

Structure–Property-Guided Polymer–Metal Hybrid Design of a Wall Plastering Spray Assembly

Amit Kumar Kundu¹, Nitesh Singh Rajput^{2,*}, Manoj Kumar Gupta³, Shweta Kulshreshtha⁴, Naveen Kumar Yadav⁵

Abstract

Wall plastering spray equipment requires a combination of low mass, dimensional stability, abrasion resistance, chemical compatibility with cementitious mortar, and comfortable operator interaction. The original assembly was primarily developed as a metallic mechanical system; however, a polymer-focused material architecture can reduce non-load-bearing mass while retaining a safe metallic pressure path. This study, therefore, presents a structure–property-guided polymer–metal hybrid design in which the pressure housing and nozzle insert remain metallic, whereas the hopper, handle shell, and grip are assigned polypropylene, short-glass-fiber-reinforced polyamide 6 (PA6-GF30), and a thermoplastic elastomer, respectively. A literature-calibrated Halpin–Tsai model with an orientation-efficiency correction was used to quantify the elastic modulus of PA6 containing 0, 15, and 30 wt% glass fiber. The resulting properties were coupled with component-level bending and thin-shell calculations and with the previously developed finite-element model of the retained aluminum load path. The orientation-corrected modulus increased from 2.40 GPa for neat PA6 to 5.19 GPa for PA6-GF30, reducing the calculated handle-tip deflection under a 120 N design load from 0.904 to 0.418 mm. The local handle stress was 15.76 MPa and the corresponding factor of safety was 5.08 for the selected PA6-GF30 grade. The polypropylene hopper exhibited a maximum hydrostatic hoop stress of only 0.034 MPa under the nominal mortar head. The retained aluminum body showed a maximum total deformation of 0.7564 mm, a peak equivalent stress of 22.74 MPa, and a factor of safety greater than 3.5. Replacing the nominal metallic hopper and handle shell reduced the calculated mass of these components from approximately 0.47 to 0.083 kg. Moisture- and temperature-dependent sensitivity analysis showed that the PA6-GF30 handle remained above a factor of safety of 4.3 in the considered hot–wet condition. The study demonstrates that functional material partitioning and polymer micromechanics can provide a practical route for lightweight, manufacturable, and ergonomically improved construction tools.

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INTRODUCTION

Wall plastering is a repetitive finishing operation in which the operator must continuously control mortar delivery, spray direction, stand-off distance, and surface coverage. Conventional manual plastering depends strongly on skill and sustains upper-limb effort, whereas mechanized spraying can improve application continuity and reduce the time required to cover a wall surface [1]. Recent mortar-spraying and plastering robots further demonstrate that nozzle alignment, posture control,

and discharge stability are central to reliable wall finishing [2]. Nevertheless, fully robotic systems remain difficult to deploy in many small and medium construction sites, and hand-guided or semi-mechanized devices, therefore, continue to require careful integration of structural reliability with operator-centred design.

The spray assembly is the primary human–machine interface of a hand-guided plastering system. It must transfer internal pressure and trigger forces, support a mortar hopper, maintain nozzle alignment, and provide a stable grip. Spray behavior is also sensitive to nozzle geometry and material-flow conditions [3, 4]. A heavy or poorly balanced assembly can increase wrist deviation and corrective motion, whereas insufficient structural stiffness can change the outlet orientation during a pass. Ergonomic studies on masonry tools have shown that handle geometry and working posture influence upper-limb muscular demand and discomfort [5, 6]. Broader construction-ergonomics studies similarly identify awkward posture, repetitive motion, and tool handling as important risk factors [7, 8].

Material selection is, therefore, inseparable from functional and ergonomic design. Aluminum alloys are attractive for pressure housing because they provide high stiffness, moderate strength, corrosion resistance, and lower density than steel. However, using metal for every component adds unnecessary mass in regions where the dominant requirements are grip comfort, low moisture uptake, impact resistance, and manufacturability. Thermoplastics and short-fiber-reinforced thermoplastics can be selectively introduced into such regions. In particular, short-glass-fiber-reinforced polyamide 6 offers a useful balance between stiffness, moldability, and component integration, while polypropylene is advantageous for lightweight hopper components with low water uptake.

Short-fiber thermoplastics cannot be treated as simple isotropic plastics. Their properties depend on fiber content, fiber aspect ratio, fiber–matrix adhesion, mold-flow-induced orientation, moisture conditioning, temperature, and strain rate. Recent studies have reported strong links between processing conditions and the tensile or fatigue properties of PA6-GF30 [9], as well as pronounced anisotropic and thermo-mechanical behavior in glass-fiber-reinforced PA6 [10, 11].

Moisture can plasticize the polyamide matrix and alter both stiffness and strength [12–15]. Consequently, a polymer component intended for construction-site use should be designed through a structure–property framework rather than by adopting a single datasheet modulus without environmental allowance.

The available spray-assembly design was originally developed using metallic pressure housing and numerical structural analysis [16]. The present work revises that design into a polymer-focused hybrid study without incorrectly replacing the primary pressure load path by a low-modulus thermoplastic.

The novelty lies in functional material partitioning: the pressure-bearing housing and abrasion-critical nozzle are retained as metallic components, while the hopper, handle shell, and grip are redesigned using polymeric materials selected through micromechanical and environmental considerations. This approach directly addresses the journal scope of polymer analysis, structure–property quantification, constitutive modelling, and material-property simulation.

The objectives of the study are to: (i) identify the polymer-relevant functional requirements of the spray assembly; (ii) select a realistic polymer–metal material architecture; (iii) predict the effective modulus of short-glass-fiber PA6 using a Halpin–Tsai model corrected for fiber orientation; (iv) quantify the effect of fiber content on handle deflection, stress, safety, and mass; (v) examine moisture and temperature sensitivity; and (vi) integrate the polymer subcomponent results with the structural response of the retained

metallic pressure body. The overall design and analysis sequence is shown in Figure 1.

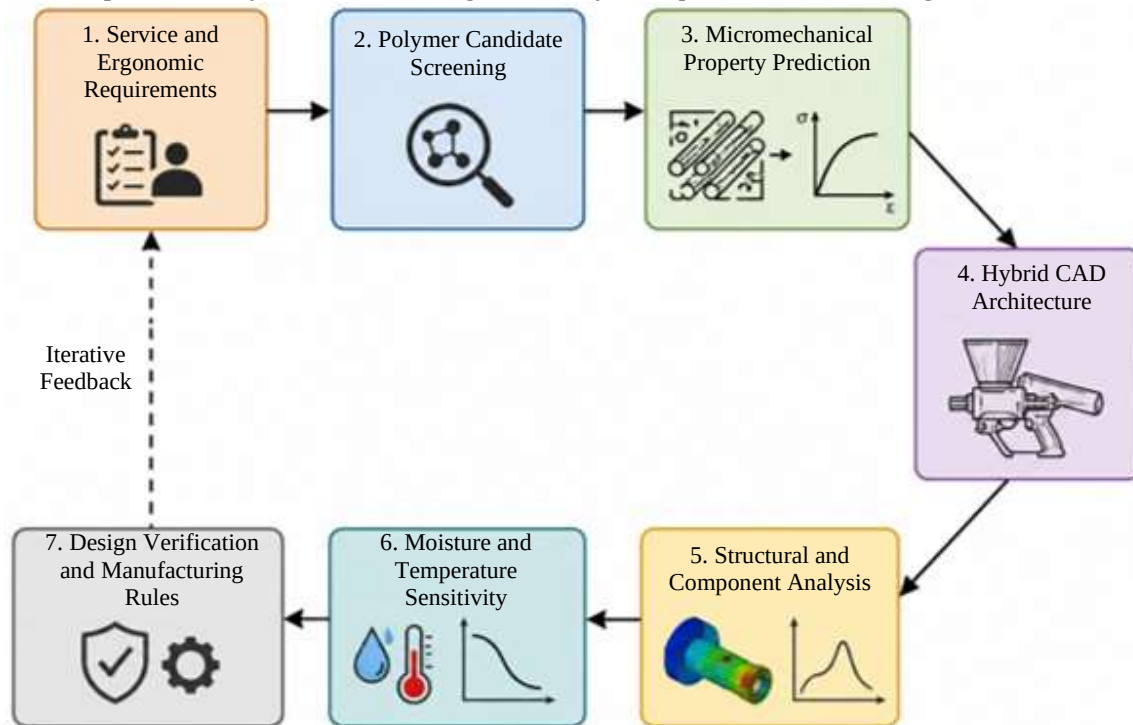


Figure 1. Structure–property-guided development workflow for the polymer–metal hybrid spray assembly.

LITERATURE REVIEW AND POLYMER DESIGN BASIS

Mechanized Plastering and the Operator–Tool Interface

Mechanized plastering studies have primarily focused on delivery mechanisms, robotic manipulation, and spray coverage. Nyemba et al. developed a mortar-spraying machine intended to reduce labor demand and improve application rate [1]. Wang et al. integrated mortar spraying and plastering into a robotic wall-construction sequence and emphasized controlled posture and movement relative to the wall [2]. Investigations of wet-mix shotcrete have further shown that nozzle geometry, material viscosity, particle interaction, and rebound influence placement quality [3, 4]. These findings establish that the discharge unit is not a passive attachment; it governs the direction, continuity, and stability of material application.

Human-guided systems additionally require an ergonomically suitable handle. Kumar et al. found that mason-trowel handle design and working posture affect shoulder and arm muscle activity during plastering [5]. Dianat et al. similarly demonstrated that handle shape influences hand performance, usability, and discomfort [6]. The implications for a spray assembly are direct: grip geometry, surface compliance, component mass, and center-of-mass location affect the operator’s ability to guide the nozzle. A polymer grip can provide local compliance and vibration damping, but the underlying structural shell must remain sufficiently stiff to prevent unwanted angular movement.

Short-Glass-Fiber-Reinforced Polyamide as a Structural Thermoplastic

PA6-GF30 is widely used for molded structural components because short glass fibers substantially increase the elastic modulus and strength of the polyamide matrix while preserving the ability to produce complex geometries. Mrzljak et al. showed that injection-molding parameters alter the quasi-static and fatigue behavior of PA6-GF30 [9]. Hartomacioğlu et al. reported an elastic modulus of approximately 5.08 GPa and tensile strength of approximately 84.98 MPa for an optimized PA6/PA6-GF30 manufacturing route [9]. These values are consistent with the conservative property range adopted

in the present design study.

The effective properties of short-fiber composites depend strongly on orientation. Mortazavian and Fatemi demonstrated that fiber orientation and anisotropy materially change tensile strength and elastic modulus [17]. Advani and Tucker introduced tensor descriptions of fiber orientation, while Folgar and Tucker described orientation evolution in concentrated fiber suspensions [18–21]. In an injection-molded handle, fibers are expected to align preferentially with the principal melt-flow direction in the skin region, while the core can contain a broader orientation distribution [22–24]. A scalar orientation-efficiency factor is, therefore, used here as a first-order homogenization parameter rather than assuming fully aligned fibers [25–27].

MATERIALS AND METHODS

Functional Requirements and Hybrid Material Architecture

The design requirements were extracted from the functional sequence of filling, gripping, trigger actuation, spraying, cleaning, and repeated field handling. Table 1 links each requirement with its material implication. Architecture intentionally separates pressure containment and abrasion resistance from low-mass ergonomic functions. This prevents an unrealistic full-polymer substitution while still making polymer selection central to the revised study.

Table 1. Functional requirements and corresponding material implications.

Requirement category	Design requirement	Material implication
Pressure and strength	Contain internal pressure and trigger reaction	Retain aluminum alloy in the main housing and lever load path.
Abrasion	Resist mortar-particle wear at the outlet	Use a replaceable stainless-steel nozzle liner.
Low mass	Reduce distal mass carried by the operator	Use polypropylene for the hopper and PA6-GF30 for the handle shell.
Grip comfort	Reduce local pressure and improve friction	Apply a thermoplastic-elastomer overmold on the grip.
Moisture stability	Limit swelling and property loss during cleaning	Use polypropylene in the mortar-contact hopper; condition PA6 properties conservatively.
Manufacturability	Enable repeatable complex geometry	Adopt injection-moldable ribs, fillets, draft angles, and uniform wall thickness.
Maintenance	Permit cleaning and replacement	Use detachable hopper and nozzle insert with accessible fasteners.
Ergonomic control	Maintain spray direction under hand force	Select handle modulus and section geometry to limit tip deflection.

The conceptual assembly is shown in Figure 2. The figure identifies the mortar hopper, control trigger, handle grip, support bracket, and nozzle outlet. These features were retained, but their material assignment was revised according to Table 1.

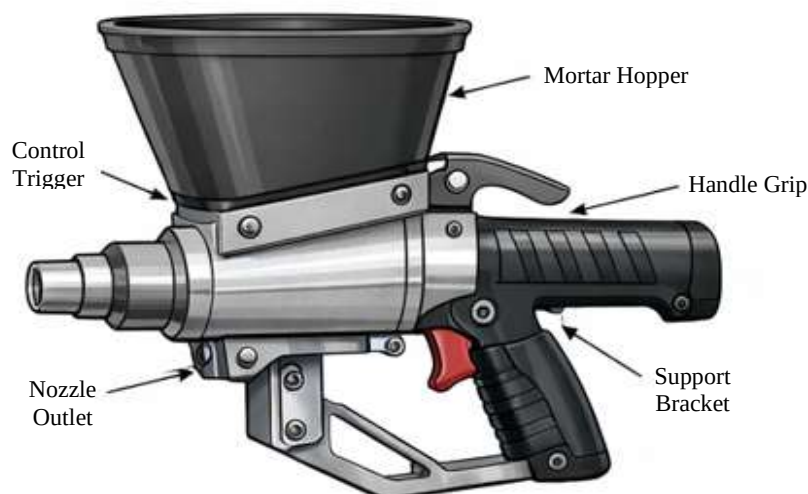


Figure 2. Conceptual layout of the spray assembly showing the functional regions used for

material partitioning.



Figure 3. Final CAD configuration used as the geometric basis for the polymer–metal hybrid design.

After requirement definition, the component geometry was consolidated in the CAD model shown in Figure 3. The pressure housing, trigger pivot, hopper collar, support bracket, and grip region were treated as separate material domains so that the polymer and metallic parts could be assessed independently.

Material Selection

Material architecture is summarized in Table 2 and illustrated schematically in Figure 4. Aluminum was retained in the main pressure housing because its modulus of 71 GPa and yield strength of 160 MPa provided the validated structural margin in the original analysis [16].

PA6-GF30 was selected for the handle shell because it offered a markedly higher modulus than neat PA6 while remaining injection moldable. Polypropylene was selected for the hopper because hydrostatic pressure is low and moisture stability is more important than high modulus. A thermoplastic elastomer was assigned only as a compliant overmold and was not included in the primary load calculation.

Table 2. Hybrid material assignment and design rationale.

Assembly component	Selected material	Primary reason
Main pressure housing and lever core	Aluminum alloy	High stiffness, validated pressure-load response, corrosion resistance.
Nozzle liner and wear insert	Stainless steel	Abrasion resistance, cleaning durability, replaceability.
Mortar hopper	Injection-molded polypropylene	Low density, low water uptake, adequate shell stiffness.
Handle structural shell	PA6-GF30	Improved modulus and strength through short-glass-fiber reinforcement.
Grip overmold	Thermoplastic elastomer	Grip friction, local compliance, vibration attenuation.

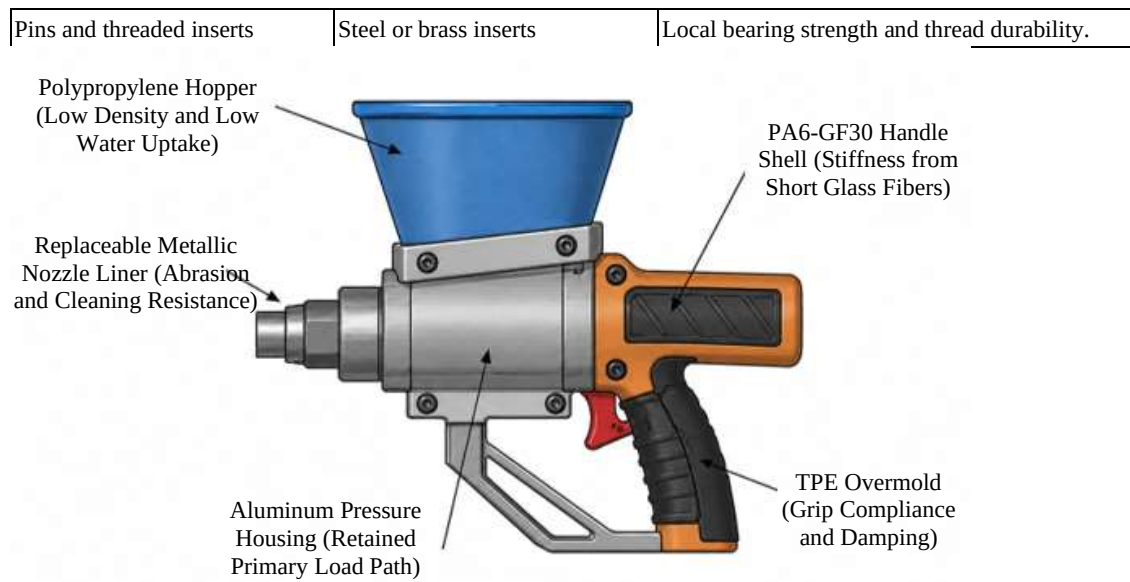


Figure 4. Functional material partitioning of the proposed polymer–metal hybrid spray assembly.

Micromechanical Property Model for PA6-GF

The glass-fiber volume fraction was calculated from the specified weight fraction using the densities of the PA6 matrix and E-glass fiber. The relationship is given by Eq. (1), where w_f is the fiber mass fraction and ρ_f and ρ_m are the fiber and matrix densities, respectively.

$$V_f = (w_f/\rho_f) / [(w_f/\rho_f) + ((1 - w_f)/\rho_m)] \quad (1)$$

The longitudinal reinforcement contribution was estimated using the Halpin–Tsai expression [23]. For a fiber aspect ratio l/d of 20, the shape parameter ξ was taken as $2l/d = 40$. The modulus ratio enters through η as shown in Eqs. (2) and (3).

$$E_{HT} = E_m [(1 + \xi\eta V_f) / (1 - \eta V_f)] \quad (2)$$

$$\eta = [(E_f/E_m) - 1] / [(E_f/E_m) + \xi] \quad (3)$$

Because the fibers are not perfectly aligned, the Halpin–Tsai increment was multiplied by an orientation-efficiency factor η_o . The effective modulus used for handling calculations was, therefore, obtained from Eq. (4). An orientation factor of 0.40 was adopted as a conservative representation of a flow-oriented skin and less-oriented core. This scalar approximation is appropriate for screening, although an orientation-tensor model would be required for a final injection-molding simulation [20, 21]. The micromechanical input parameters used during experimentation are shown in Table 3.

$$E_{eff} = E_m + \eta_o(E_{HT} - E_m) \quad (4)$$

Table 3. Micromechanical input parameters used for PA6-GF property prediction.

Parameter	Value	Basis
PA6 matrix modulus, E_m	2.40 GPa	Representative dry engineering value.
E-glass fiber modulus, E_f	72 GPa	Conventional E-glass property.
PA6 density, ρ_m	1.13 g cm ⁻³	Matrix density.
Glass-fiber density, ρ_f	2.55 g cm ⁻³	E-glass density.
Fiber aspect ratio, l/d	20	Short-fiber screening assumption.
Halpin–Tsai shape parameter, ξ	40	$\xi = 2l/d$.
Orientation-efficiency factor, η_o	0.40	Conservative injection-molded orientation correction.

Glass-fiber contents	0, 15, and 30 wt%	Material-comparison levels.
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Handle Component Model

The nominal geometry adopted for the PA6-GF30 handle analysis is shown in Figure 5. The handle shell was represented as a cantilevered hollow section with an effective free length of 100 mm, an outer width of 30 mm, an outer depth of 22 mm, and a uniform wall thickness of 3 mm. These dimensions represent the load-bearing region of the CAD grip rather than the thermoplastic-elastomer overmold. A resultant design force of 120 N was applied at the free end of the handle to represent a conservative combined gripping and handling load. The second moment of area was calculated from the difference between the outer and inner rectangular sections. The elastic tip deflection and nominal bending stress were calculated using Eqs. (5) and (6).

$$\delta = FL^3/(3E_{eff}I) \quad (5)$$

$$\sigma_b = FLc/I \quad (6)$$

A stress-concentration factor of 2.2 was applied to the nominal bending stress to account for the trigger opening, screw boss, and local geometric transitions. The factor of safety was calculated from the conservative allowable tensile stress divided by the resulting local stress. This treatment does not replace a detailed anisotropic finite-element model, but it provides a transparent screening calculation that directly links polymer modulus and strength to component performance.

Hopper Shell Calculation and Mass Estimation

The nominal hopper geometry used in the analytical shell calculation is also presented in Figure 5. The hopper was represented as a thin polypropylene frustum with a top diameter of 95 mm, an outlet diameter of 50 mm, a height of 85 mm, and a uniform wall thickness of 2.5 mm.

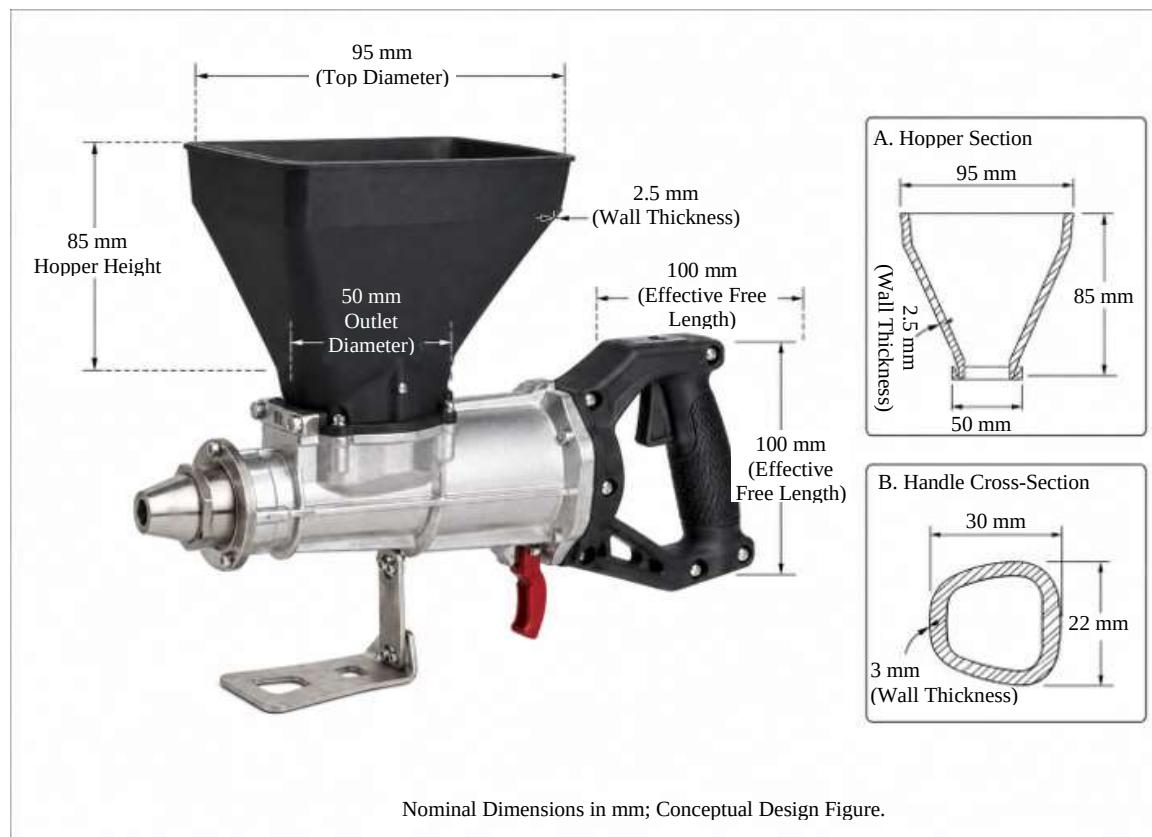


Figure 5. Dimension drawing of proposed polymer-metal hybrid spray assembly.

The maximum hydrostatic pressure was calculated using a mortar density of 2100 kg m^{-3} . At the lower wall, the pressure was only approximately 1.75 kPa. The corresponding circumferential stress was estimated using the thin-shell expression $\sigma_h = pr/t$. The mass of the hopper and handle shell was calculated from the nominal CAD volume and material density. The same geometry was also evaluated using stainless steel for the hopper and aluminum for the handle shell to quantify the component-level mass reduction enabled by polymer substitution.

Figure 5 consolidates the nominal dimensional parameters used in the analytical assessment of the polymer components. The dimensions shown for the hopper and handle correspond directly to the simplified geometries employed in the hydrostatic-stress, bending-deflection, and component-mass calculations. The pressure housing, nozzle, trigger, support bracket, fasteners, and connecting features are shown only to illustrate the overall assembly configuration and are not intended as fully dimensioned manufacturing details.

Retained Metallic Load-Path Analysis

The pressure housing and lever core were retained in aluminum because the original static structural model showed a maximum total deformation of 0.7564 mm, a peak equivalent stress of 22.74 MPa, and a factor of safety greater than 3.5 under the considered combined loading [16]. The model used tetrahedral elements, bonded or no-separation contacts where appropriate, fixed support at the connected interface, a manual lever load, and internal pressure on the mortar flow path. These results are used only for the retained metallic subassembly; they are not attributed to polymer components. The distinction is essential because a direct modulus substitution from aluminum to unreinforced or short-fiber PA6 in the same pressure-body geometry would produce excessive deformation.

Environmental Sensitivity

Three handle conditions were considered: dry at 23°C, moisture-conditioned at 23°C, and hot–wet at 60°C. Literature on PA6 and PA6-GF composites shows that moisture and temperature reduce matrix-dominated stiffness and strength [12–15, 17, 28]. The effective moduli used in the sensitivity study were 5.19, 4.55, and 3.95 GPa, while the corresponding conservative allowable stresses were 80, 74, and 68 MPa. The same handle geometry and load were used in all cases. This procedure quantifies the design margin under environmental degradation without presenting the values as direct experimental measurements of the present component.

RESULTS AND DISCUSSION

Effect of Glass-Fiber Content on Effective Modulus

The calculated fiber volume fractions for 15 and 30 wt% glass fiber were 0.0725 and 0.1596, respectively. After applying the orientation-efficiency correction, the effective modulus increased from 2.40 GPa for neat PA6 to 3.62 GPa for PA6-GF15 and 5.19 GPa for PA6-GF30. Figure 6 shows the corresponding decrease in handle-tip deflection. The relationship is nonlinear because both the conversion from weight fraction to volume fraction and the Halpin–Tsai reinforcement term contribute to the modulus increase.

At 30 wt% reinforcement, the predicted tip deflection was 0.418 mm, compared with 0.600 mm for PA6-GF15 and 0.904 mm for neat PA6. Thus, PA6-GF30 reduced the deflection by approximately 30% relative to PA6-GF15 and by approximately 54% relative to neat PA6.

This trend illustrates the principal structure–property contribution of the study: increased fiber content raises the composite modulus and directly improves directional stability of the handle. The selected 30 wt% level also remains compatible with conventional injection molding, whereas substantially higher fiber contents can increase viscosity, promote fiber breakage, and complicate filling of thin ribs and grip features.

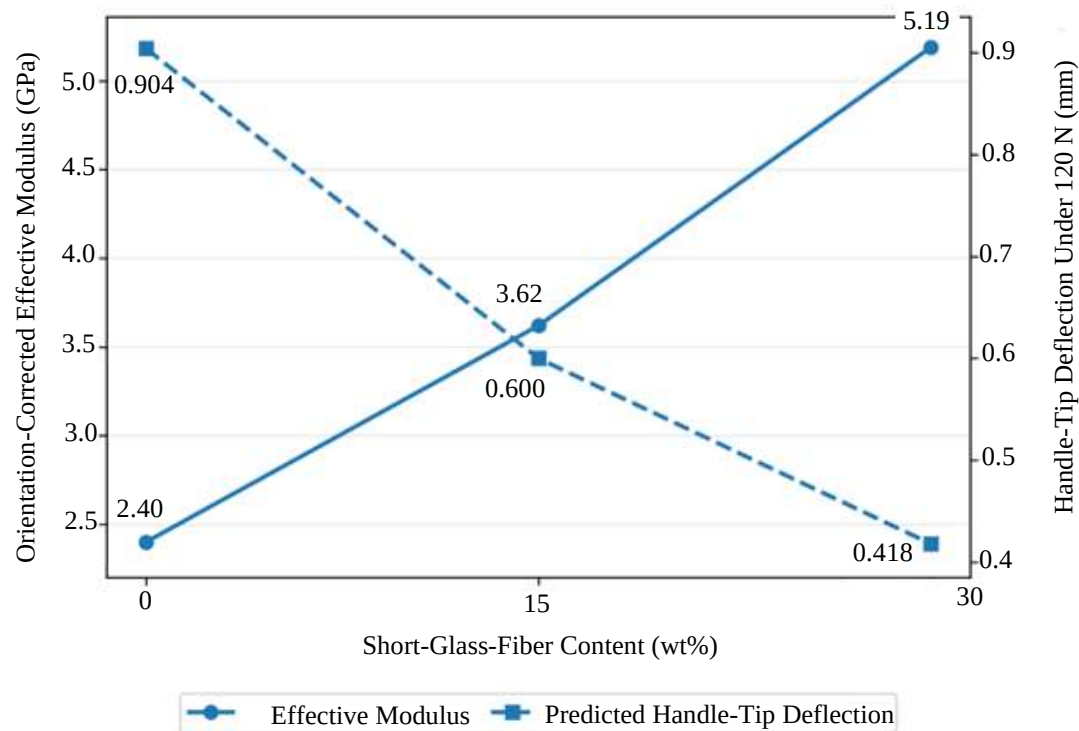


Figure 6. Predicted influence of glass-fiber content on orientation-corrected modulus and handle-tip deflection.

Comparison of Candidate Handle Materials

Table 4 compares the calculated response of common polymer candidates and the aluminum reference for the same hollow handle geometry. The local stress was 15.76 MPa for all materials because the calculation was force-controlled and linear elastic; material selection, therefore, affected deflection, mass, and factor of safety rather than the nominal stress distribution. Polypropylene and ABS provided the lowest masses but did not meet a preferred factor-of-safety target of 3.0 in the trigger-hole region. Neat PA6 marginally exceeded this target, while both glass-fiber-reinforced grades provided a stronger margin.

Table 4. Calculated handle response for candidate materials under a 120 N design load.

Material	E (GPa)	Density (g cm ⁻³)	Tip deflection (mm)	Local stress (MPa)	FOS	Shell mass (g)
Polypropylene	1.50	0.91	1.447	15.76	1.78	25.1
ABS	2.10	1.05	1.034	15.76	2.54	29.0
PA6	2.40	1.13	0.904	15.76	3.49	31.2
PA6-GF15	3.62	1.20	0.600	15.76	4.44	33.1
PA6-GF30	5.19	1.36	0.418	15.76	5.08	37.5
Aluminum reference	71.0	2.65	0.031	15.76	10.15	73.1

Aluminum gave the smallest deflection as shown in Figure 7, but the 37.5 g PA6-GF30 shell was approximately 49% lighter than the equivalent 73.1 g aluminum shell and still limited elastic movement to less than 0.5 mm. This result supports the hybrid approach rather than an all-polymer or all-metal design.

The load-bearing pressure chamber benefits from aluminum stiffness, while the handle can accept a small increase in elastic compliance in exchange for lower distal mass, molded ergonomics, and an integrated soft grip.

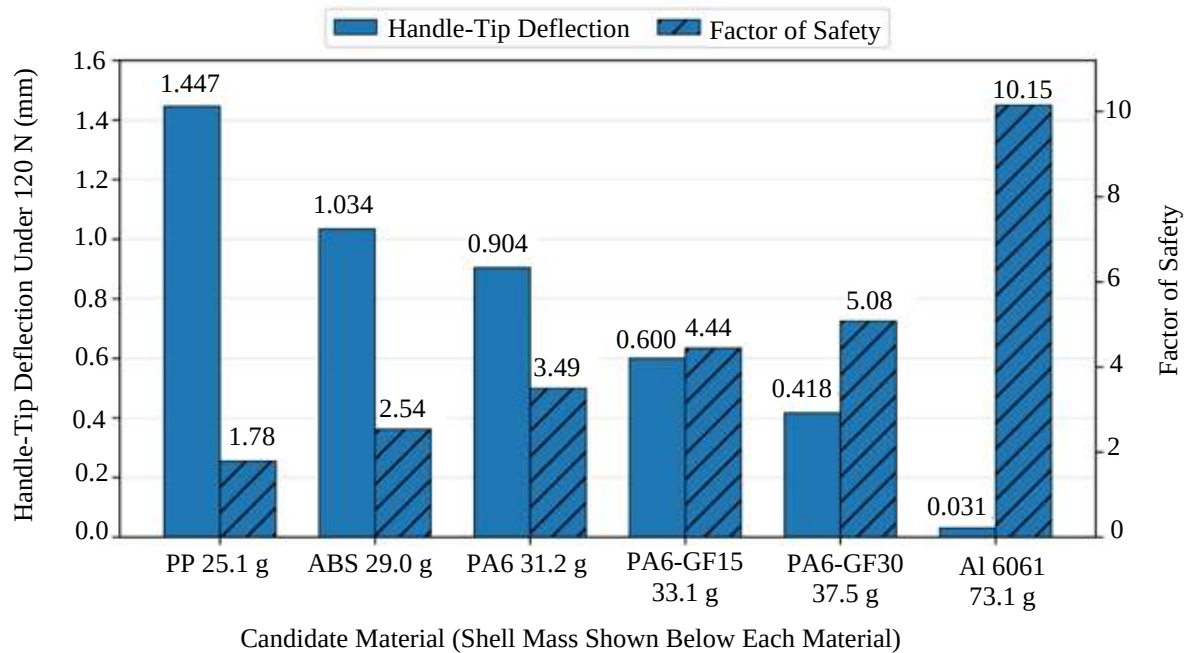


Figure 7. Comparison of handle-tip deflection, factor of safety, and calculated shell mass for candidate materials.

Hopper Performance and Component-Level Mass Reduction

The maximum hydrostatic pressure generated by the nominal mortar head was approximately 1.75 kPa. With a 47.5 mm maximum radius and 2.5 mm wall thickness, the calculated polypropylene hoop stress was only 0.034 MPa. The associated elastic radial expansion was approximately 0.001 mm, confirming that hydrostatic loading is not the critical design condition for the hopper. The more important local requirements are collar stiffness, impact resistance, and secure attachment to the metallic housing. These can be addressed by a ribbed lower collar, local metal inserts, and a generous transition radius.

For the nominal geometry, the polypropylene hopper mass was approximately 45 g, whereas an equivalent stainless-steel hopper would weigh approximately 392 g. When combined with the PA6-GF30 handle shell, the two polymer-substituted components had a calculated mass of approximately 0.083 kg, compared with approximately 0.47 kg for the nominal stainless-steel hopper and aluminum handle shell. The resulting component-level mass reduction was approximately 82%. Because the nozzle, fasteners, hose connection, and pressure housing were not included in this calculation, the value should not be interpreted as the percentage reduction of the entire device. It nevertheless demonstrates that selective polymer substitution can substantially reduce the mass carried away from the operator's wrist.

Integrated Structural Response of the Hybrid Assembly

The integrated results are summarized in Table 5. The metallic pressure path remained well within its allowable stress range, while the polymer handle and hopper satisfied their separate component-level criteria. This division of responsibility is the central design outcome. It avoids the common error of applying a single material to the complete assembly despite fundamentally different loading and environmental requirements.

The previously reported geometric optimization reduced stress hotspots by approximately 18–22% and deflection by approximately 30–35% relative to the initial metallic configuration [16]. In the revised hybrid design, these metallic improvements are retained, and additional mass reduction is obtained without assigning the pressure-body result to the polymers. The polymer contribution is, therefore, additive: it improves mass distribution and grip integration while the metallic subassembly preserves pressure containment and alignment.

Table 5. Integrated performance of the polymer–metal hybrid spray assembly.

Component response	Calculated or retained result	Interpretation
Aluminum pressure-body deformation	0.7564 mm	Maintains overall outlet alignment under the retained service load.
Aluminum pressure-body equivalent stress	22.74 MPa	Below the aluminum allowable limit.
Aluminum pressure-body factor of safety	>3.5	Adequate structural reserve for the primary load path.
PA6-GF30 handle-tip deflection	0.418 mm	Acceptable elastic compliance with manual guidance.
PA6-GF30 local handle stress	15.76 MPa	Below the conservative dry allowable stress.
PA6-GF30 handle factor of safety	5.08	Provides margin at the trigger-hole region.
Polypropylene hopper hoop stress	0.034 MPa	Hydrostatic pressure is non-critical.
Mass of polymer-substituted hopper and handle	0.083 kg	Approximately 82% lower than the nominal metal equivalents.

Environmental Sensitivity of the PA6-GF30 Handle

Figure 8 shows the sensitivity of the PA6-GF30 handle to moisture and temperature. Reducing the effective modulus from 5.19 GPa in the dry state to 4.55 GPa after conditioning increased the predicted deflection from 0.418 to 0.477 mm. In the hot–wet condition, the modulus was reduced to 3.95 GPa and the deflection increased to 0.549 mm. The factor of safety decreased from 5.08 to 4.70 and 4.31, respectively, but remained above the target value of 3.0 in all three conditions.

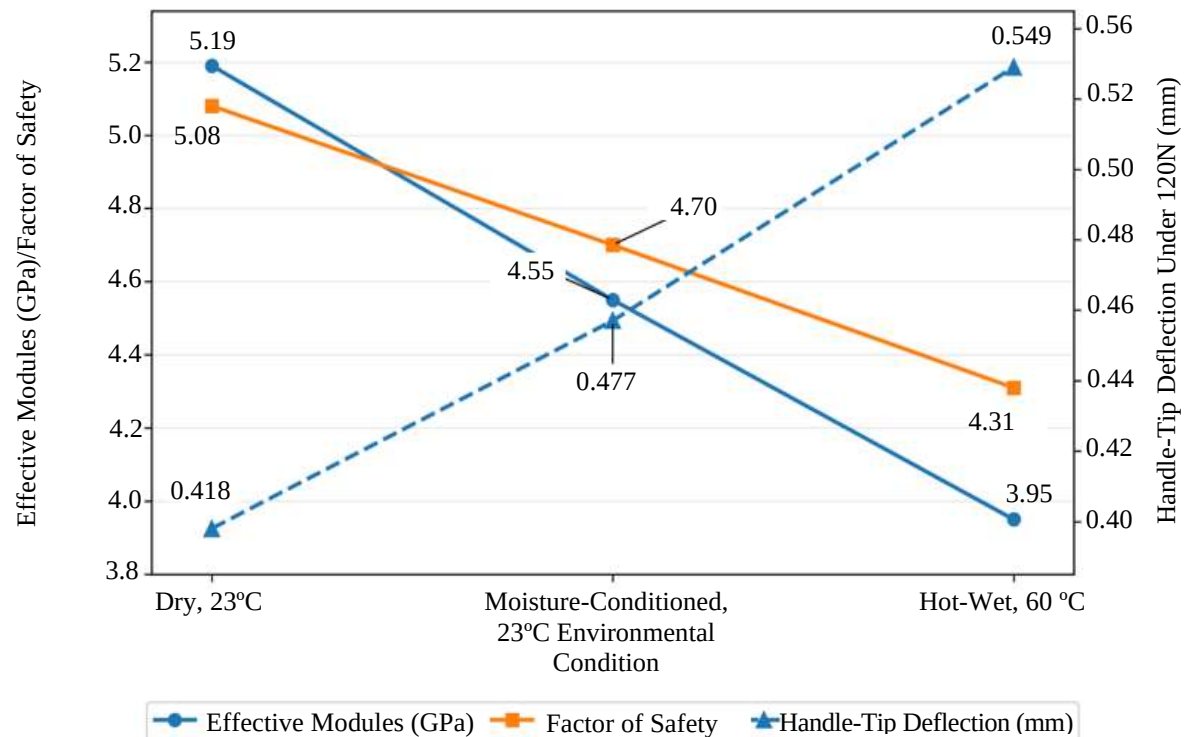


Figure 8. Sensitivity of PA6-GF30 handle modulus, deflection, and factor of safety.

The results shown in Table 6 indicate that environmental conditioning should be included in the design allowable rather than treated as an afterthought. Although the calculated safety margin remained acceptable, a final component should include fiber-flow alignment along the handle

axis, radiused trigger openings, and locally thickened screw bosses. A surface coating is not expected to prevent bulk moisture uptake permanently; therefore, dimensional allowances and conditioned mechanical data are more reliable than assuming a perfectly dry component throughout service.

Table 6. Environmental sensitivity of the PA6-GF30 handle.

Condition	Effective modulus (GPa)	Allowable stress (MPa)	Tip deflection (mm)	Factor of safety
Dry, 23°C	5.19	80	0.418	5.08
Moisture-conditioned, 23°C	4.55	74	0.477	4.70
Hot–wet, 60°C	3.95	68	0.549	4.31

Manufacturing and Polymer-Processing Implications

The PA6-GF30 handle shell should be designed for injection molding with uniform nominal wall thickness, gradual rib transitions, and adequate draft. Gate placement should promote melting flow along the handle axis because the principal bending stress is also aligned with this direction. Such alignment increases effective axial stiffness, but excessive convergence around the trigger opening can create weld lines and a local reduction in strength. The trigger hole and fastener bosses should, therefore, be positioned away from major flow-front meeting zones or reinforced by molded-in inserts.

The polypropylene hopper can be molded with a thicker lower collar and thinner upper wall because the collar transfers attachment and impact loads, whereas the wall primarily contains low hydrostatic pressure. A detachable design allows the hopper to be removed for cleaning. The nozzle liner should remain replaceable so that abrasive wear does not require disposal of the polymeric housing or hopper. The use of a thermoplastic-elastomer overmold on the grip introduces a further interface-design requirement: the substrate surface and overmold grade must be selected for mechanical interlocking or compatible adhesion.

From a sustainability perspective, a multi-material design should be assembled in a way that permits separation at end of life. Mechanical fastening is preferable to permanent adhesive bonding between the hopper, handle shell, metal housing, and nozzle insert. Material identification marks can be molded into the polymer parts. Recycled polymer content may be considered in future work, but it should be qualified because fiber-length degradation, contamination, and repeated processing can change modulus and impact performance.

Ergonomic and Productivity Implications

The polymer–metal hybrid design is intended to improve the operator interface without making unverified physiological claims. The reduced mass of the hopper and handle components lowers the moment generated about the wrist, while the PA6-GF30 shell limits handle deflection and the thermoplastic-elastomer overmold can improve grip friction. These features are expected to support more predictable spray guidance and reduce the frequency of corrective movement. The intended interaction of the operator with the assembly is shown in Figure 9.

Productivity gains should not be inferred solely from structural calculations. Actual improvement must be established through plastered areas per unit time, coating-thickness uniformity, material rebound or overspray, operator-rated discomfort, and rework.

Nevertheless, the present analysis identifies a credible mechanical pathway: selective polymer substitution reduces carried mass, while sufficient handle stiffness and the retained metallic load path preserve directional control. This provides a better foundation for future field testing than an unqualified claim that any lightweight polymer replacement will improve performance.



Figure 9. Intended operator interaction with the polymer–metal hybrid spray assembly during wall plastering.

LIMITATIONS AND EXPERIMENTAL VALIDATION REQUIREMENTS

The present study is a literature-calibrated analytical and numerical design investigation. A dimensioned conceptual representation of the proposed polymer–metal hybrid assembly has been included in Figure 5 to clarify the nominal hopper and handle geometries used in the calculations. The figure is not a photograph of a fabricated prototype, and no complete physical prototype was manufactured or experimentally tested in the present work. The PA6-GF30 and polypropylene properties were not measured from specimens produced using the final mold and processing conditions. Fiber orientation was represented using a scalar orientation-efficiency factor, whereas an injection-molded component may exhibit a three-dimensional skin–core orientation field. The handle calculation was linear elastic and used a simplified hollow-section representation. The hopper calculation considered hydrostatic loading but did not include impact, attachment torque, long-term creep, or repeated field loading.

Before journal submission as an experimentally validated polymer study, the final materials should be tested using tensile specimens prepared according to ISO 527-2, water uptake according to ISO 62, and, where relevant, flexural, impact, creep, and abrasion tests. Micro-computed tomography or polished-section microscopy should be used to quantify fiber orientation near the trigger opening. Differential scanning calorimetry and thermogravimetric analysis can establish the thermal state and reinforcement content, while Fourier-transform infrared spectroscopy can verify polymer identity and assess chemical change after mortar exposure. Component-level strain or displacement measurements should then be compared with the analytical and finite-element predictions.

Field validation should include repeated spraying and cleaning cycles, dimensional inspection of the hopper collar, trigger-cycle durability, grip usability, and wall-coverage measurements. These experiments will determine whether the predicted mass and stiffness benefits translate into lower operator effort and more consistent plastering. The current paper, therefore, provides a complete polymer-focused design framework and numerical basis, while clearly identifying the measurements required for final qualification.

CONCLUSION

This study revised a wall plastering spray assembly into a polymer-focused, structure–property-guided hybrid design. The principal pressure load path was retained in aluminum, the abrasion-critical nozzle was retained as a replaceable metallic insert, and polymeric materials were assigned to the hopper, handle shell, and grip according to their functional requirements. This partitioning was more realistic than a complete replacement of the metallic structure by a low-modulus thermoplastic.

A Halpin–Tsai model corrected for fiber orientation predicted effective moduli of 2.40, 3.62, and 5.19 GPa for PA6 containing 0, 15, and 30 wt% glass fiber. For the nominal handle geometry and a 120 N design load, PA6-GF30 reduced the tip deflection to 0.418 mm, compared with 0.904 mm for neat PA6. The local stress was 15.76 MPa and the calculated factor of safety was 5.08. The polypropylene hopper experienced only 0.034 MPa hydrostatic hoop stress, confirming that collar and impact design are more critical than pressure containment.

The retained aluminum pressure body exhibited a maximum deformation of 0.7564 mm, a peak equivalent stress of 22.74 MPa, and a factor of safety greater than 3.5. At the same time, substitution of the nominal metallic hopper and handle shell reduced the calculated mass of these components from approximately 0.47 to 0.083 kg. Moisture and temperature sensitivity increased the PA6-GF30 handle deflection to 0.549 mm in the hot–wet condition, but the factor of safety remained 4.31.

The main contribution is the direct connection of polymer microstructure, effective modulus, environmental sensitivity, component geometry, and practical tool performance. The framework provides a scientifically defensible basis for lightweight polymer use in construction equipment and identifies the tensile, thermal, moisture, orientation, abrasion, and field tests required for final experimental validation.

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