

ENGINEERING VERIFICATION OF A POLYJET-MANUFACTURED COMPONENT BY FINITE ELEMENT ANALYSIS

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ABSTRACT

This study presents the finite element-based structural verification of a functional pneumatic timing distribution component used in the strip-feeding system of an industrial eccentric press. The component was manufactured by PolyJet material jetting on a Stratasys Objet260 Connex3 system from Digital ABS Plus. A linear static model was developed in SOLIDWORKS Simulation 2022 using nominal manufacturer-based material properties. Five lateral loading cases from 10 to 50 N were analyzed under identical boundary conditions. In every case, the critical region was located at the transition between the functional arm and the base. At 50 N, the calculated stress remained far below the nominal tensile strength of 55 MPa, corresponding to a tensile-strength reserve ratio of approximately 16.8. The results demonstrate a predictable linear response and high static stiffness within the investigated load range, while defining the limitations of the idealized model and the requirements for future contact, fatigue and experimental studies.

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1. INTRODUCTION

Additive manufacturing (Gibson et al., 2021) offers clear advantages for low-volume functional components, replacement parts and rapid design iterations because complex geometries can be produced directly from CAD data without dedicated tooling. ISO/ASTM 52900 classifies material jetting as a process in which droplets of build material are selectively deposited (Standard ISO/ASTM 52900, 2021). PolyJet is a widely used implementation of this principle and is capable of producing fine layers, smooth surfaces and detailed internal features. These characteristics are relevant to compact pneumatic components containing small pockets, radii and functional sliding surfaces.

Most published experimental-numerical studies on material jetting focus on standard tensile specimens, graded coupons, lattices or multimaterial architectures. Fewer studies address a real rigid PolyJet machine element in its functional geometry and explicitly separate preliminary structural verification from experimental validation.

The literature demonstrates that close agreement between finite element predictions and experiments is achievable when the constitutive description and the physical test are defined consistently. Previous simulation studies have supported experimental verification and the use of numerical models for analysis and optimization (Grigorova et al., 2026; Stoimenov, 2023). (Salcedo et al., 2018) compared full-field strain maps from tensile tests of material-jetted graded specimens with finite

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element results based on calibrated material models and predicted the maximum matrix strain within 5%. Although they studied fused-filament-fabricated PLA rather than PolyJet photopolymers, (Torre & Brischetto, 2022) reached a complementary conclusion: experimentally identified orthotropic properties produced excellent predictions in bending and bending-torsion tests, whereas an isotropic model based on feedstock data could not reproduce orientation-dependent behaviour. Together, these studies indicate that numerical accuracy is governed less by the solver alone than by the fidelity of the material model, boundary conditions and load representation.

Königshofer et al. (2021) and Tee et al. (2020) investigated statistically significant orientation-dependent variations of 3D printed specimens produced on an Objet 500 Connex 3. Their findings show that nominal CAD geometry and catalogue properties can provide a practical first approximation, but they cannot by themselves establish the predictive accuracy of a component-level numerical model.

The required modelling fidelity depends on the deformation regime and the architecture of the printed material. For flexible PolyJet materials, (Abayazid & Ghajari, 2020) showed strong strain-rate, relaxation and build-orientation effects and obtained accurate predictions only after calibrating a visco-hyperelastic model. For material-jetted matrix-inclusion composites, (Kornfellner et al., 2024) reported that neglecting the effective printed geometry and non-ideal interfacial stiffness could change the estimated elastic modulus by as much as 44%. These results concern more complex material systems than the rigid single-material part studied here, but they clarify the limits of interpreting a nominal isotropic linear-elastic analysis as a validated representation of service behaviour. Mesh quality and linear load-response consistency support numerical verification; predictive accuracy additionally requires experimentally measured loads, component-specific material data and comparison with physical deformation. The objective of the present work is therefore to quantify the sensitivity of a PolyJet-manufactured machine element to controlled lateral forces. Maximum von Mises stress, resultant displacement and equivalent strain are evaluated to identify the critical region and assess preservation of the functional geometry. Experimental-numerical investigations have demonstrated that finite element analysis can reproduce the global deformation behaviour of material-jetted structures when the geometry, boundary conditions and material properties are defined consistently (Zhang et al., 2021; Mora et al., 2022). Much of the literature nevertheless concerns standard specimens, lattices or architected metamaterials rather than real industrial machine elements. The present study addresses this gap by evaluating a rigid PolyJet-manufactured pneumatic timing distribution component in its actual functional geometry.

2. MATERIALS AND METHODS

2.1 Component manufacture and material model

The study presents the finite element-based structural verification of a functional pneumatic timing distribution component used in the strip-feeding system of an industrial eccentric press. The component investigated (Figure 1) in this work operates inside a precision-machined aluminium housing. During reciprocating motion, two internal pockets alternately connect and interrupt air passages leading to two actuator chambers. The component therefore controls the forward and return strokes of the feeder and contributes directly to the operating takt of the press. Its acceptance cannot be based only on resistance to fracture: excessive elastic displacement could also disturb the relative position of the internal pockets and impair switching accuracy. The production CAD geometry was used for both additive manufacture and finite element modelling. The component was manufactured by PolyJet material jetting on a Stratasys Objet 260 Connex 3 system from Digital ABS Plus. The building material consists of two liquid resins: RGD 515S base photopolymer and RGD 531 hardening component which are mixed during 3D printing. The nominal layer thickness was 30 μm , and SUP705 was used as the removable support material. This material is intended for functional prototypes and tooling where greater stiffness and toughness are required than those offered by standard rigid photopolymers. The material inputs are summarized in Table 1 (Stratasys, 2021). Material-jetting research shows, that the validity of a numerical model depends on the selected constitutive assumptions and the magnitude and rate of deformation (Bagheri & Jin, 2019; Slesarenko & Rudykh, 2018).

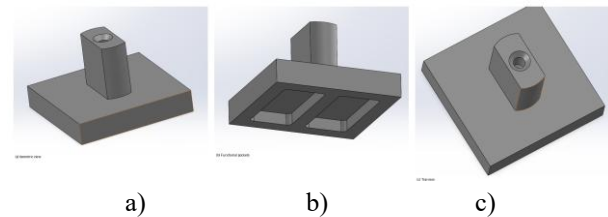


Figure 1. Investigated pneumatic timing distribution component: a) isometric CAD view, b) internal functional pockets, and c) top view

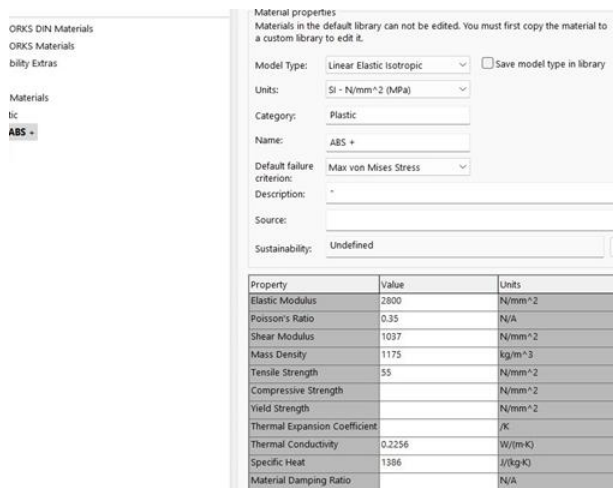
For the numerical study, the component was represented as a homogeneous, isotropic, linear-elastic solid. This idealization was selected for preliminary static verification because the analyzed forces generated small strains and stresses substantially below the nominal tensile strength. The Poisson ratio of 0.35 was treated as an engineering assumption because it was not specified in the available manufacturer data sheet.

Table 1. Material and manufacturing parameters used in the numerical model

Parameter	Value
Material	Digital ABS Plus
Base / hardening components	RGD515S / RGD531
Printer	Stratasys Objet260 Connex3
Layer thickness	30 μm
Support material	SUP705
Elastic modulus	2800 MPa
Poisson's ratio	0.35
Density	1175 kg/m ³
Nominal tensile strength	55 MPa

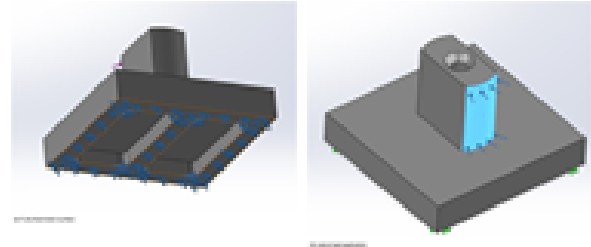
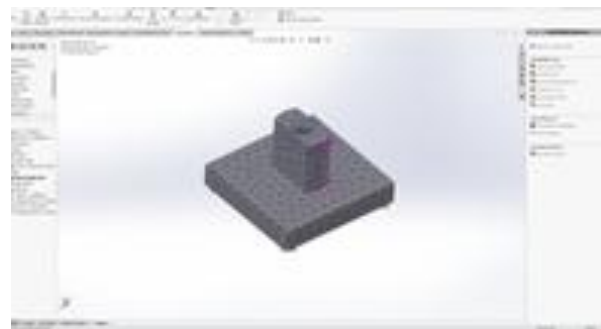
2.2 Finite element model and boundary conditions

The analyses were performed in SOLIDWORKS Simulation 2022 using a linear static solver. The mechanical properties of the material were set according to the Technical specification of the manufacturer. The parameters were verified experimentally in related experimental work by the authors (Paneva et al., 2026). The fields of the software program were filled in with the data and visualized in Figure 2.

**Figure 2.** Digital ABS Plus material definition used in SOLIDWORKS Simulation

The lower support surface was fully constrained as an idealised representation of the structural support. This boundary condition evaluates the component under a fixed-base assumption and does not reproduce sliding contact or friction against the aluminium housing. A lateral force was applied to the same side surface for every study. Five simulations were solved at 10, 20, 30, 40 and 50 N, while geometry, material data, boundary conditions and mesh settings were kept unchanged. The selected force interval is a parametric range, not a measured service-load spectrum, and the results are consequently interpreted as a preliminary linear static verification rather than proof of operational durability.

The boundary condition of the simulation was set and shown in Figure 3. The base is fully fixed on the lower support surface (a) and lateral force was applied to the functional arm (b). The model was discretised using a high-quality curvature-based solid mesh, shown in Figure 4.

**Figure 3.** Idealised boundary conditions: (a) fully fixed lower support surface and (b) lateral force applied to the functional arm.**Figure 4.** Curvature-based solid finite element mesh of the investigated component.

The mesh contained 8,468 nodes and 5,091 solid elements. The maximum and minimum element sizes were 2.58187 and 0.12909 mm, respectively. A total of 98.6% of the elements had an aspect ratio below 3, the maximum aspect ratio was 4.2026, and no distorted elements were reported. The condition of simulation and mesh parameters were described on Table 2.

Table 2. Finite element model and mesh parameters

Parameter	Setting / value
Software	SOLIDWORKS Simulation 2022
Study type	Linear static
Material model	Linear elastic, isotropic
Support	Fully fixed lower surface
Applied forces	10, 20, 30, 40 and 50 N
Mesh type	Curvature-based solid mesh, high quality
Nodes / elements	8,468 / 5,091
Maximum / minimum element size	2.58187 / 0.12909 mm
Maximum aspect ratio	4.2026
Distorted elements	0

3. RESULTS

3.1. Load-dependent structural response

A linear static model was developed in SOLIDWORKS Simulation 2022 using nominal manufacturer-based material properties. Five lateral loading cases from 10 to 50 N were analysed under identical boundary conditions and the results are presented in Table 3. In every case, the critical region was located at the transition between the functional arm and the base. View of the distribution of stress under the maximum investigated load of 50 N is shown in Figure 5.

Table 3. Numerical results for the investigated loading cases

Force (N)	Stress (MPa)	Displacement (mm)	Equivalent strain	Reserve ratio*
10	0.655	0.004162	1.916×10^{-4}	84.0
20	1.309	0.008324	3.833×10^{-4}	42.0
30	1.964	0.01249	5.749×10^{-4}	28.0
40	2.618	0.01665	7.666×10^{-4}	21.0
50	3.273	0.02081	9.582×10^{-4}	16.8

*Ratio between the nominal tensile strength (55 MPa) and the calculated maximum von Mises stress; it is not a fatigue- or yield-based safety factor

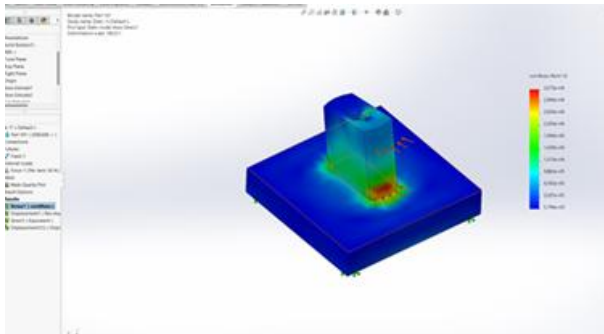


Figure 5. Equivalent von Mises stress distribution under the maximum investigated load of 50 N

The highest stress occurs at the transition between the functional arm and the base. Using the lower reported tensile strength of 55 MPa as a conservative reference, the 50 N case gives a tensile-strength reserve ratio of approximately 16.8. This ratio indicates a large static margin relative to nominal tensile failure, but it is deliberately not presented as a conventional factor of safety against yielding because the manufacturer data do not provide a verified yield strength for the printed material.

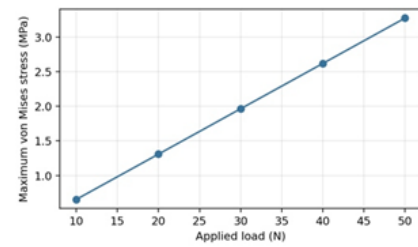
Furthermore, tensile strength does not address fatigue, creep, wear or the effect of repeated sliding contact. The maximum stress, displacement and equivalent strain increased almost proportionally with the applied force. The similarity of the contour patterns across the five studies indicates that the loading magnitude changed the response amplitude without changing the governing

deformation mechanism. This behavior is consistent with the assumptions of a linear static model.

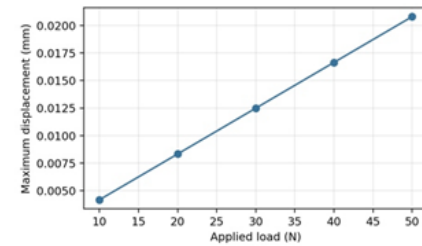
For every load case, the maximum von Mises stress occurred at the transition between the functional arm and the base. The applied lateral force generates a bending moment, making this geometric transition the critical structural section. At 50 N, the maximum stress was 3.273 MPa. The corresponding maximum displacement was 0.02081 mm and the maximum equivalent strain was 9.582×10^{-4} .

4. DISCUSSION

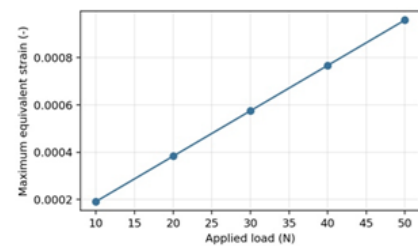
The results show a predictable linear response within the investigated force interval. Stress, displacement and strain all increased by approximately a factor of five when the force increased from 10 to 50 N. The load-response relationships for maximum von Mises stress, maximum displacement and maximum equivalent strain as functions of the applied force are graphically presented in Figure 6. This consistency supports the internal numerical repeatability of the five studies, but it should not be interpreted as experimental validation of the model.



a) Stress



b) Displacement



c) Equivalent strain

Figure 6. Load-response relationships: (a) maximum von Mises stress, (b) maximum displacement and (c) maximum equivalent strain as functions of the applied force

The displacement result is particularly important for the function of the component. A pneumatic timing element may become functionally inaccurate before reaching a material-strength limit if elastic deformation changes the alignment of the internal air-distribution pockets. The calculated maximum displacement of 0.02081 mm under the maximum analysed force indicates high static stiffness in the idealised fixed-base configuration. The apparent structural stiffness, calculated as F/δ , is approximately 2.40 kN/mm for all five load cases, as expected for a linear model.

The critical region identified at the base transition provides a clear direction for future design studies. If greater load capacity or fatigue resistance is required, the local fillet radius or cross-sectional thickness may be increased and assessed using the same numerical workflow. The geometric freedom of PolyJet manufacturing makes such modifications straightforward without dedicated tooling.

The main limitations arise from the idealised fully fixed boundary condition, nominal isotropic material data and the absence of contact, friction and cyclic loading. Therefore, the present study is best interpreted as a preliminary static verification and load-sensitivity analysis. A complete durability assessment would require measurement of the actual operating force, experimental characterisation of printed specimens, contact modelling with the aluminium housing and fatigue or wear testing.

4.1 Design implications

The numerical results provide a direct basis for targeted geometric improvement. Because the peak stress is consistently located at the transition between the functional arm and the base, future variants should prioritise this zone. Increasing the local fillet radius would reduce the geometric discontinuity and distribute the bending stress over a larger area. A moderate local increase in cross-sectional thickness may also improve stiffness while preserving the external envelope required by the aluminium housing. These modifications can be evaluated using the same parametric finite element workflow before any new part is manufactured.

The apparent stiffness of approximately 2.40 kN/mm provides a useful comparative indicator for design iteration. It is not a material property and should not be generalised beyond the present boundary conditions; however, it can be used to compare alternative geometries of the same component under identical numerical assumptions. A redesigned variant would be considered mechanically improved if it reduced the peak stress and displacement without compromising the pneumatic pockets, sliding clearances or manufacturability.

4.2. Experimental validation strategy

The next stage of the investigation should establish the actual force history acting on the component during machine operation. This can be achieved by measuring

actuator pressure, recording the effective loaded area and, where possible, using a load cell or instrumented fixture to determine the lateral reaction force. The measured load spectrum should then replace the present parametric interval. Experimental displacement measurements at the functional arm would provide the most direct first validation of the linear static model.

A second validation stage should address the effects excluded from the current model. Contact between the polymer component and the aluminium housing should be represented with frictional sliding, and the material model should be calibrated using specimens printed on the same Objet 260 Connex 3 system and in the same build orientation. Because the component operates repetitively, fatigue, creep and wear testing are required before claims concerning service life can be made. These additions would convert the current preliminary verification into a complete durability assessment.

5. CONCLUSION

The following conclusions were drawn from the simulation and engineering verification:

- The adopted finite element workflow consistently identified the transition between the functional arm and the base as the governing structural region.
- Within the investigated interval of 10–50 N, stress, displacement and strain increased linearly, supporting the use of a linear static model for this preliminary assessment.
- At 50 N, the maximum stress was 3.273 MPa and the maximum displacement was 0.02081 mm, indicating a high static strength reserve and limited elastic deformation in the idealised fixed-base model.
- The calculated tensile-strength reserve ratio of 16.8 is a comparative static indicator and should not be interpreted as proof of fatigue life, wear resistance or safe operation under unmeasured service loads.
- The methodology provides a practical basis for further optimisation and experimental validation of PolyJet-manufactured pneumatic machine components.

The study demonstrates how a real industrial function, additive manufacture and numerical assessment can be integrated into a compact verification workflow. For low-volume components, this approach can identify critical regions and quantify stiffness before repeated prototype manufacture. The method is transferable to related pneumatic distribution elements, provided that service loads, contact conditions and material data are defined for the specific application.

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