Feasibility and experimental investigation of mechanical properties of sustainable concrete incorporating cow dung ash and plastic waste

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- This paper explores the use of sustainable materials in the production of reinforced concrete. Specimens were developed using cow dung ash as a partial cement replacement and plastic waste as an additive. Ordinary portland cement 53 Grade was used for the control specimens.
- Testing was conducted to review the performance of the beams, including load-bearing capacity, deflection, and flexural strength.

Concrete is a fundamental material in modern construction due to its robustness, durability, and cost-effectiveness. However, its production and maintenance contribute significantly to environmental challenges. The manufacturing of portland cement, a primary component of concrete, is energy intensive and emits considerable amounts of carbon dioxide (CO_2), a leading greenhouse gas. The environmental footprint of cement production has prompted researchers to explore sustainable alternatives that reduce CO_2 emissions and enhance material performance.[1]

This study focuses on a novel concrete mixture that incorporates cow dung ash and plastic waste as supplementary materials. Cow dung ash, a byproduct of cattle farming that is often discarded or used inefficiently, exhibits pozzolanic properties that can partially replace cement in concrete, potentially enhancing concrete's long-term strength and sustainability.[2] Plastic waste, a significant environmental pollutant, can be repurposed as an additive to improve the flexural strength and durability of concrete.[3] The goal of this research is to use these waste materials to develop a sustainable and environmentally friendly concrete mixture that exhibits superior performance characteristics, thereby addressing both waste management and material performance issues in the construction industry.

Given the increasing concerns about climate change and resource depletion, the construction industry is under pressure to adopt more sustainable practices. The use of alternative materials in concrete can address environmental issues and also provide economic benefits by reducing the concrete industry's reliance on traditional raw materials.[4] The integration of waste materials such as cow dung ash and plastic waste into concrete production exemplifies a circular economy approach, where waste products are repurposed to create valuable building materials.[5]

Previous research explored the uses of cow dung ash and recycled plastic waste in concrete individually but did not consider their combined application. In this study, the primary objective was to investigate the feasibility of incorporating cow dung ash as a partial replacement for cement and plastic waste as an admixture to develop an optimized sustainable concrete mixture, referred to in this research as optimized concrete mixture or optimized mixture.

In the experimental investigation, the authors determined the optimal proportions of cow dung ash and plastic waste to enhance the performance of the optimized concrete mixture under static loading while maintaining workability and durability comparable to conventional concrete and then compared the compressive strength, flexural strength, and durability of specimens made with the experimental concrete mixture to controls made with conventional concrete. The findings of this study could pave the way for more widespread adoption of sustainable materials in the construction industry, ultimately contributing to a reduction in the environmental impact of building practices.[6]

Literature review

The environmental impact of conventional concrete production is well documented, with the calcination process in cement manufacturing being a contributor to CO_2 emissions.[7] Cement production is responsible for approximately 8% of global CO_2 emissions.[8] In addition, the extraction of natural aggregates, such as sand and gravel, leads to the depletion of natural resources and environmental degradation.[9]

The incorporation of industrial byproducts and waste materials in concrete has been extensively studied as a sustainable option. Fly ash, silica fume, and slag have been used to replace portions of cement, resulting in reduced CO_2 emissions and improved material properties.[10] Similarly, agricultural waste products such as rice husk ash and bagasse ash have shown promise as supplementary cementitious materials.[11] Cow dung ash, which can be derived from the combustion of cow dung, is rich in pozzolanic compounds such as calcium oxide and silicon dioxide.[12] Research has demonstrated that cow dung ash can enhance the compressive strength and durability of concrete when used as a partial cement replacement.[13] Studies have also indicated that cow dung ash can improve the workability and reduce the setting time of concrete mixtures.[14]

The use of plastic waste in concrete has gained attention in the context of the growing plastic pollution crisis. Incorporating plastic waste into concrete can enhance concrete's flexural strength, toughness, and impact resistance.[15] Studies have shown that plastic waste can reduce the density and thermal conductivity of concrete, making it suitable for lightweight and thermal-insulating applications.[16] Challenges include achieving a homogeneous mixture and ensuring that the mechanical properties of the concrete are not compromised.[17]

The synergistic effects of cow dung ash and plastic waste in concrete can lead to improved mechanical properties, reduced environmental impact, and better waste management solutions.[18] However, the adoption of sustainable concrete incorporating waste materials also presents challenges. One of the main challenges is ensuring the uniform distribution and compatibility of cow dung ash and plastic waste within the concrete matrix. The chemical composition of cow dung ash varies, depending on the source and combustion conditions, and that variability can affect the pozzolanic activity and overall performance of the concrete.[19] Similarly, the physical and chemical properties of plastic waste, such as its density, melting point, and chemical reactivity, can influence the workability and mechanical properties of the concrete mixture.[20]

Despite these challenges, the potential benefits of sustainable concrete are significant. The use of cow dung ash as a partial cement replacement can lower CO_2 emissions associated with cement manufacturing. In addition, the incorporation of plastic waste can enhance the flexural strength and impact resistance of the concrete.[21] Previous studies have demonstrated that the synergistic effects of combining multiple waste materials can lead to improved concrete performance, offering a sustainable solution to the construction industry's environmental challenges.[22] The successful use of sustainable concrete requires a comprehensive understanding of the material properties, mixture proportions, and performance characteristics of these types of concrete.[23]

Materials

Cement

For this research, ordinary portland cement (OPC) 53 Grade (7.7 ksi) was selected because of its high early strength and widespread application in structural concrete. This grade of cement is commonly used for demanding structural projects where rapid strength gain is critical. The use of OPC 53 Grade ensures early strength development and long-term durability. OPC 53 is comparable to ASTM Type III cement, which is also designed for high early strength. It differs from Type I cement, which is intended for general-purpose applications, and Type II cement, which offers moderate sulfate resistance.

Cow dung ash

Cow dung ash has a specific gravity of 2.70, reflecting the ratio of its density compared to water, which is critical for calculating appropriate proportions in concrete and determining the overall weight of the material. Cow dung ash is also very fine, with 95% of its particles passing through a

75 μm (0.00295 in.) sieve. As a result, it is suitable for use as a supplementary cementitious material. Given its fine particle size, cow dung ash can help fill voids in the concrete, resulting in a denser and more cohesive mixture. The moisture content of cow dung ash is 8.5%, indicating a relatively high water content. Its bulk density of 1565 kg/m^3 (2641 lb/yd^3) influences handling and mixing processes. Cow dung ash also demonstrates good soundness, with a value of 10 mm (0.39 in.), ensuring stability in volume after setting and reducing the risk of cracking in concrete over time. These physical properties make cow dung ash a promising alternative material for partial cement replacement, capable of contributing to sustainability and improved performance when appropriately incorporated into concrete mixtures. **Table 1** provides detailed information on the physical properties of cow dung ash.

A separate study will need to be conducted to quantify the exact CO_2 emissions and other gases released during the production of cow dung ash. However, previous research has demonstrated that the combustion of organic matter like cow dung predominantly releases CO_2, water vapor, and minor quantities of other gases, such as carbon monoxide, nitric oxide, and methane, depending on the combustion conditions and efficiency. For example, Sarker et al.[24] highlighted that the calcination of agricultural waste materials, including cow dung, results in the release of CO_2 due to the breakdown of carbon compounds. These studies also emphasized that controlled combustion can significantly mitigate harmful emissions. These insights will guide the design and execution of the planned experimental setup as part of our ongoing research in future work.

Plastic waste

The plastic waste used in the experimental investigation originated from the Cauvery River basin in Chidambaram, India. Although the specific location is not critical for the research itself, it provides context regarding the potential type and composition of plastic waste encountered in this region. The collected plastic waste primarily consisted of nondegradable plastics such as polyethylene and polypropylene, along with impurities such as dirt, organic residues, oils, and nonplastic materials.

To prepare the plastic waste for use in concrete, a systematic cleaning and shredding process was employed. Initially, workers manually sorted the plastic waste, separating it from nonplastic items, including metals, glass, and stones, as well as organic matter, such as leaves and twigs. The sorted plastic waste was then washed in large cleaning tanks filled with water and a mild detergent solution, where it was agitated for 15 to 20 minutes to loosen and eliminate surface contaminants, such as oils and dirt. After washing, the plastic waste was thoroughly rinsed multiple times with clean water to remove detergent residue. The cleaned plastic was subsequently spread out on drying racks under sunlight to remove all residual moisture, ensuring its suitability for shredding and incorporation into the concrete mixture.

Table 1. Physical properties of cow dung ash

Property	Value
Specific gravity	2.70
Fineness passing 75 μm sieve, %	95
Moisture content, %	8.5
Bulk density, kg/m^3	1565
Soundness, mm	10

Note: 1 mm = 0.0394 in.; 1 kg/m^3 = 1.6875 lb/yd^3.

Once dried, the plastic waste was processed using a mechanical shredder (**Fig. 1**), where it was broken down into fine uniform particles suitable for incorporation into the concrete mixture. The shredded particles were then inspected to ensure cleanliness and uniformity, with any inadequately cleaned material reprocessed. The plastic waste particles were incorporated into the concrete mixture at a proportion of 1.5% by weight of the binder.

Table 2 summarizes the physical properties of the plastic waste. The shredded plastic waste used in the concrete mixture was nondegradable, with a particle size of 2 to 4 mm (0.08 to 0.16 in.). Particle size was determined through a sieve analysis in accordance with the Bureau of Indian Standards (IS) 2386 (part 1),[25] where the shredded plastic was passed through a series of standard sieves and the particle distribution was calculated.

Mechanical shredder   Shredded plastic waste

Figure 1. Processing of plastic waste.

Table 2. Physical properties of plastic waste	
Property	**Value**
Type of plastic	**Nondegradable shredded plastic**
Particle size, mm	2 to 4
Specific gravity	0.90
Fineness modulus	2.56
Density, kg/m^3	1565
Water absorption	negligible

Note: 1 mm = 0.0394 in.; 1 kg/m^3 = 1.6875 lb/yd^3.

The specific gravity of plastic waste was 0.90. Specific gravity was measured using the pycnometer method outlined in IS 2386 (part 3).[26] The procedure involves weighing the plastic sample in air and in water and then using those values to calculate the specific gravity.

The fineness modulus of the shredded plastic waste was 2.56. This value, which indicates the relative coarseness or fineness of particles, was calculated using the sieve analysis method described in IS 383.[27] The cumulative percentage retained on standard sieves was divided by 100 to obtain the fineness modulus.

The density of the shredded plastic waste was 1565 kg/m^3 (2641 lb/yd^3). Density was calculated from the measured volume and mass of the shredded plastic waste in accordance with IS 2386 (part 3).[26] This property is critical in calculating the mixture proportions.

The water absorption of the plastic waste was negligible (that is, the plastic waste did not absorb water in any significant quantity). Water absorption was tested by immersing the plastic in water for 24 hours and measuring any increase in weight, in accordance with IS 2386 (part 3).[26] These properties are essential for understanding the behavior of shredded plastic in concrete, particularly how it interacts with the other components and influences the workability, strength, and durability of the concrete mixture.

Experiment

Determining the optimum concrete mixture proportions

To determine the optimum concrete mixture proportions for the novel concrete used in this experimental study, several options were prepared based on IS 10262[28] specifications for Grade M20 (2.9 ksi) concrete. The cement was partially replaced with 5%, 10%, 15%, and 20% cow dung ash, and 1.5% of plastic waste was used as an admixture. In addition, a high-range water-reducing admixture (HRWRA) was incorporated into the concrete at 0.6% of the total binder content (equivalent to 2.23 kg/m^3 [3.76 lb/yd^3]) to improve workability and prevent cluster formation.

As described in a previous paper,[29] cubes and cylinders were cast to determine compressive and tensile strength after curing periods of 7, 14, and 28 days. The specimens containing 15% cow dung ash and 1.5% plastic waste (M-C85-CDA15-PW1.5) demonstrated the highest performance with these specimens exhibiting significant improvements in both tensile and compressive strengths relative to specimens made with the other mixtures that we considered.[29] (In this case, M refers to the mixture number, C85 indicates 85% ordinary portland cement, CDA15 denotes 15% cow dung ash, and PW1.5 represents 1.5% plastic waste.) The addition of HRWRA enhanced flowability and contributed to the overall improvement in the concrete's mechanical properties.

Figure 2 shows the components of the concrete mixture. **Table 3** summarizes the proportions for the optimized concrete mixture. The mixture proportions by weight for this optimized sustainable concrete are 1 part total binder (cement plus cow dung ash), 1.62 parts fine aggregate, 3.06 parts coarse aggregate, 0.52 parts water, and 0.015 parts plastic waste, plus HRWRA equaling 0.6% of the total binder content.

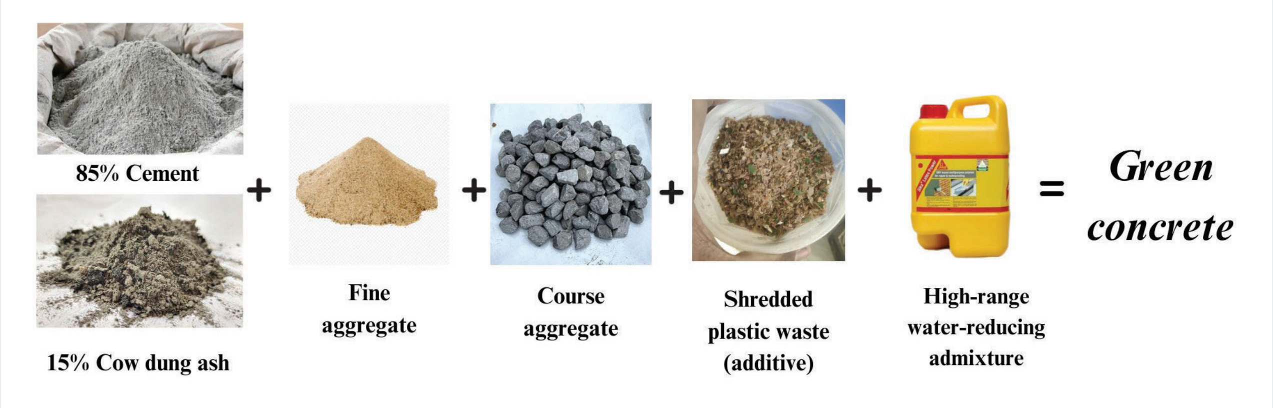

Figure 2. Components of optimized sustainable concrete mixture proportions.

Table 3. Composition of Grade M20 concrete and the optimized concrete mixture M-C85-CDA15-PW1.5

Material	Grade M20 concrete, kg/m^3	M-C85-CDA15-PW1.5, kg/m^3
Ordinary portland cement	384	326.4
Cow dung ash	0	57.6
Sand (fine aggregates)	617.72	601.55
Coarse aggregates	1168.83	1138.05
Plastic waste	0	5.76
Water	192	192
High-ranging water-reducing admixture	0	3.84

Note: M-C85-CDA15-PW1.5 = concrete mixture with 85% ordinary portland cement, 15% cow dung ash, and 1.5% plastic waste by weight of cement. 1 kg/m^3 = 1.6875 lb/yd^3.

Beam casting

Figure 3 illustrates six reinforced concrete beam samples prepared for structural performance testing. Three samples were made the standard Grade M20 (2.9 ksi) concrete as the control and three with the optimized concrete (M-C85-CDA15-PW1.5). Each beam measured 1000 mm (39.37 in.) in length, 150 mm (5.91 in.) in width, and 150 mm in depth and was reinforced with two 10 mm (0.39 in.) diameter bars for the bottom reinforcement, two 8 mm (0.31 in.) diameter bars for the top reinforcement, and 6 mm (0.24 in.) diameter stirrups spaced at 150 mm center to center.

High-quality stainless steel formwork was used to ensure accurate dimensions and stability during casting. The internal surfaces of the forms were coated with a release agent to facilitate easy release. Reinforcement bars were precisely placed within the forms, with spacers used to maintain the required cover.

A mechanical mixer was used to achieve homogeneous concrete mixtures. The workability of the concrete mixtures was a critical factor in this study. Slump tests were conducted for each batch to assess workability. The Grade M20 (2.9 ksi) concrete exhibited a slump of 75 mm (2.95 in.), indicating adequate workability for beam casting, whereas the optimized concrete showed a slump of 90 mm (3.54 in.), reflecting enhanced workability due to the HRWRA. This enhanced workability facilitated easier handling and compaction of the concrete, leading to a more uniform and defect-free finish.

The concrete was placed in the formwork in layers. In accordance with IS 516,[30] a needle vibrator was used during casting to eliminate air voids and ensure proper compaction of each layer. The surfaces of the beams were leveled and finished with a trowel for a smooth finish.

The beams were released from the forms 24 hours after casting and then cured in a tank for 28 days, following the specifications of IS 456.[31] Proper curing ensures full hydration of the cement particles, contributing to the overall structural integrity of the beams. The saturated curing method employed in this study provided optimal hydration, enabling the concrete to achieve its full strength and durability potential under controlled laboratory conditions.

While the saturated curing method used in this experiment is not feasible on-site or in precast concrete plants, alternative methods, such as intermittent wet curing or the use of curing compounds, can achieve comparable results. The findings from this study serve as a benchmark, demonstrating the potential of the optimized concrete under ideal conditions and offering guidance for adapting curing practices in practical applications. Future research will focus on assessing the performance of the optimized concrete under real-world curing scenarios to further validate its applicability.

Mechanical testing and analysis

The static load testing of the optimized concrete mixture and control beams was conducted using a comprehensive setup

Figure 3. Reinforced concrete beam samples.

designed to measure deflection and assess the performance of the beams under increasing load. The deflection of the beams was monitored manually at predefined intervals along their length. Markers were placed at specific points to record deflection values during the loading process, ensuring consistent and accurate data collection.

The beams were positioned on a universal testing machine equipped with a hydraulic loading system capable of applying a gradually increasing load. The load was applied incrementally in a controlled manner (**Fig. 4**), and deflection was measured at each load stage. Observations were carefully noted, with special attention given to the behavior of the beams as the load increased.

The test setup was connected to a data acquisition system, which continuously logged the deflection values throughout the test. This system was crucial for capturing real-time data and ensuring that each load increment was accurately correlated with the corresponding deflection measurements. The recorded data provided a detailed understanding of the beam performance, allowing for thorough analysis of their load-bearing capacity and structural behavior under static loading.

Results and discussion

The static load test results reveal substantial improvements in the performance of the specimens made with the optimized concrete mixture (M-C85-CDA15-PW1.5) compared with the control beams (**Table 4**). The optimized mixture beams demonstrated a higher maximum load capacity, withstanding 95 kN (21.4 kip), compared with 85 kN (19.1 kip) for the control beams. This finding indicates a notable increase in the load-bearing capability of the optimized mixture beams, likely due to the improved microstructural properties provided by the inclusion of cow dung ash and plastic waste. In addition, the deflection at maximum load for the optimized mixture beams was lower, measuring 8 mm (0.31 in.) compared with 12 mm (0.47 in.) for the control beams. This reduced deflection suggests that the optimized concrete mixture has greater stiffness and resistance to deformation under load, which could make it well suited for structural applications where minimal deflection is essential.

The flexural strength of the optimized concrete was 6.2 MPa (0.9 ksi), significantly exceeding the 5.6 MPa (0.8 ksi) flexural strength of Grade M20 (2.9 ksi) concrete. This improvement results from the synergistic effects of cow dung ash and plastic waste. The pozzolanic reaction of cow dung ash enhances the concrete's microstructure by reducing porosity, whereas the fibrous nature of the plastic waste reinforces the matrix effectively distributing stress and improving flexural performance.

Figure 5 compares the load versus deflection behavior for the optimized mixture beams and control beams under static loading. The graph includes individual trial data and averaged values, offering a comprehensive view of performance differences between the two types of beams. The visual represen-

Figure 4. Load setup for testing of concrete beam specimen.

Table 4. Static load test results for optimized concrete mixture beams and control beams

Parameter	Mixture type	Test 1	Test 2	Test 3	Average
Maximum load, kN	Grade M20 concrete	83.5	86.0	85.5	85.0
	M-C85-CDA15-PW1.5	94.0	95.5	95.5	95.0
Deflection, mm	Grade M20 concrete	11.8	12.0	12.2	12.0
	M-C85-CDA15-PW1.5	7.8	8.0	8.2	8.0
Flexural strength, MPa	Grade M20 concrete	5.5	5.6	5.7	5.6
	M-C85-CDA15-PW1.5	6.1	6.2	6.3	6.2

Note: M-C85-CDA15-PW1.5 = concrete mixture with 85% ordinary portland cement, 15% cow dung ash, and 1.5% plastic waste by weight of cement.
1 mm = 0.0394 in.; 1 kN = 0.225 kip; 1 MPa = 0.145 ksi.

tation emphasizes the uniformity of the optimized concrete specimens across trials, suggesting the suitability of the optimized concrete mixture for applications requiring resistance to static loading. **Figures 6**, **7**, and **8** compare individual performance parameters for the optimized concrete beams and the control beams. As these figures illustrate, the specimens made with the optimized concrete mixture exhibited lower deflection, higher flexural strength, and greater load-bearing capacity across all trials and averages.

Conclusion

This study demonstrated the potential benefits of using cow dung ash and plastic waste as supplementary materials in sustainable concrete, with a focus on performance of specimens under static loading. Beams made with the optimized concrete mixture showed significant improvements in mechanical properties compared with control specimens made with conventional Grade M20 (2.9 ksi) concrete, particularly under static load scenarios such as compressive and flexural tests.

The inclusion of 15% cow dung ash as a partial replacement for cement contributed to the development of a denser and more cohesive microstructure, which is critical under static compressive loads. The pozzolanic properties of cow dung ash, which promote secondary hydration reactions, helped fill microscopic voids in the concrete matrix, increasing the compressive strength of the test beams. Thus, the optimized

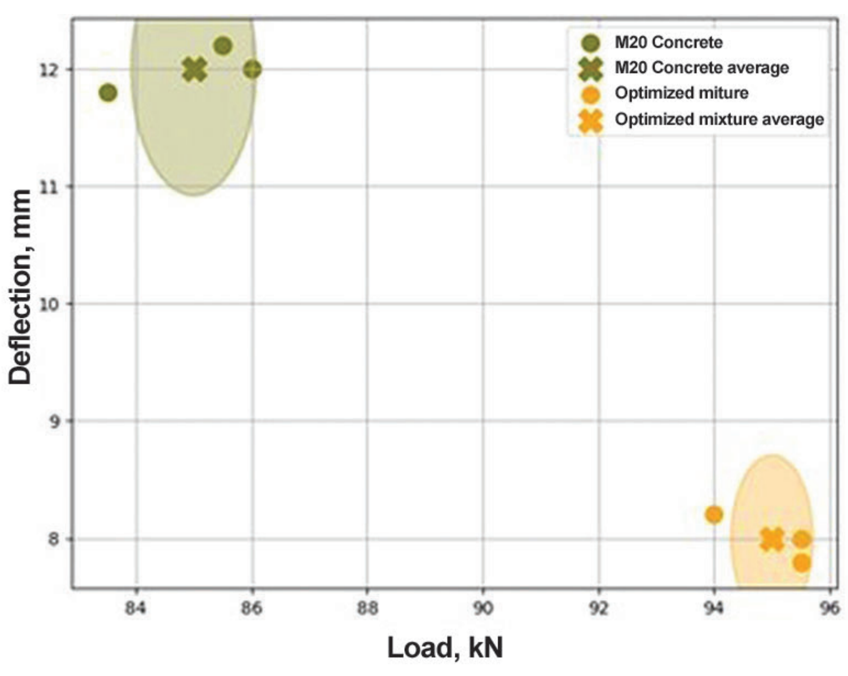

Figure 5. Static load versus deflection for standard Grade M20 concrete and optimized concrete mixture samples.
Note: 1 mm = 0.0394 in.; 1 kN = 0.225 kip.

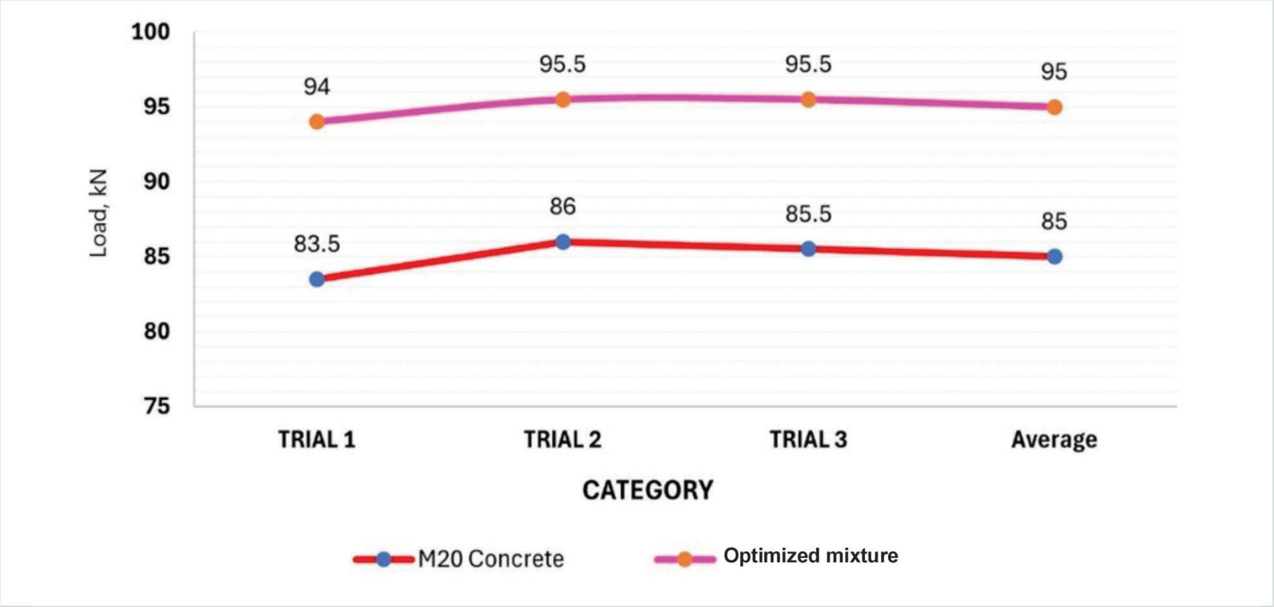

Figure 6. Comparison of maximum static load for standard Grade M20 concrete and optimized concrete mixture samples.
Note: 1 kN = 0.225 kip.

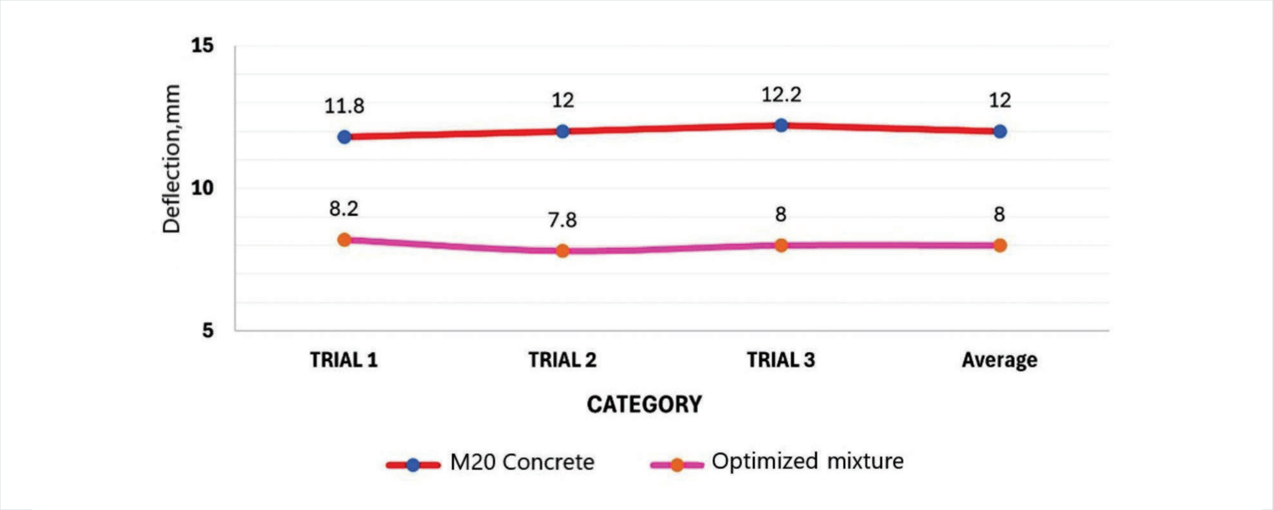

Figure 7. Comparison of deflection for standard Grade M20 concrete and optimized concrete mixture samples.
Note: 1 mm = 0.0394 in.

concrete specimens could withstand higher static loads before failure, demonstrating superior load-bearing capacity, than the control beams made with Grade M20 (2.9 ksi) concrete.

The use of 1.5% plastic waste provided a noticeable improvement in flexural strength. The fibrous nature of plastic waste acted as micro-reinforcement within the concrete, helping to bridge cracks and distribute stress more evenly across the beams during static loading. This reinforcement was associated with a significant reduction in deflection, a critical parameter under static loads. The deflection values for the optimized concrete specimens were lower than those for the control beams, indicating that the optimized concrete specimens had enhanced stiffness and improved resistance to bending forces.

Under static loading, the beams made with optimized concrete demonstrated superior structural integrity. The enhanced compressive and flexural strength, coupled with the reduced deflection, resulted in higher overall load-bearing capacity. These findings suggest that the optimized concrete mixture could be a viable alternative for structural applications where

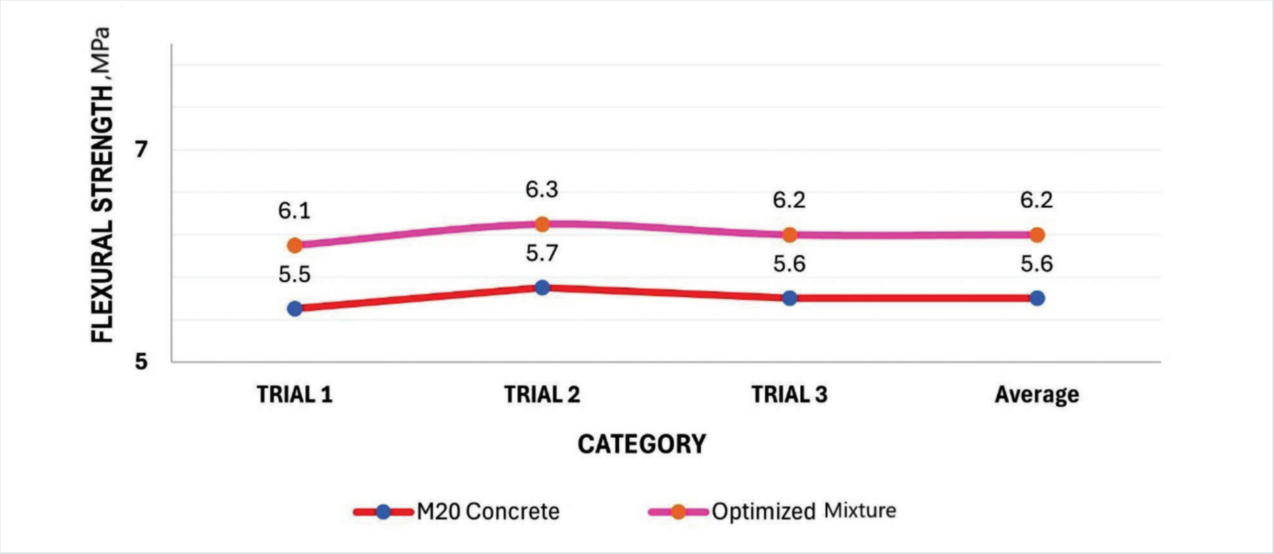

Figure 8. Comparison of flexural strength for standard Grade M20 concrete and optimized concrete mixture samples. Note: 1 MPa = 0.145 ksi.

static loads predominate, such as columns, beams, and load-bearing walls.

In addition to mechanical enhancements, the use of cow dung ash and plastic waste addresses sustainability concerns. Integrating these waste materials could reduce the environmental impact of concrete production and improve the performance of concrete under static loading.

While the study has provided evidence to support the feasibility of using cow dung ash and plastic waste in sustainable concrete, several areas warrant further investigation, as follows:

- Long-term deflection and creep testing. This study focused on immediate performance under static loading and did not consider long-term deflections due to creep and other time-dependent factors. It is important to investigate long-term performance, particularly because plastic waste may influence the creep behavior of concrete over time. Future research should address this aspect through sustained loading tests.
- Fire resistance and smoke index testing. The behavior of the optimized concrete under high-temperature conditions must be investigated to evaluate safety and the material's suitability for applications in fire-prone environments.
- Durability under harsh conditions. Extended studies are needed to evaluate the concrete's durability when exposed to aggressive environmental conditions, such as cycles of freezing and thawing, corrosive chemicals, and marine environments.
- Life-cycle and environmental impact assessments. A comprehensive life-cycle assessment would be useful to quantify the environmental benefits of using the proposed sustainable concrete, including reductions in CO_2 emissions and resource depletion.
- Field trials and practical applications. Large-scale field trials are important to validate laboratory findings and assess the performance of structures using the proposed concrete in real-world scenarios. Long-term monitoring in the field will be needed to evaluate whether the concrete is a practical, viable, and reliable option.
- Innovative applications. There may be beneficial applications for the proposed sustainable concrete in nonstructural elements, such as precast concrete blocks, pavers, and lightweight panels.

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Abstract

This paper reports findings from an experiment to explore the potential of a novel concrete mixture for sustainable construction, with a specific focus on performance in static load testing. The mixture includes cow dung ash, which has supplementary cementitious properties, as a replacement for 15% of ordinary portland cement and incorporates 1.5% plastic waste as an admixture to enhance flexural strength and mitigate deflection. To assess the efficacy of the optimized concrete mixture, reinforced concrete beam specimens were cast and subjected to static load testing, with their performance compared with that of conventional Grade M20 (2.9 ksi) concrete beams. The experimental results indicate that the optimized concrete mixture specimens exhibited superior performance under static loading, demonstrating greater load-bearing capacity, enhanced stiffness, and reduced deflection relative to the control beams. Furthermore, the optimized concrete displayed a markedly improved capacity for energy absorption under static loading conditions.

Keywords

Cow dung ash, deflection, flexural strength, plastic waste, static loading, sustainable concrete.

Review policy

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