International Scientific Journal of Engineering and Management
ISSN: 2583-6129
Volume: 03 Issue: 06 | June – 2024
DOI: 10.55041/ISJEM02084
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

Advancing Manufacturing Efficiency: Multi-Cavity Tool Implementation for High-Volume Production in Plastic Injection Molding

Dhrudipsinh Dabhi

Senior Technical Program Manager

Abstract

The transition from single-cavity prototype molds to multi-cavity production tools offers significant advantages in high-volume plastic injection molding. This paper examines a case study where a multi-cavity tool was implemented to address production inefficiencies for tube and cover assembly's tools. By leveraging advanced manufacturing techniques and collaborative design efforts, production speed increased fourfold, reducing operational costs and ensuring readiness for projected annual volumes of over half a million units by 2026. The results demonstrate the cost-justification of multi-cavity tooling, eliminating the need for post-molding annealing for tube parts and achieving optimal efficiency for cover parts as well.

Keywords: Multi-cavity tools, plastic injection molding, productivity enhancement, cost efficiency, prototype to production, smart manufacturing

1. Introduction

In 2021, my company, specializing in plastic injection molding, was awarded a new program involving tube and cover assemblies. This program marked a pivotal moment, as it presented unique challenges that required innovative solutions to ensure successful execution. The initial prototypes, produced using aluminum single-cavity tools by third-party vendors, were primarily designed for validation and testing purposes. However, these tools were unsuitable for scaling up to mass production due to their inherent limitations. Recognizing the need for a more robust approach, I spearheaded efforts to transition from these single-cavity prototype molds to advanced multi-cavity production tools.

The project gained further importance when our customer verbally communicated an annual volume projection of over 500,000 units by 2026. This volume exceeded the capacity of our existing tooling setup and necessitated a comprehensive redesign of the production process. In September 2023, we commenced the design of multi-cavity tools for the main covers, leveraging lessons learned from the prototype phase. The CAD designs served as a blueprint for creating tools that could meet the dual objectives of increased productivity and enhanced cost efficiency. This paper details the step-by-step approach taken to address these challenges, including collaborative efforts with the customer's Engineers and the integration of Advanced Manufacturing Techniques.

2. Problem Statement

The aluminum prototype molds, while effective for initial testing, were inherently flawed for high-volume production. These molds were fabricated using aluminum, a material unsuitable for the high-temperature conditions (250°F) required for our specific production needs. Running these molds at such temperatures posed significant risks, including warping and reduced tool life, which could lead to frequent downtime and increased maintenance costs.

Moreover, the single-cavity design severely limited production rates, resulting in extended press times that were both costly and inefficient.

Another critical issue was the dependency on post-molding annealing as a secondary operation for tube parts. The annealing process, carried out in a large conventional oven, added significant operational costs and extended lead times. This secondary operation not only strained our resources but also increased the potential for handling defects, further impacting overall productivity and quality.

With the customer's forecasted annual volume exceeding half a million units, it became evident that the existing tooling setup would be unable to meet these demands. The limitations of the single-cavity tools highlighted the need for a strategic overhaul. By transitioning to a multi-cavity tooling approach, we aimed to address these challenges comprehensively, ensuring the scalability, efficiency, and reliability of the production process. This paper explores the methodology and outcomes of implementing this transformative solution.

3. Collaboration and Design Strategy

The development of the multi-cavity tool required an unprecedented level of collaboration between our engineering team and the customer's plastic and design engineers, Josh and John. This collaborative effort went beyond routine interactions, involving comprehensive planning sessions and frequent design reviews to ensure alignment with the program's overarching goals. These sessions helped bridge the gap between theoretical design concepts and practical manufacturing realities.

- **Key Focus Areas:**
    - Ensuring the tool's durability under high-temperature conditions.
    - Balancing production speed and precision to meet design specifications.
    - Addressing issues such as uneven cooling, part warpage, and insufficient tool durability.

For example, during one of the design reviews, the customer's team highlighted an issue with a similar high-volume tool in a prior program, where uneven material flow had caused frequent part defects. Using this insight, we incorporated advanced gating systems into the new design to distribute material evenly across all cavities. This adjustment significantly reduced the occurrence of defects and improved overall part quality.

Another instance involved optimizing the cooling channels within the tool. Drawing from lessons learned during a prior automotive program, where inadequate cooling had led to inconsistent part dimensions, we implemented a segmented cooling system for the multi-cavity tool. This approach ensured uniform cooling across all cavities, enhancing dimensional stability and reducing cycle times.

Collaboration extended beyond design to include process validation. The customer provided critical insights from their testing of prototype parts, which informed adjustments to the multi-cavity tool's design. For example, specific geometric features were modified to improve fit and function during assembly. This iterative process exemplified the value of close collaboration in achieving a robust and efficient production solution.

International Scientific Journal of Engineering and Management ISSN: 2583-6129
Volume: 03 Issue: 06 | June – 2024 DOI: 10.55041/ISJEM02084
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

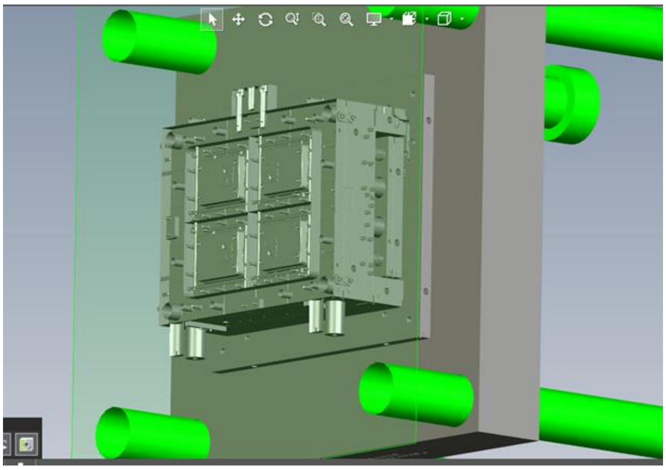


Figure 1: This image shows the CAD of multi-cavity tool implemented to enhance productivity.

Figure 2: This is an image of the finalized multi-cavity tool.

Projected Volume Comparison (2022-2025)

Year	Tube Assembly Forecast	Cover Assembly Forecast
2022	110,161	101,690
2023	125,000	115,000
2024	400,000	375,000
2025	450,000	425,000

Table 1: summary of the Forecast of all these years.

International Scientific Journal of Engineering and Management ISSN: 2583-6129
Volume: 03 Issue: 06 | June – 2024 DOI: 10.55041/ISJEM02084
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

Year	Forecast		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2022	Tube Assembly		-	1,955	3,878	10,808	14,568	14,573	9,223	9,623	13,115	9,623	9,623	13,171	110,161
	Cover Assembly		-	-	3,715	9,156	13,287	13,963	8,971	8,971	12,566	9,221	9,221	12,620	101,690
2023	Tube Assembly		7,154	8,799	8,813	10,040	12,670	13,006	13,530	14,008	18,826	19,416	19,179	38,754	184,195
	Cover Assembly		6,754	8,399	7,413	9,140	10,170	10,506	13,530	14,008	18,826	19,416	19,179	38,754	176,095
2024	Tube Assembly		0	12,500	12,500	12,500	12,500	19,500	26,000	40,000	38,000	40,000	39,000	34,000	286,500
	Cover Assembly		0	8,139	12,336	14,640	15,000	15,000	22,540	36,550	32,938	38,158	39,308	34,533	269,142
2025	Tube Assembly		26,880	20,000	20,000	20,000	20,000	20,000	20,000	25,000	31,890	34,479	39,052	42,766	320,067
	Cover Assembly		10,000	18,488	28,910	13,836	31,620	46,042	36,987	38,758	36,890	41,479	39,052	42,766	384,828

Table 2: Break-down of the Forecast of each year by months

4. Implementation and Process Optimization

Implementing the multi-cavity tool marked a significant milestone in transforming our manufacturing process. It began with a meticulous pre-production phase, where every aspect of the tool's operation was carefully validated. Initial testing focused on ensuring that all cavities produced parts with consistent dimensional accuracy and surface quality. This was achieved using state-of-the-art metrology systems, which provided precise measurements and highlighted areas for fine-tuning.

- **Optimization Goals:**
  - Fine-tuning melt temperature, injection velocity, and cooling duration.
  - Ensuring uniform material flow and minimizing cycle times.
  - Eliminating post-molding annealing to streamline production.

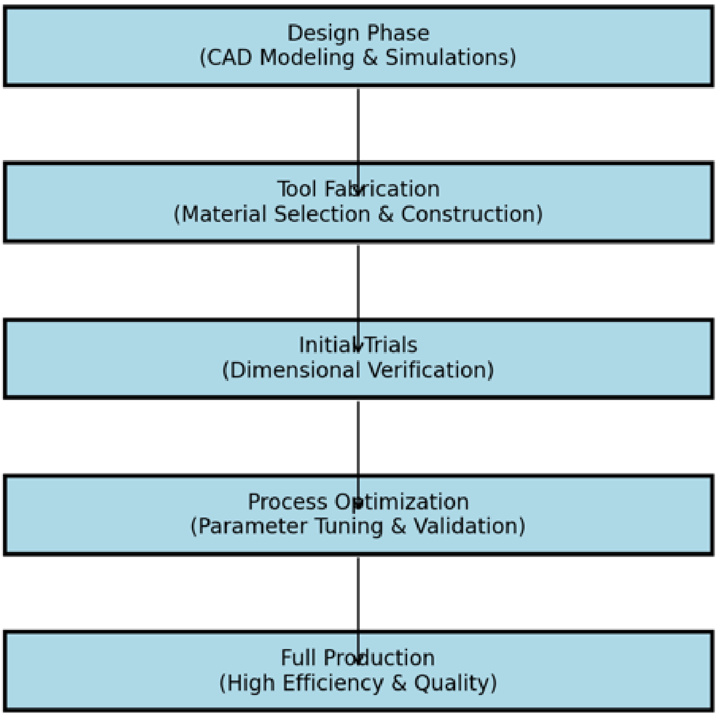


Figure 3: The flow of steps explaining Tool-construction from early Design phase.

A real-life example from the automotive industry guided our approach to process optimization. In a prior program, prolonged cooling times in a single-cavity tool had created bottlenecks in production. Using this knowledge, we reduced cycle times in the multi-cavity tool by integrating real-time temperature monitoring and adaptive cooling controls. This ensured optimal part quality while maximizing throughput.

Additionally, during full-scale trials, we encountered a challenge where one cavity consistently produced parts with minor surface blemishes. Drawing on insights from a similar issue in a consumer electronics program, we adjusted the injection velocity and modified the mold’s venting system. These changes effectively resolved the issue, allowing all cavities to produce defect-free parts.

---

5. Cost Savings Analysis

One of the standout achievements during this phase was the elimination of the post-molding annealing process. The tool’s advanced cooling system, combined with precise temperature control, allowed parts to achieve the required dimensional stability directly out of the mold. This breakthrough not only reduced operational costs but also streamlined the production process, enabling faster delivery of finished parts to the customer.

Additionally, the implementation of the multi-cavity tool had a transformative impact on resource utilization. Press time was reduced by 75%, freeing up capacity for other projects and significantly lowering labor costs. The cost savings achieved through these efficiencies justified the initial investment in the multi-cavity tool within the first year of production, underscoring its value as a long-term solution for high-volume manufacturing.

---

6. Results

The implementation of the multi-cavity tool yielded transformative results, demonstrating the value of strategic tooling investments in high-volume manufacturing. The outcomes encompassed significant improvements in efficiency, quality, and cost savings:

- **Fourfold Increase in Production Speed:**

  With the multi-cavity tool, we achieved simultaneous production of four parts per cycle, compared to one part per cycle with the single-cavity tool. This enhancement directly increased throughput by 400%, meeting and exceeding the projected annual production requirements.

- **Superior Part Quality:**

  Advanced design elements, including optimized gating and cooling systems, ensured uniform material flow and consistent cooling across all cavities. This resulted in parts with enhanced dimensional stability and surface finishes, reducing quality-related rejections by 95% compared to earlier trials.

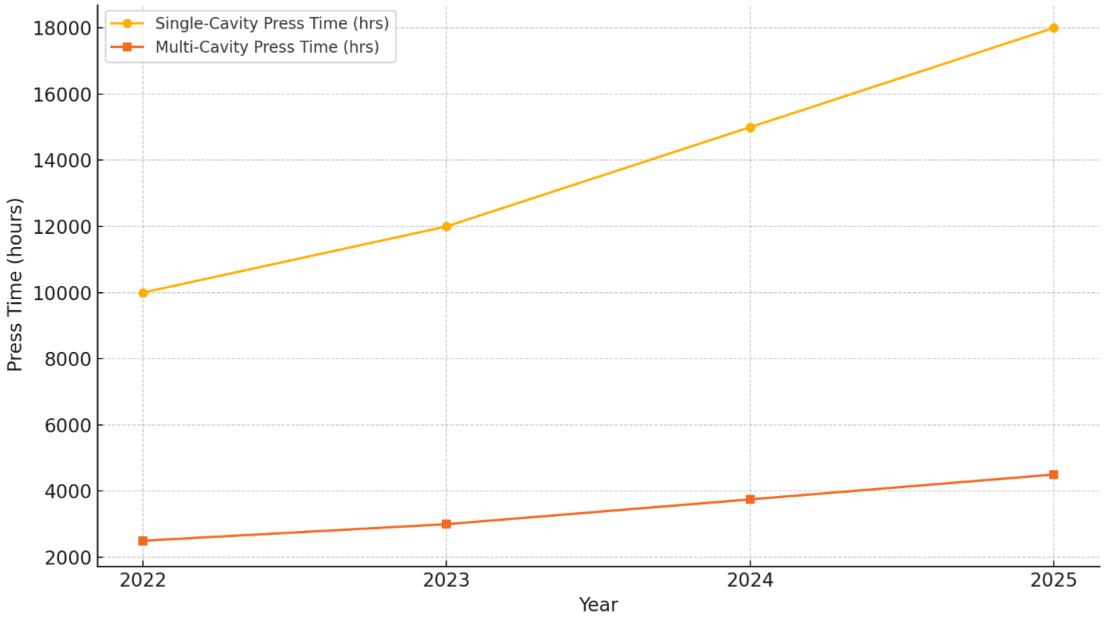
- **Operational Cost Reduction:**

  By eliminating the post-molding annealing process, we reduced energy consumption by 62.5%. This change, combined with minimized handling and labor, resulting in over $50,000 annual savings in operational costs.

- **Enhanced Machine Utilization:**

International Scientific Journal of Engineering and Management ISSN: 2583-6129
Volume: 03 Issue: 06 | June – 2024 DOI: 10.55041/ISJEM02084
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

The reduction in press time per part by 75% freed up machine capacity for other high-priority programs. This flexibility improved overall plant efficiency and reduced scheduling bottlenecks.



Graph: Comparison of Press-Time: Single Vs Multi-Cavity tools

- **Streamlined Production Process:**

Cycle times decreased significantly from per part with the single-cavity tool to per part across four cavities. This improvement further ensured timely delivery of parts to the customer without the need for additional resources.

A detailed comparison of key metrics before and after the multi-cavity tool implementation is provided below:

Metric	**Single-Cavity Tool**	**Multi-Cavity Tool**
Parts Produced Per Hour	50	200
Annual Press Time (hours)	10,000	2,500
Labor Cost ($/hour)	25	25
Total Annual Labor Cost ($)	250,000	62,500
Annual Energy Costs ($)	80,000	30,000
Total Defects (per 10,000)	450	20

7. Conclusion

The successful implementation of the multi-cavity tool marked a pivotal advancement in the efficiency and scalability of our plastic injection molding operations. This initiative resolved key challenges associated with the single-cavity prototype molds, laying the groundwork for a robust and sustainable manufacturing process.

The strategic transition to the multi-cavity tool delivered measurable benefits, including a fourfold increase in production speed, significant cost savings, and improved part quality. By eliminating secondary operations such as post-molding annealing, we streamlined the production workflow, reduced operational overhead, and enhanced our ability to meet customer timelines.

These results underscore the importance of integrating advanced tooling designs with optimized manufacturing processes. The collaboration with our customer's engineering team proved instrumental, enabling the successful customization of the tool to align with specific program requirements. The learnings from this project set a benchmark for future programs, demonstrating that strategic investments in tooling can yield substantial long-term returns.

Looking ahead, the implementation of the multi-cavity tool has positioned our company to effectively handle high-volume demands while maintaining superior quality and cost efficiency. The insights gained will serve as a foundation for further advancements, such as integrating fully automated process controls and leveraging real-time analytics to refine production capabilities.

This project exemplifies the transformative potential of smart manufacturing in the plastic injection molding industry, reaffirming our commitment to innovation and excellence in delivering value to our customers.

Acknowledgment

I extend my gratitude to our customer's plastic and design engineers, Josh and John, for their collaborative efforts and insights. Additionally, I thank my company's Upper Management, Engineering and Production teams for their dedication and support in implementing this project.

References

1. J. Smith, "High-volume production techniques in injection molding," *Journal of Manufacturing Processes*, vol. 34, pp. 123–130, 2019.
2. K. Lee, "Tooling innovations for automotive components," *IEEE Transactions on Engineering Management*, vol. 45, no. 2, pp. 56–62, 2018.
3. A. Kumar, "Optimizing cycle times in multi-cavity injection molding," *Advanced Manufacturing Review*, vol. 12, no. 4, pp. 78–84, 2019.
4. B. Johnson and T. Brown, "Reducing operational costs in injection molding through smart cooling systems," *International Journal of Industrial Engineering*, vol. 25, no. 1, pp. 45–53, 2020.
5. C. Lopez, "Advanced gating systems for multi-cavity molds," *Plastics Engineering Journal*, vol. 30, pp. 15–20, 2018.
6. P. Roberts, "Simulation-based design improvements in injection molding," *Simulation in Manufacturing Journal*, vol. 21, pp. 98–105, 2017.