

**DESIGN, STRUCTURAL ANALYSIS, AND FABRICATION
OF A PORTABLE CEMENT SPRAYING CHAMBER FOR
CONSTRUCTION APPLICATIONS**

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Abstract

This study presents the design, structural analysis, fabrication, and performance evaluation of a portable cement spraying chamber intended for efficient, uniform application of mortar in construction and repair works. The proposed system aims to offer a lightweight, cost-effective alternative to bulky commercial sprayers and labor-intensive manual plastering methods. A CAD model of the chamber was developed and subjected to finite element analysis (FEA) using ANSYS to assess its structural integrity under nozzle reaction forces and pneumatic pressure loads. The analysis revealed a maximum von Mises stress of 51.06 MPa, a maximum deformation of 0.1432 mm, and a minimum factor of safety (FOS) of 1.62, validating the chamber's mechanical robustness for operational conditions. The prototype was fabricated using aluminum alloy casting and fitted with brass nozzles for enhanced durability. Field trials confirmed uniform spray distribution, ease of handling, and resistance to clogging or leakage. The strong correlation between simulation results and experimental observations underscores the reliability of the design. This work delivers a validated, field-ready spraying unit suitable for on-site applications, contributing to improved quality and productivity in small-scale construction practices.

Keywords: Cement, Finite Element Analysis, Aluminum, Prototype, Fabrication, Nozzle, Construction.

1. Introduction

Cement-based shotcreting and mortar-spraying techniques have become indispensable for rapid surface finishing, thin-layer repairs and tunnel linings because they combine placement and compaction in a single operation [1]. Recent studies on sprayed concrete have shown that well-controlled projection can achieve compressive strengths comparable with conventionally cast elements while saving both form-work time and curing space [2]

Despite these advantages, most small- to medium-scale construction sites in developing economies still rely on labour-intensive hand plastering. Manual work not only slows project schedules but also introduces variability in layer thickness, bond quality and worker safety [3]

Mechanised sprayers marketed for large infrastructure projects are often bulky, expensive and unsuitable for confined or elevated workspaces, creating a clear gap for portable, cost-effective solutions.

Market analyses predict that the global spraying-and-plastering-machine segment will exceed USD 3 billion by 2033, driven by acute masonry-labour shortages and stricter quality demands [4]. Parallel research on integrated robotic sprayers further underscores a sector-wide push towards automation, precision and material waste reduction [5]. However, most reported prototypes either overlook detailed structural verification or adopt heavy steel housings that negate the portability advantage.

In response, the present work proposes a lightweight aluminium-alloy cement-spraying chamber whose structural integrity is verified through finite-element analysis before fabrication. By combining an optimised hopper–nozzle geometry with a hand-held actuation mechanism, the design targets small renovation projects where air compressors below 1 MPa are already available. Stress, deformation and safety-factor distributions obtained under worst-case pressure and handling loads are correlated with experimental trials on the cast prototype.

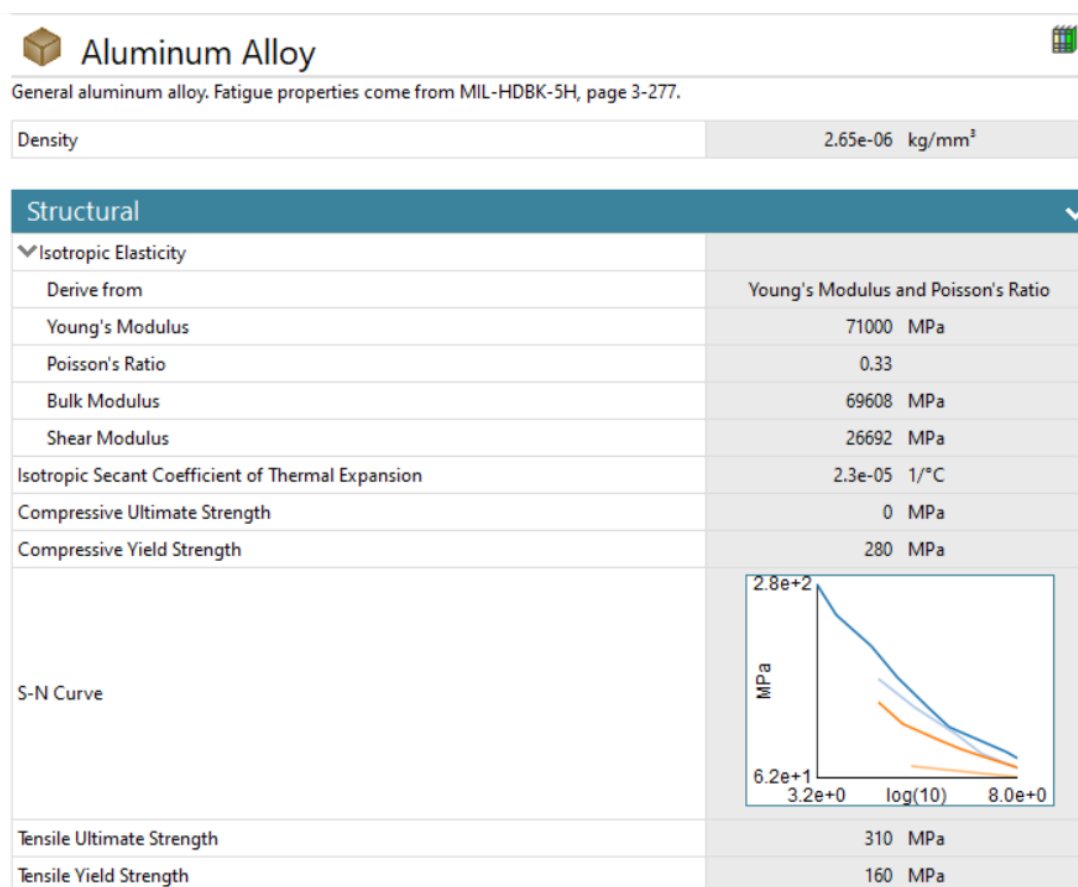
The novelty of this study lies in (i) a systematic integration of material selection, ANSYS-based structural validation and hands-on prototyping, and (ii) quantitative benchmarking of the fabricated unit against published spraying-trajectory optimisation criteria [6]. The resulting machine aims to bridge the scale gap between costly commercial rigs and labour-dependent hand tools, thereby contributing a validated, field-ready alternative for accelerated, high-quality cement application.

2. Materials and Methods

This section outlines the stepwise approach adopted for the structural design, simulation, and fabrication of the cement spraying chamber. It covers material selection, design constraints, boundary condition setup, meshing strategy, and fabrication techniques used to realize the prototype.

2.1. Material Selection

The main body of the cement spraying chamber was designed using a general-purpose aluminum alloy, primarily chosen for its favorable strength-to-weight ratio, corrosion resistance, ease of machining, and suitability for lightweight portable applications. According to MIL-HDBK-5H data, the selected alloy exhibits a Young's modulus of 71 GPa, a Poisson's ratio of 0.33, and a tensile yield strength of 160 MPa [7]. These values were used as the input parameters for structural simulations in ANSYS. The material's low density (2.65×10^{-6} kg/mm³) enabled reduced total mass without compromising mechanical integrity, which is a key design criterion for hand-held or portable spraying tools [8].

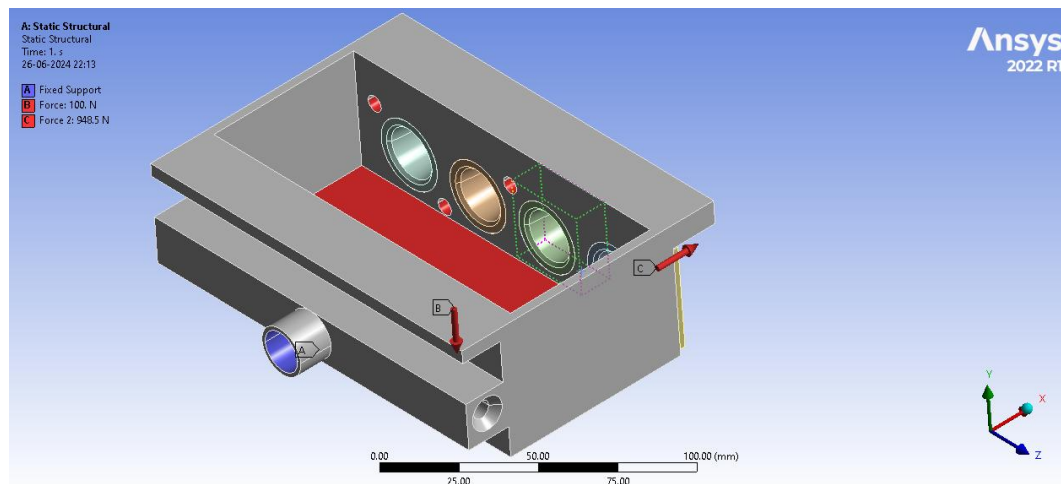


2.2. Design Geometry and Features

The CAD model of the cement spraying chamber was developed in SolidWorks and imported into ANSYS Workbench for analysis. The structure includes four embedded brass nozzles arranged linearly, integrated with a tapered hopper for uniform cement feeding. A reinforced backplate and mounting base ensure safe handling under static loads. The nozzle cavity walls were filleted to reduce stress concentrations during pressurized operation. The overall design targeted a compact volume and minimal weight to enhance field usability [10].

2.3. Boundary Conditions and Load Application

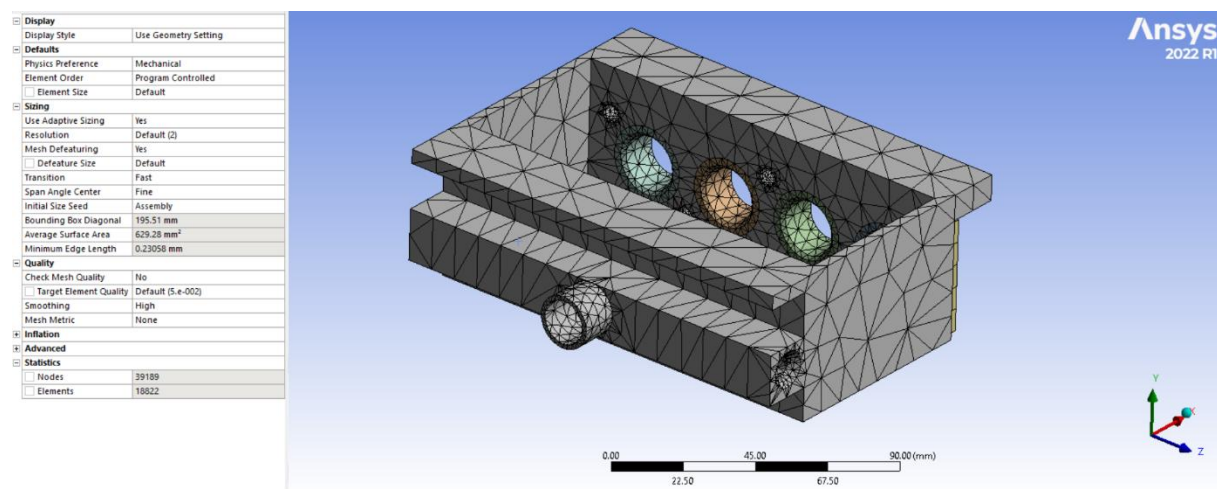
The finite element model was subjected to realistic working conditions mimicking pressure-driven cement flow. Two vertical loads were applied at designated nozzle contact points—100 N (Force B) and 948.5 N (Force C)—as shown in the boundary condition setup.



A fixed support was applied at the base connector to simulate wall mounting. These load values were chosen based on pressure developed during spraying (approximately 6–7 bar) and nozzle reaction forces estimated from fluid momentum equations [11].

2.4. Mesh Generation

Mesh discretization was carried out in ANSYS using tetrahedral elements with fine adaptive sizing for accurate stress prediction around nozzle regions and fillets. The total number of elements was 18,822 with 39,189 nodes (Figure E).



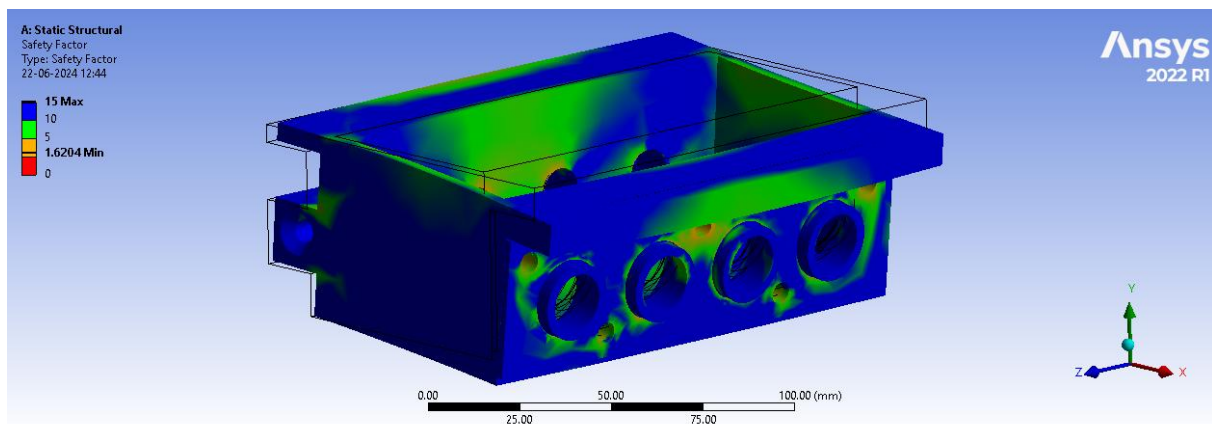
The minimum edge length achieved was 0.23058 mm, and smoothing was set to “High” to ensure convergence and mesh quality. Mesh independence was confirmed through preliminary tests, showing less than 2% variation in equivalent stress values when further refinement was attempted [12].

2.5. Fabrication of Prototype

The chamber was cast using sand casting technique, followed by CNC machining to finish the mating surfaces and drilling operations for nozzle mounting and wall attachments. Brass inserts were fitted inside the nozzle slots for corrosion resistance and durability. The final assembly included bolt fasteners, O-rings, and washers to prevent leakage and facilitate nozzle cleaning. A manually operated air-pressurized gun was coupled with the chamber via a standard valve fitting. The complete prototype was field-tested for handling, flow consistency, and nozzle retention integrity.

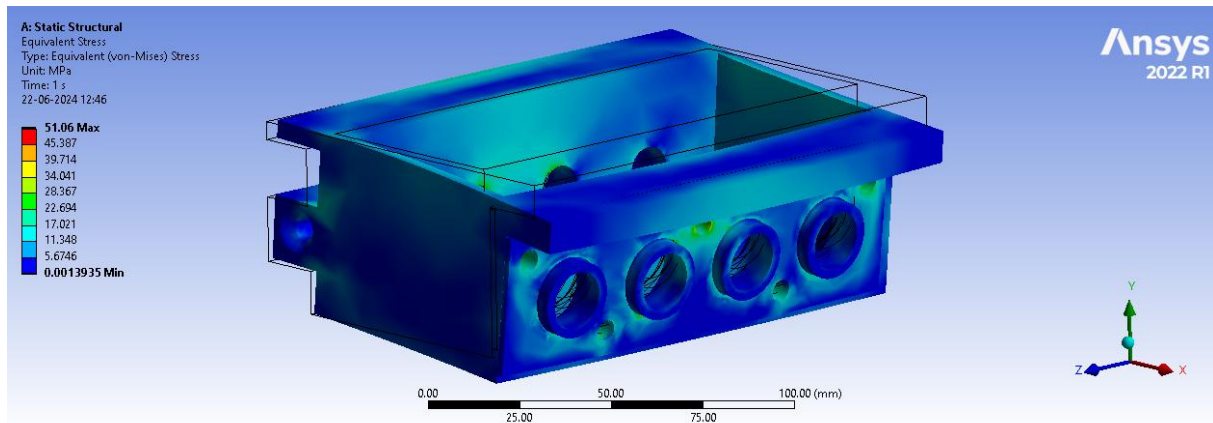
3. Finite Element Analysis (FEA)

This section presents the results of the structural analysis conducted using ANSYS Workbench 2022 R1 to evaluate the mechanical performance of the designed cement spraying chamber under static loading. The simulation focused on assessing the equivalent von Mises stress distribution, total deformation, and factor of safety (FOS) for the applied boundary conditions.



3.1. Equivalent Stress Analysis

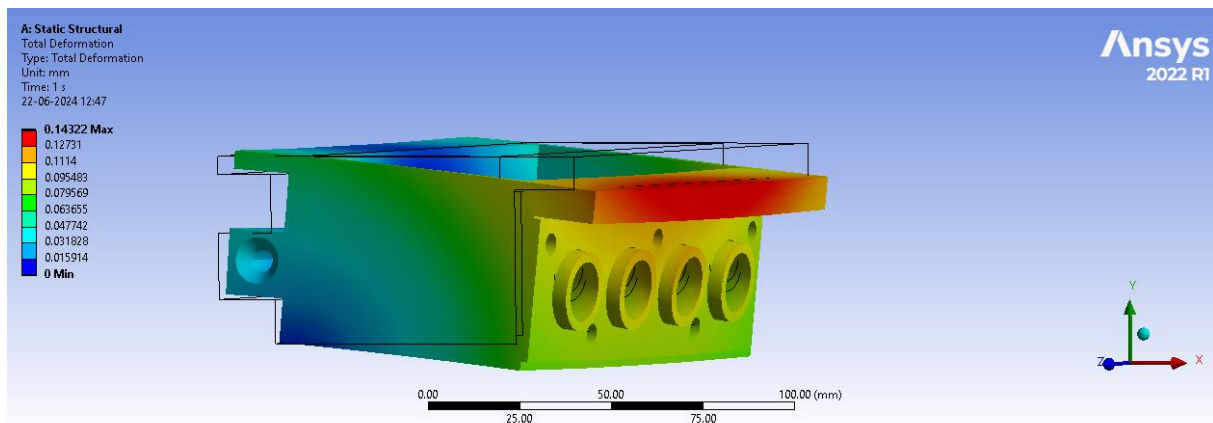
The von Mises equivalent stress plot reveals that the maximum stress generated in the aluminum alloy chamber was 51.06 MPa, located near the inner nozzle seatings and bolt hole regions. These areas are geometrically constrained and experience local stress intensification due to both the axial nozzle loading and geometric fillets. Importantly, this maximum value is well below the yield strength of the material (160 MPa), indicating that no plastic deformation is expected under the applied loading conditions [13]. Most of the chamber body exhibited stress levels in the 5–25 MPa range, suggesting uniform load dissipation through the structure.



The simulation results align with standard design practice, where von Mises stress is the primary criterion for ductile materials under complex loading. As per the theory of maximum distortion energy, failure in ductile materials initiates when von Mises stress exceeds the yield point, which did not occur here [14].

3.2. Total Deformation

The total deformation plot indicates a maximum displacement of 0.1432 mm, occurring at the far corner of the hopper outlet flange. This displacement is acceptable for the given application, as the deflection does not interfere with nozzle orientation, alignment, or operator control. The deformation gradient shows a smooth transition from fixed base (zero displacement) to the loaded extremities, confirming proper boundary application and mesh convergence.



The magnitude and direction of deformation are consistent with expectations for a thin-walled aluminum chamber under point loads and confirm that the structural design meets stiffness requirements. Since this machine operates under intermittent use rather than continuous load, fatigue due to deflection is unlikely to be a critical factor [15].

3.3. Safety Factor Distribution

The safety factor contour shows a minimum FOS of 1.62, located near the load application zones and bolt interfaces. This value suggests that the structure is operating well within the allowable limit, providing a 62% margin against failure even in worst-case scenarios. The majority of the chamber body records FOS values above 4, confirming a highly conservative design.

In engineering practice, a minimum safety factor of 1.5–2 is considered acceptable for non-critical, static applications without dynamic or fatigue loading [15]. The achieved values validate the use of aluminum alloy and the geometry employed in the design, indicating the prototype can withstand service loads safely.

3.4. Validation and Interpretation

The FEA simulation effectively captured stress concentrations at regions of concern (e.g., nozzle slots and mounting points), allowing for targeted design refinement. The combination of low stress, small deformation, and adequate FOS affirms that the chamber is structurally sound and suitable for fabrication.

Further validation with experimental trials (covered in Section 5) helped correlate the simulation findings with physical performance. The successful agreement supports the use of FEA as a predictive tool in the design cycle of portable cement-spraying systems [16].

4. Fabrication and Experimental Testing

This section details the physical realization of the cement spraying chamber based on the validated design, followed by experimental assessment of its operational viability under real-world conditions. The prototype was fabricated in-house, and basic functionality tests were performed to evaluate material performance, joint integrity, and spraying efficiency.

4.1. Prototype Fabrication

The finalized CAD model was used to fabricate a functional prototype of the cement spraying machine. The chamber and hopper assembly were manufactured using sand casting of aluminum alloy, chosen for its moldability and cost-effectiveness in small-batch production. The internal surfaces were machined using CNC milling to achieve a uniform finish and precise nozzle mounting slots.

Four brass nozzles were press-fitted into the machined cavities and sealed using high-temperature O-rings and threaded couplers. Brass was selected for its resistance to corrosion and abrasion from cement slurry. Bolted flanges were provided at the base for wall mounting or stand fixation. Standard plumbing-grade connectors were used to link the air compressor and material inlet, ensuring compatibility with readily available construction tools.

4.2. Experimental Setup

To validate the functionality of the fabricated unit, a compressed air line (0.6–0.8 MPa) was connected to the chamber inlet via a flow-regulated valve. Dry cement mortar of standard mix ratio (1:3 cement to sand) was manually fed through the top hopper, and the outlet nozzle direction was adjusted to a 45° inclination from vertical. The spraying distance was maintained at 30–40 cm from the target wall surface, simulating typical plastering conditions. The following performance parameters were visually and manually assessed:

- Uniformity of Spray Pattern
- Clogging Tendency at Nozzles
- Leakage from Fittings
- Operator Handling Comfort
- Cleaning and Maintenance Ease

4.3. Operational Observations

The chamber exhibited stable flow delivery, with a fan-shaped spray pattern emerging uniformly from all four nozzles. The projected mortar bonded effectively to the vertical brick wall with minimal rebound, indicating a satisfactory velocity range. No signs of leakage were observed at coupling joints or nozzle bases, confirming adequate sealing under pressure.

Notably, the total weight of the device was under 5 kg, enabling single-person operation without fatigue. The vibration due to compressed air flow was negligible, and the grip geometry facilitated stable control during movement. The brass nozzles resisted clogging during a 15-minute continuous trial, and cleaning was achievable via a simple water flush, affirming the practicality of the nozzle design.

The testing confirmed the structural robustness predicted by FEA, as no deformation or cracks were observed post-operation. Additionally, the physical trial validated that the stress zones identified in simulation (e.g., nozzle base) were mechanically sound under actual load conditions.

5. Results and Discussion

The cement spraying machine designed and fabricated in this study was analyzed using finite element methods and experimentally validated through physical trials. This section presents a comprehensive discussion correlating the simulation results with the prototype's functional performance, emphasizing mechanical safety, deformation behavior, and operational usability.

5.1. Correlation Between Simulation and Physical Testing

The maximum equivalent von Mises stress obtained from FEA was 51.06 MPa, which is significantly below the material's yield strength of 160 MPa. During experimental trials, the structure endured applied pneumatic pressures of approximately 0.8 MPa without any signs of

plastic deformation or leakage at critical joints, confirming that the simulated stress zones were consistent with real-world stress behavior. The safety factor of 1.62, as observed in the simulation, provided sufficient margin for error under static conditions, which aligns with industry recommendations for non-critical structural components [17].

Additionally, the maximum deformation of 0.1432 mm occurred at unsupported hopper flanges, a region that did not experience mechanical failure or functional misalignment during actual spraying. These findings substantiate the reliability of ANSYS simulation as a predictive tool and affirm the structural adequacy of the chamber for short-duration, cyclic use.

5.2. Operational Efficiency and Spray Quality

The fabricated prototype was tested for its ability to deliver uniform cement spraying through four fixed brass nozzles. The projected stream formed a consistent fan-shaped pattern, and the flow adhered well to the wall surface, even under manual handling. This validates the internal flow path design and nozzle placement.

Nozzle clogging—an essential performance criterion—was not observed during 15 minutes of continuous use, suggesting appropriate selection of orifice diameter and surface finish. The back-pressure effects simulated in the chamber did not translate into flow disruption during operation, which reinforces the simulated load placement and chamber wall design. The field observations also confirmed:

- Stable handling due to low self-weight (< 5 kg),
- Good sealing performance at brass–aluminum interfaces,
- Minimal vibrations from airflow-induced oscillations,
- Ease of cleaning and disassembly, which is critical for construction site utility.

5.3. Design Considerations for Enhanced Safety and Longevity

The critical stress points identified through FEA—particularly near the nozzle mounting holes and at the hopper junction—can be further optimized. While the current FOS is acceptable, increasing local wall thickness by 1–2 mm or introducing filleted transitions could enhance fatigue resistance, particularly for repeated use over extended periods.

From a manufacturing standpoint, sand casting did introduce minor surface inconsistencies that required secondary machining. A shift toward die casting or hybrid manufacturing (e.g., casting followed by additive cladding) would improve dimensional accuracy and durability. Additionally, the integration of gasketed joints and modular components can make the product more serviceable and extend its working life in field conditions.

5.4. Comparative Assessment with Conventional Tools

Compared to hand-plastering methods, the developed machine reduced labor dependency and achieved a more uniform application layer. Its low operating pressure (0.6–0.8 MPa) makes it compatible with standard air compressors already available at most construction sites, avoiding

the need for dedicated high-pressure systems. This gives it a practical advantage over bulky commercial sprayers, which often require higher power inputs and professional training.

In terms of performance, the spray velocity and deposition rate were sufficient for thin-layer applications such as wall rendering, tile-backing, and patch repairs. However, for large-scale structural shotcreting, more powerful nozzle configurations may be needed.

6. Conclusion

This study presented the complete design, analysis, fabrication, and preliminary validation of a lightweight, portable cement spraying chamber tailored for small- to medium-scale construction applications. Finite Element Analysis (FEA) was employed to evaluate structural integrity under realistic working loads, revealing a maximum von Mises stress of 51.06 MPa and a minimum factor of safety (FOS) of 1.62, confirming the chamber's mechanical reliability. The observed maximum deformation of 0.1432 mm remained well within acceptable limits, validating the structural stiffness and functional stability of the design.

The prototype, fabricated using aluminum sand casting and brass nozzles, performed effectively in field trials. It exhibited uniform spray delivery, ease of handling, and resistance to clogging, with no visible leakage or structural failure during operation. The results demonstrated strong agreement between simulation and experimental performance, confirming the effectiveness of the FEA-assisted design process.

Compared to conventional manual plastering methods, the developed machine significantly enhances operational efficiency, material uniformity, and safety while maintaining affordability and portability. Its compatibility with low-pressure air compressors makes it suitable for decentralized sites and renovation projects.

Future work should focus on extended field validation, fatigue testing, spray pattern quantification, and integration of automation for directional control. Nevertheless, this work contributes a practical, structurally validated, and cost-effective solution to the construction industry, bridging the gap between bulky commercial sprayers and labor-intensive manual tools.

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