Performance and Environmental Impact of Lightweight Concrete: A Study on Ingredient Proportions and Sustainability

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Abstract:

Lightweight concrete (LWC) has emerged as a sustainable alternative to conventional concrete, offering reduced density, improved thermal insulation, and lower environmental impact. This study evaluates the mechanical properties and environmental sustainability of LWC by analysing the effects of varying ingredient proportions, including Lightweight Expanded Clay Aggregates (LECA), Expanded Polystyrene Beads (EPS), Waste Iron Chips, No-Fines Concrete, and Blast Furnace Slag. Experimental results demonstrate that LECA-based concrete exhibits superior strength-to-weight ratios, making it suitable for structural applications, while EPS-based concrete offers excellent thermal insulation but lower mechanical strength. The environmental analysis reveals that the use of industrial by-products like Waste Iron Chips and Blast Furnace Slag significantly reduces the carbon footprint of concrete production. This study provides valuable insights into optimizing lightweight concrete mixes for both performance and sustainability, contributing to the advancement of eco-friendly construction materials.

Keywords:

Lightweight Concrete, Mechanical Properties, Environmental Impact, Sustainable Construction, LECA, EPS, Waste Iron Chips, Blast Furnace Slag.

1. Introduction

The construction industry is increasingly prioritizing sustainability, efficiency, and innovation, driving the demand for advanced materials like lightweight concrete (LWC). LWC offers numerous benefits, including reduced structural load, enhanced thermal insulation, and improved workability. However, the performance of LWC is highly dependent on the quality and characteristics of its ingredients, such as lightweight aggregates, cementitious materials, and admixtures. This study focuses on two key objectives:

i. Evaluating the mechanical properties of LWC with varying ingredient proportions.
ii. Analysing the environmental impact of different ingredient combinations, including energy consumption and carbon footprint.

The findings of this study aim to provide practical guidelines for engineers and researchers in developing high-performance, sustainable LWC solutions.

2. Materials and Methods

2.1 Materials

The following materials were used in this study:

- Lightweight Expanded Clay Aggregates (LECA): Porous, lightweight, and durable.
- Expanded Polystyrene Beads (EPS): Lightweight, thermally insulating, but with lower mechanical strength.
- Waste Iron Chips: Industrial by-product used to enhance compressive strength.
- No-Fines Concrete: Eliminates fine aggregates, offering superior permeability and lightweight properties.
- Blast Furnace Slag: Supplementary cementitious material that improves durability and reduces carbon emissions.

2.2 Experimental Design

- Mix Proportions: Various lightweight concrete mixes were designed with different replacement ratios of lightweight materials (0%, 5%, 10%, 15%, 20%, 25%, and 30%).
- Testing Procedures:
  - Compressive Strength: Tested at 7, 14, 28, and 56 days using standard cube specimens (150 mm × 150 mm × 150 mm).
  - Tensile Strength: Split tensile strength tests were conducted on cylindrical specimens (150 mm diameter × 300 mm height).
  - Flexural Strength: Tested on beam specimens (500 mm × 100 mm × 100 mm) using a four-point loading setup.
  - Environmental Impact: Energy consumption and carbon footprint were calculated based on material production and transportation data.

3. Results and Discussion

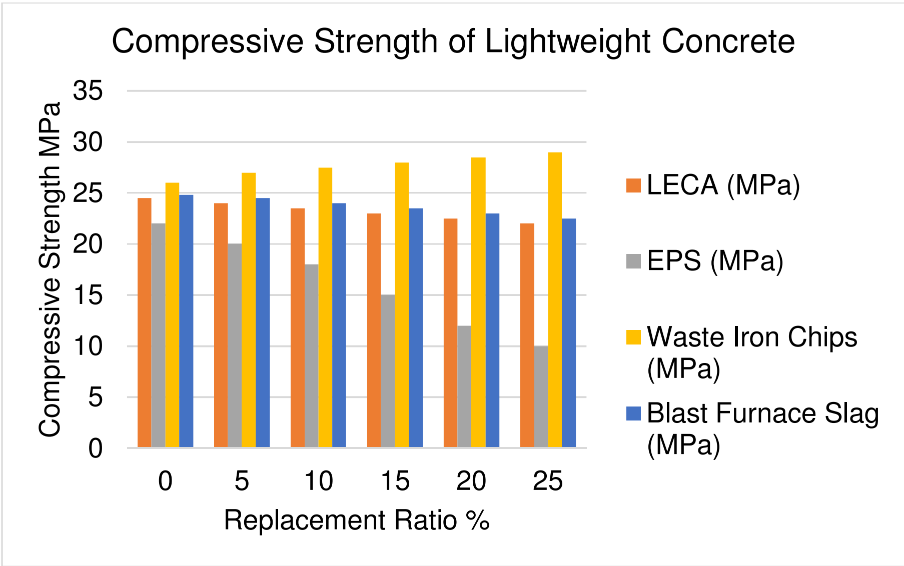
3.1 Mechanical Properties

3.1.1 Compressive Strength

The compressive strength of LWC varied significantly based on the type and proportion of lightweight aggregates. Graph 1 shows the compressive strength results for different mixes.

Table 1: Compressive Strength of Lightweight Concrete

Replacement Ratio (%)	LECA (MPa)	EPS (MPa)	Waste Iron Chips (MPa)	Blast Furnace Slag (MPa)
0	25	25	25	25
5	24.5	22	26	24.8
10	24	20	27	24.5
15	23.5	18	27.5	24
20	23	15	28	23.5
25	22.5	12	28.5	23
30	22	10	29	22.5



Graph 1: Compressive Strength of Lightweight Concrete with Varying Ingredient Proportions

- LECA-based concrete exhibited moderate compressive strength (20-25 MPa) with a density reduction of 20-30%.
- EPS-based concrete showed lower compressive strength (10-15 MPa) but excellent thermal insulation properties.

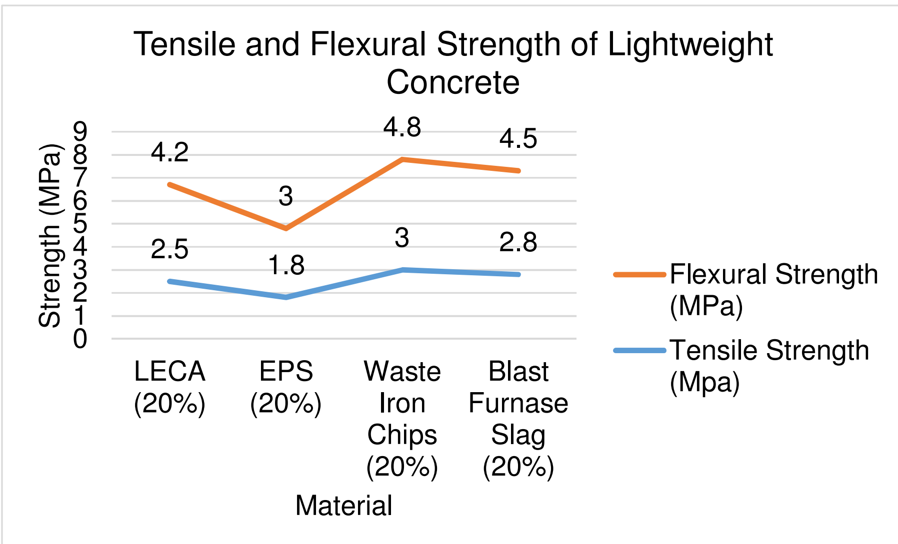
- Waste Iron Chips enhanced compressive strength by 15-20% due to additional reinforcement in the concrete matrix.

3.1.2 Tensile and Flexural Strength

The tensile and flexural strength results are summarized in Table 2.

Table 2: Tensile and Flexural Strength of Lightweight Concrete

Tensile and Flexural Strength of Lightweight Concrete		
Material	Tensile Strength (Mpa)	Flexural Strength (MPa)
LECA (20%)	2.5	4.2
EPS (20%)	1.8	3
Waste Iron Chips (20%)	3	4.8
Blast Furnace Slag (20%)	2.8	4.5



Graph 2: Tensile and Flexural Strength of Lightweight Concrete with different materials

- Waste Iron Chips provided the highest tensile and flexural strength, making them suitable for structural applications.
- EPS-based concrete had the lowest tensile and flexural strength, limiting its use to non-structural applications.

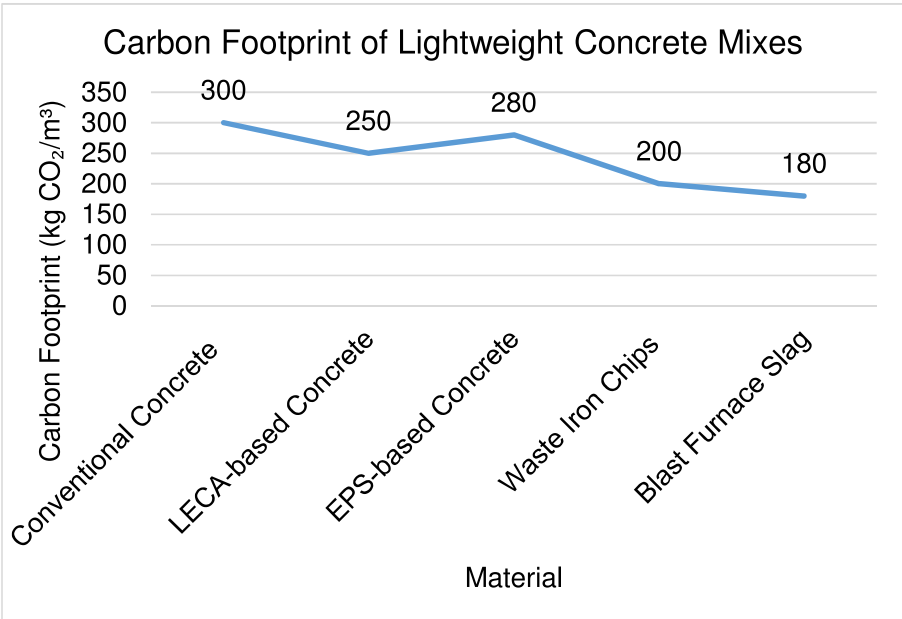
3.2 Environmental Impact

3.2.1 Carbon Footprint

The carbon footprint of LWC was calculated based on the energy consumption during material production and transportation. Graph 3 compares the carbon footprint of different LWC mixes.

Table 3: Carbon Footprint of Lightweight Concrete Mixes

Material	Carbon Footprint (kg CO_2/m^3)
Conventional Concrete	300
LECA-based Concrete	250
EPS-based Concrete	280
Waste Iron Chips	200
Blast Furnace Slag	180



Graph 3: Carbon Footprint of Lightweight Concrete Mixes

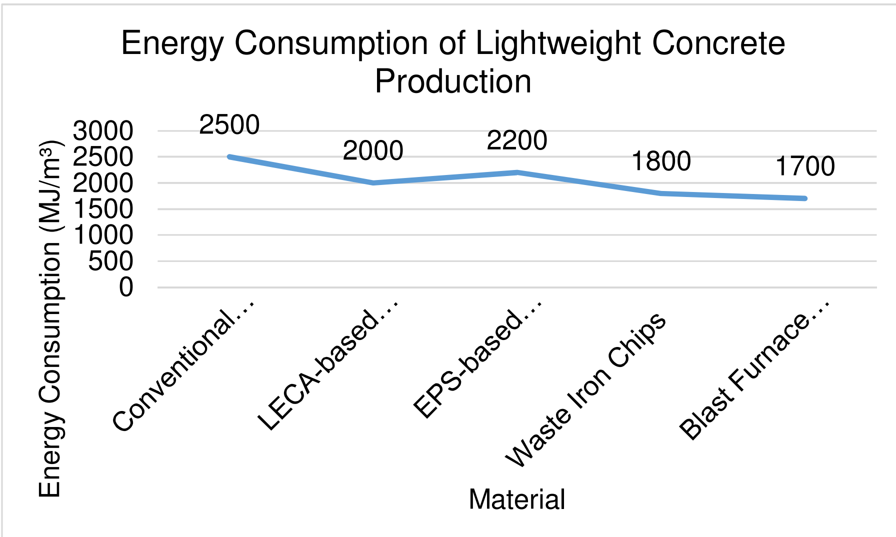
- Blast Furnace Slag reduced the carbon footprint by 30-40% compared to conventional concrete.
- EPS-based concrete had a higher initial carbon footprint due to the energy-intensive production of EPS beads.

3.2.2 Energy Consumption

The energy consumption of LWC production is summarized in Table 4.

Table 4: Energy Consumption of Lightweight Concrete Production

Energy Consumption of Lightweight Concrete Production	
Material	Energy Consumption (MJ/m³)
Conventional Concrete	2500
LECA-based Concrete	2000
EPS-based Concrete	2200
Waste Iron Chips	1800
Blast Furnace Slag	1700



Graph 4: Energy Consumption of Lightweight Concrete Production

- Waste Iron Chips and Blast Furnace Slag demonstrated the lowest energy consumption, making them environmentally favourable.

4. Conclusion

This study provides a comprehensive analysis of the mechanical properties and environmental impact of lightweight concrete. The key findings are:

1. LECA-based concrete offers a balanced combination of strength and weight reduction, making it suitable for structural applications.

2. EPS-based concrete is ideal for non-structural applications requiring thermal insulation but has lower mechanical strength.

3. Waste Iron Chips and Blast Furnace Slag significantly enhance the sustainability of LWC by reducing carbon emissions and energy consumption.

The results highlight the potential of lightweight concrete in promoting sustainable construction practices. Future research should focus on optimizing mix designs and exploring the long-term performance of LWC under varying environmental conditions.

5. References

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