



# FEASIBILITY STUDY OF POLYMER-BASED BENDING DEVICES MANUFACTURED VIA MATERIAL EXTRUSION ADDITIVE MANUFACTURING FOR SMALL-BATCH PRODUCTION AND PROTOTYPING

Cristian Giolu<sup>1</sup>, Cătălin Gheorghe Amza<sup>2</sup>

<sup>1</sup>National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independenței, Bucharest, Romania,  ORCID No. 0009-0002-5826-5637, cristian.giolu@stud.fir.upb.ro

<sup>1</sup>National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independenței, Bucharest, Romania, *Corresponding author*,  ORCID No. 0000-0002-6621-5034, catalin.amza@upb.ro

**ABSTRACT:** This research explores the technical viability of utilising Material Extrusion (MEX) Additive Manufacturing (AM) technology for the fabrication of bending devices. The primary objective of this undertaking is to investigate the potential for decreasing production costs and accelerating lead times. The present study builds upon the findings of earlier investigations by means of an examination of the performance of polymer-based devices, which had previously been subjected to finite element analysis (FEA). The method advances the field by using a polymer-based die. The findings suggest that this method has potential application in small-batch production and prototyping, with a consistency between the experimental results and the predictions made via finite element analysis.

**KEYWORDS:** additive manufacturing; bending die; material extrusion; metal bending; PLA; sheet metal;

## 1. INTRODUCTION

The fabrication of bending dies through conventional manufacturing methods entails significant expenditures, primarily attributable to material procurement, labour, and machining operations. Notably, the selection of die materials—commonly high-strength tool steels or specialized alloys—represents a major cost factor, as these materials must exhibit exceptional resistance to the elevated pressures and cyclic loading characteristic of the bending process [1, 2].

In mass production contexts, the substantial initial investment required for die manufacturing is amortized over a large number of produced parts, thereby yielding a favorable per-unit cost [1, 2, 3, 4]. However, the economic viability of bending dies diminishes markedly in low-volume or batch production scenarios, where the fixed costs associated with die fabrication cannot be effectively distributed [1, 2, 3]. The substantial upfront investment in die manufacturing becomes disproportionate when economies of scale cannot be fully realised. Additionally, the long operational lifespan of dies—typically beneficial in mass production—poses challenges in low-volume contexts, as fixed costs for maintenance, storage, and refurbishment remain constant regardless of production volume. These factors contribute to elevated per-part costs and extended production cycles, further reducing cost-effectiveness for bespoke or small-batch manufacturing.

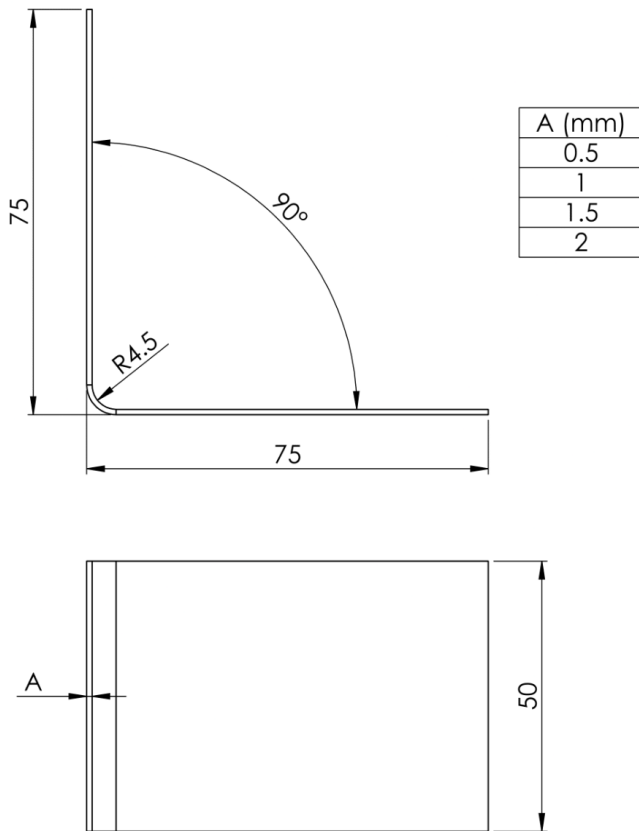
In recent years, the potential integration of additive manufacturing (AM) technology into sheet metal processing has emerged as a subject of increasing research interest, offering a novel and potentially disruptive paradigm within the field. Specifically, the fabrication of stamping dies via AM has garnered attention among researchers, with preliminary investigations demonstrating encouraging outcomes [5]. This approach offers potential solutions to the limitations of traditional die manufacturing, particularly in customisation, cost reduction, and lead time optimisation. Initial findings indicate that AM may confer distinct advantages in low-batch production and for the realization of geometrically complex die designs—scenarios in which conventional manufacturing approaches often encounter limitations in terms of cost efficiency and design flexibility.

Among AM processes, Material Extrusion (MEX) has emerged as a focal point due to its accessibility and relatively low cost. Building upon the foundational work of Cristian et al. [6], which examined the operational behaviour of sheet metal processing devices fabricated through AM, this study aims to extend the existing body of knowledge. A series of workpieces will be produced via bending using a die manufactured by MEX. The dimensional characteristics of these workpieces will be systematically compared against those predicted by the finite element analysis (FEA) presented in [6]. This comparative analysis is intended to elucidate the practical conditions governing the implementation of

AM in sheet metal forming processes, while also identifying and addressing potential limitations—particularly those pertaining to the dimensional accuracy of AM-fabricated devices.

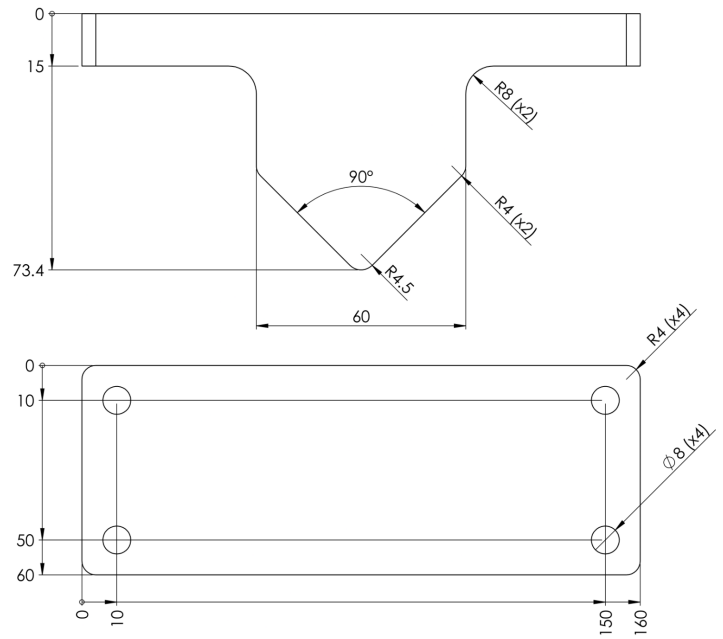
## 2. MATERIALS AND METHODS

A suitable component is selected for investigation. Subsequently, the design and fabrication of the bending apparatus are conducted, followed by a series of experimental trials. For the experimental exploration of the process, a v-bending part is selected (Figure 1). This type of geometry is frequently encountered in industrial applications and serves as a suitable model for examining the mechanical behaviours and challenges associated with bending of metal sheets. Thus, the angular dimensional deviation (the angular dimensional deviation refers to the measured difference in the angular dimensions of a formed part compared to its intended design specifications) of the formed components will be measured, and the obtained values will be systematically recorded in a tabulated format for comparative analysis. The results are compared to the FEA results and, based on the findings, conclusions are drawn regarding the feasibility and performance of the bending device manufactured via additive processes.

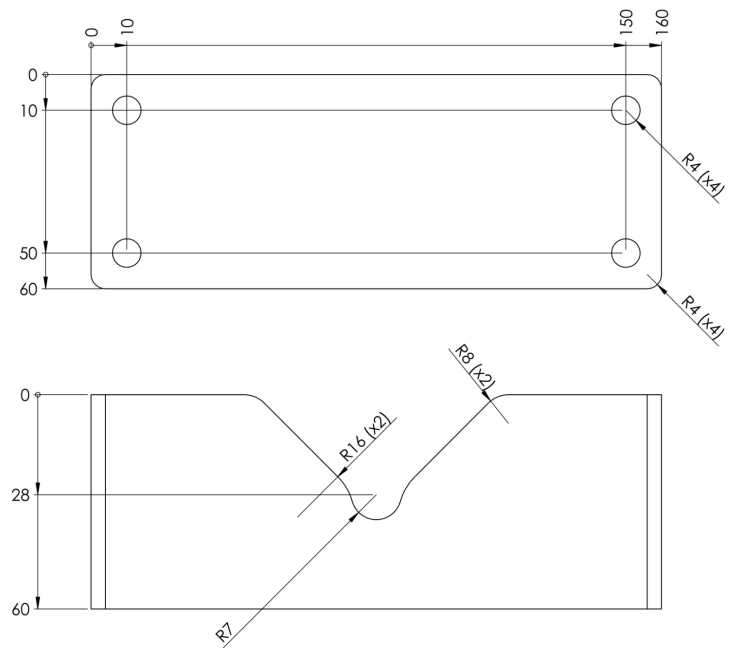


**Figure 1.** Workpiece dimensions

The two forming components—the punch (Figure 2) and the forming plate (Figure 3)—were designed to include mounting holes, facilitating their assembly onto the die frame using standardised fasteners, specifically screws and dowel pins.



**Figure 2.** Punch dimensions

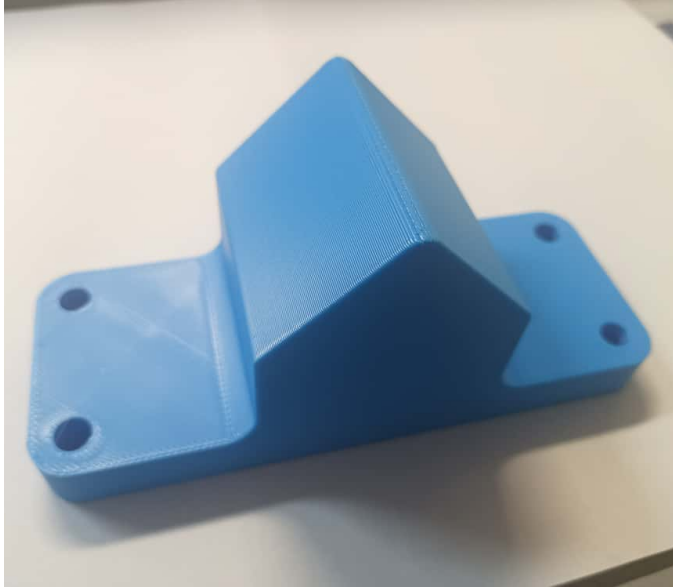


**Figure 3.** Bending plate dimensions

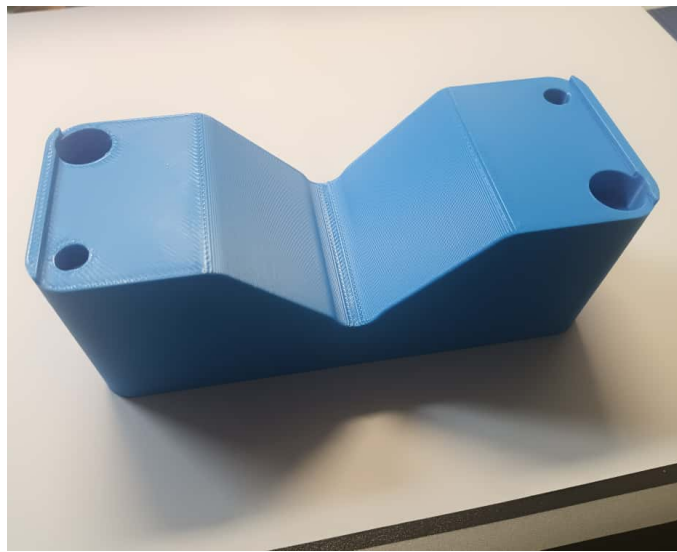
## 3. DEVICE MANUFACTURING AND TESTING PARAMETERS

For the additively manufactured components such as the punch (Figure 4) and bending plate (Figure 5), the selected process parameters comprised a 70% infill

density and a wall thickness of four layers. The PLA filament diameter was 1 mm, while the nozzle diameter measured 0.4 mm. The print speed was maintained at 60 mm/s, with total fabrication times of over 4 hours for the punch and over 6 hours for the bending plate. The nozzle and bed temperatures were set to 190 °C and 60 °C, respectively. Fabrication was performed using a Bambu Lab P1S 3D printer.



**Figure 4.** Printed part - punch



**Figure 5.** Printed part - bending plate

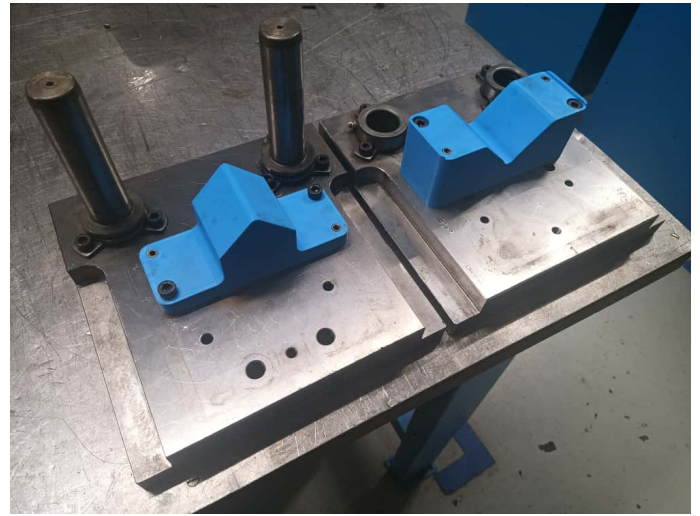
During the design phase of the bending plate (Figure 5), a set of locating edges was incorporated to centre the workpiece and ensure dimensional uniformity in the resulting components.

**Table 1.** Print characteristics of the PLA parts

	Punch	Bending plate
Printing time (hh:mm)	4:20	6:44
Material cost (€)	7.64	11.69
Material mass (g)	305.7	467.6

The total cost of the additively manufactured components was €19.33 (Table 1). With a production

run of 50 workpieces, the theoretical cost per piece amounted to €0.38. This represents a substantial cost reduction compared to a conventionally manufactured device, where the raw material cost alone is €192 [7], resulting in a blank cost of €3.84 per unit. Consequently, the AM approach achieved a 90% decrease in per-unit manufacturing cost.



**Figure 6.** Bending die assembly

The bending die (Figure 6) was subsequently affixed to the press machine (model Hans Schoen UTE-B) using clamping brackets to ensure stable fixation during the stamping trials. A total of 50 components (Figure 7) were fabricated at a ram speed of 60 mm/s under an applied force of 2500 kN.

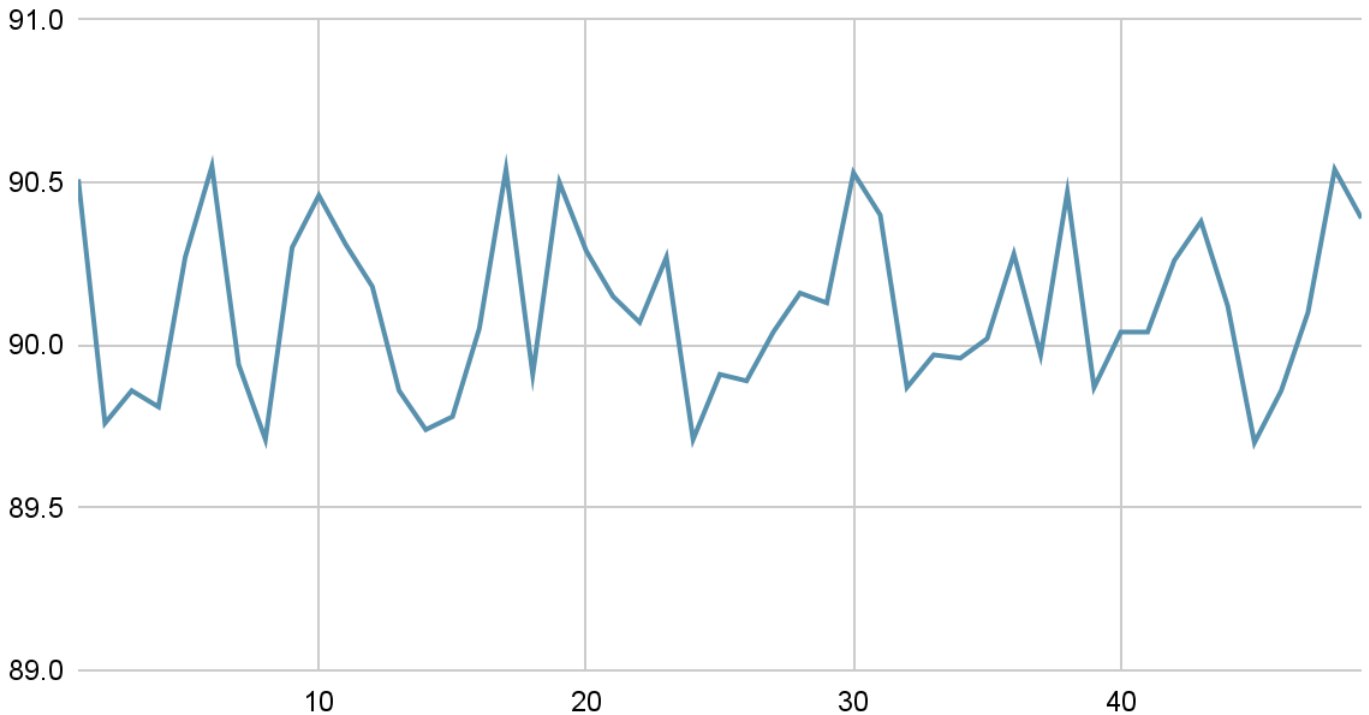


**Figure 7.** Example of resulted workpieces

#### 4. RESULTS

Dimensional measurement of the parts was conducted by assessing the angle resulting from the bending process. A digital protractor was employed to precisely determine their dimensional characteristics.

## Angular dimensional deviation



**Figure 8.** Angular dimensional deviation

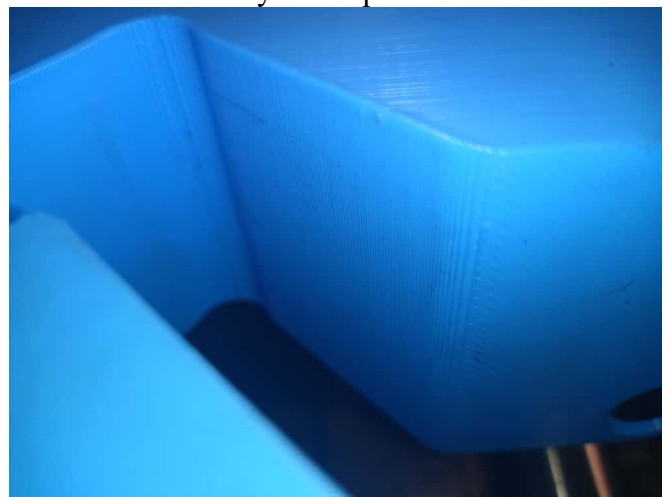
A consistent dimensional trend was observed among the measured parts (Figure 8), with no significant variations detected; the largest discrepancy occurred between Part #6 and Part #45, exhibiting an angular difference of  $0.85^\circ$ .

Subsequent to the measurement of the workpieces, negative bending was observed in some components, resulting in angles that were surprisingly below  $90^\circ$ . The smallest recorded angle was  $89.7^\circ$ , while the largest measured  $90.5^\circ$ , with an average of  $90.1^\circ$ . The dimensional precision of the device was assessed by comparing the angular measurements against the ISO DIN 2768-mk standard [8]. This standard defines general tolerances for linear and angular dimensions, as well as geometrical characteristics such as straightness, flatness, and perpendicularity. This standard is commonly applied in instances where specific tolerances are not individually indicated on technical drawings. The range of tolerance grades extends from f (fine) to v (very coarse).

The dimensional analysis of the workpieces revealed that 25 components fell within the fine (f) and medium (m) tolerance grades, while 13 components were classified under the coarse (c) grade. The remaining 12 workpieces were categorised as very coarse (v) according to the ISO DIN 2768-mk standard. This finding suggests that the device

attained a high level of angular precision in the formed components.

Upon inspection of the bending device components, no signs of wear were identified—only subtle imprint marks (Figure 9), likely caused by the repeated placement of metal sheets in the same position. However, these marks did not appear to influence the dimensional accuracy of the parts.



**Figure 9.** Resulted imprint marks

## 5. CONCLUSIONS

This study assessed the feasibility of using AM to produce active components for a bending die, which was then employed to form a series of fifty

workpieces from 1 mm DIN 1.1121 steel. The resulting components were measured, and their angular dimensions were compared with the predictions of a FEA simulating the same conditions. The FEA proved highly effective in forecasting the experimental outcomes, as the physical test results closely corresponded with the simulated data.

Dimensional analysis of the formed parts revealed remarkable consistency, with only small deviations—up to  $0.85^\circ$ —observed across the batch. This uniformity suggests that the method is capable of supporting larger-scale production runs without compromising precision. The dimensional analysis of the workpieces revealed that the majority (25 out of 50) met the fine (f) and medium (m) tolerance grades as per the ISO DIN 2768-mk standard, indicating a high level of angular precision in the manufacturing process. While some components (25 out of 50) fell into the coarse (c) or very coarse (v) tolerance grades, the overall average angle of  $90.1^\circ$  suggests that the device generally performed within acceptable limits.

Furthermore, the AM-produced components demonstrated no significant deformation when subjected to bending forces, though minor surface imprints were noted, likely due to repeated contact with the metal sheets during forming. Importantly, these imprints did not adversely affect the dimensional tolerances of the final parts.

The findings of this study highlight the considerable potential of AM-fabricated sheet metal bending devices for industrial applications. The process offers distinct advantages, including a substantial reduction in per-unit cost—lowering expenses to 0.38 EUR per part compared to 3.84 EUR per part for conventionally manufactured dies—as well as significantly shorter production times. These benefits position AM as a compelling alternative to traditional die manufacturing methods, particularly in scenarios where flexibility, cost efficiency, and rapid production are prioritised.

Looking ahead, future research could explore the integration of topology optimisation within the design process to further reduce material consumption,

manufacturing time, and overall costs. Additionally, further investigation into the performance of AM-produced dies for high-volume production and complex geometries would help validate their long-term durability and precision. Such advancements could reinforce the role of AM as a transformative technology in the field of sheet metal forming, offering a scalable, cost-effective solution for modern manufacturing challenges.

## 6. REFERENCES

1. Tang, D.; Eversheim, W.; Schuh, G.; Chin, K.-S. Concurrent metal stamping part and die development system. *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, 217, pp. 805–825 (2003).
2. Bouaziz, Z.; Ben Younes, J.; Zghal, A. Cost estimation system of dies manufacturing based on the complex machining features. *Int. J. Adv. Manuf. Technol.* 28, pp. 262–271, (2006).
3. Nagahanumaiah, K.; Mukherjee, N.P.; Ravi, B. An integrated framework for die and mold cost estimation using design features and tooling parameters. *Int. J. Adv. Manuf. Technol.*, 26, pp. 1138–1149, (2005).
4. Hattalli, V.L.; Srivatsa, S.R. Sheet Metal Forming Processes—Recent Technological Advances. *Mater. Today Proc.*, 5, pp. 2564–2574, (2018).
5. Strano, M., Rane, K., Farid, M.A. et al. Extrusion-based additive manufacturing of forming and molding tools. *Int J Adv Manuf Technol* 117, pp. 2059–2071 (2021).
6. Giolu, C., Amza, C., & Sumanariu, C. Influence of polymer type on tolerance in additively manufactured bending dies. *Nonconventional Technologies Review*, 29(3) (2025).
7. Standard plates. Available online: <https://www.meusburger.com> (accessed on 12 Oct 2025)
8. *ISO 2768-1:1989*; General Tolerances Part 1: Tolerances for Linear and Angular Dimensions without Individual Tolerance Indications. Available online: [ISO 2768-1:1989 - General tolerances — Part 1: Tolerances for linear and angular dimensions without individual tolerance indications](https://www.iso.org/standard/50000.html) (accessed on 12 Oct 2025).