps contributes to improved resistance against cracking. The increase in strength can be attributed to the effective filling of voids and improved interaction between the aluminium caps and cement paste.

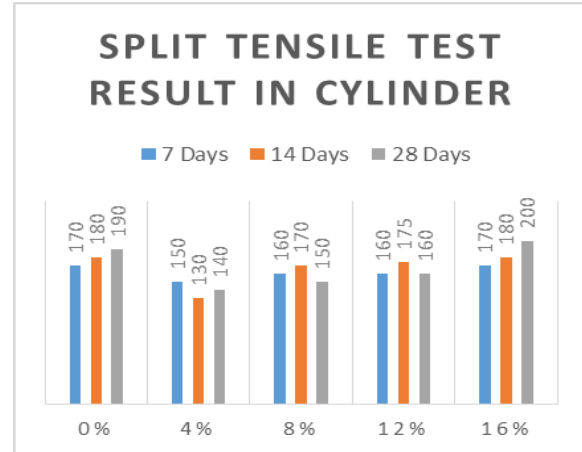
### RESULT OF THE CUBE

No	Days	0%	4%	8%	12%	16%
1	7th day	400	275	295	310	450
2	14th day	450	290	370	410	460
3	28th day	490	350	430	470	300



### RESULT OF THE CYLINDER

No	Days	0%	4%	8%	12%	16%
1	7th day	170	150	160	160	170
2	14th day	180	130	170	175	185
3	28th day	190	135	150	160	200



## VI. CONCLUSION

From the experimental investigation on the partial replacement of coarse aggregate with aluminium caps in concrete, it is concluded that the strength of concrete varies with the percentage of replacement. The test results indicate that compressive strength and split tensile strength do not significantly improve at lower replacement levels such as 8% and 12%. However, a noticeable increase in strength is observed at 16% replacement, which gives the maximum strength among all the mixes. The improvement at 16% may be due to better packing, improved stress distribution, and effective interaction between aluminium caps and the cement matrix at this specific proportion. At lower percentages, the aluminium caps may not contribute effectively to strength, whereas at 16%, they enhance the performance of concrete. Therefore, it can be concluded that 16% is the optimum percentage for partial replacement of coarse aggregate with aluminium caps in this study. This approach also supports sustainable construction by utilizing waste materials while maintaining or improving concrete strength.

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