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Designing of Mold Tool and Enhancing Product Quality with Mold Flow Analysis in Blow Molding: A Review

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Abstract - This review paper study on optimizing mold tool design and employing mold flow analysis to enhance product quality in blow molding. By leveraging advanced simulation techniques, we aim to predict and address common defects, including warpage, sink marks, and air traps. The methodology involves CAD-based mold design, injection molding simulation, Blow Molding and physical testing for validation. The anticipated outcomes include improved product quality, minimized defects, and cost-effective production, contributing to more efficient and reliable blow molding processes.

Key Words: Product design, Mould tool design, Injection moulding process, Blow moulding process, Mold flow analysis, Solid works, AutoCAD.

1.INTRODUCTION

Melting plastic in a hopper is the first step in the moulding process. After then, the plastic is injected into a cold, securely sealed mould. The plastic rapidly adopts the shape of the mould. Once it has completely set, the Mold is opened and the plastic object is released.

Blow molding is a widely used manufacturing process for creating hollow plastic parts, such as bottles and containers. The quality of these parts is significantly influenced by the design of the Mold tool and the efficiency of the molding process. This project focuses on designing an optimized Mold tool and utilizing Mold flow analysis to enhance product quality in blow molding.

Injection moulding is a manufacturing process for producing component by injecting molten material into a mould cavity. In these process, plastic material is forced to flow at high pressure in a highly softened state through a nozzle into the mould impression. The shape of the product is in final form and can be produced very quickly in the manufacturing process. Material for the part is fed into a heated barrel, mixed, and injected into a mould cavity, where it cools and hardens to the configuration of the cavity.

By integrating advanced simulation techniques, we aim to predict and mitigate common defects such as warpage, sink marks, and air traps. The project will involve designing the mold tool using CAD software, simulating the injection molding process, and validating the results through physical testing. The ultimate goal is to achieve improved product quality, reduced defects, and cost-effective production.

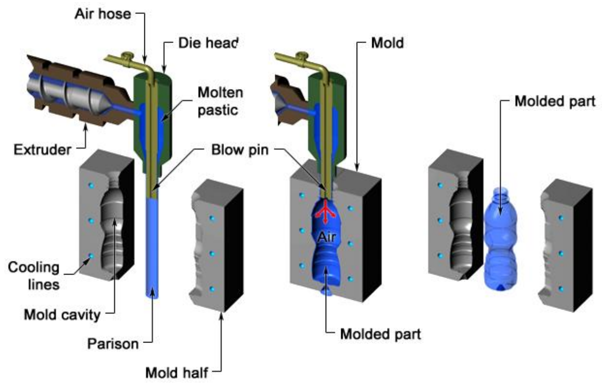

Fig 1.1. Blow Molding Process

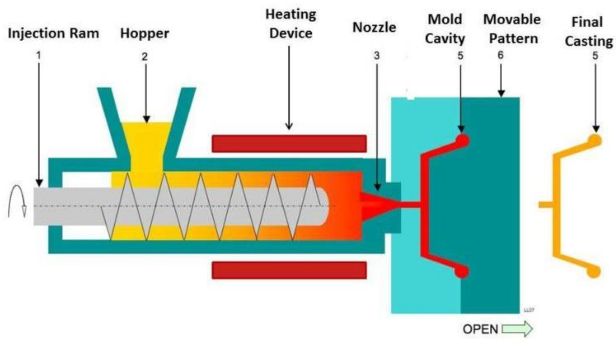

Fig 1.2. Injection Molding Process

2. Literature Review

1. Wang, Wan, et al. "Blow Moulding Mould for Plastic Production" In this article, a blow molding mold for plastic production is described, which consists of a base and a flow stabilizing mechanism, the upper surface of the base is fixedly connected

with a fixed mold, and a movable mold matched with the fixed mold is further slid ably connected to the base. This paper outlines the historical context of blow molding, evaluates existing mold designs, emphasizes the importance of flow control, highlights recent innovations, and identifies research gaps that the current study aims to address. This comprehensive review provides a solid foundation for the proposed advancements in blow molding mold technology.

2. Zexi, M. "Blow molding equipment for producing high-precision plastic barrel" In this paper, a blow molding equipment for producing a high-precision plastic barrel is described, which consists of a base, a top plate, a controller, an air blowing pipe, a pressurizing chamber, a compressor, two molds and four air cylinders. The advancements in blow molding technology presented in this paper could have significant implications for industries that rely on high-precision plastic components. The ability to produce barrels with minimal shrinkage and high accuracy can lead to better product performance and reduced waste in manufacturing processes.

3. K. M. Au & K. M. Yu "Conformal cooling channel design and CAE simulation for rapid blow mould" This study focuses on enhancing the efficiency and quality of blow moulding processes by proposing an innovative method of integrating conformal cooling channels (CCC) into the blow mould design. By leveraging computer-aided design and analysis tools, the research explores the fabrication of CCC in blow moulds through rapid tooling technology. The use of computer-aided engineering simulations helps validate the improved cooling performance of CCC compared to traditional straight line-drilled cooling channels (SLDCC). The findings suggest that the proposed CCC design leads to significantly reduced cooling time and improved temperature uniformity in blow-moulded parts, highlighting its potential for enhancing productivity and quality in the blow moulding industry. The study proposes an effective method for designing Conformal Cooling Channels (CCC) in blow molds by utilizing Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) tools to enhance cooling performance during the blow molding process.

4. Yan Tang "Application of CAE for mold flow analysis in plastic molding mold design" In this paper, the basic structural form and parameters of the mold's parting surface, winding injection system, and cooling system are determined by mold flow analysis, which is used to move the mold filling analysis to the computer, and the mold casting and cooling system's design scheme can be evaluated and optimized according to the analysis results.

5. Sudhanshu Bhushan Panda et al. "Characterization and Optimization of Tool Design of an Injection Molded Part Through Mold-Flow Analysis" This study involves that The mold is manufactured taking inputs from 'Mold-flow Plastic Part Advisor' and injection-molded parts were created, which enhanced product quality, decreased cycle time, and decreased process and product costs.

6. Satoshi Kitayama et al. "Optimization of mold temperature profile and process parameters for weld line reduction and short cycle time in rapid heat cycle molding" following study involves that Plastic injection molding (PIM) is a technology for producing lightweight, high-gloss plastic products. Traditional methods for optimizing PIM parameters rely on trial and error and engineering experience. Computer-aided engineering (CAE) and design optimization are emerging as effective alternatives. Weld lines negatively impact product quality, requiring elimination for better aesthetics and strength. Key approaches to eliminate weld lines include optimizing process parameters, cooling channel layout, and adopting rapid heat cycle molding (RHCM). Inappropriate process parameters can lead to poor product quality, such as long weld lines due to low mold temperatures. Previous studies have utilized methods like the Taguchi method and multi-objective particle swarm optimization for parameter optimization. Conformal cooling channels have been shown to enhance cooling performance and product quality. RHCM dynamically controls mold temperature, improving weld line reduction by heating above the glass transition temperature. The paper aims to optimize mold temperature profiles and process parameters to minimize weld lines and cycle time.

7. Shaochuan Feng et al. "Design and fabrication of conformal cooling channels in molds" This review paper delves into the design, manufacturing, and application of Conformal Cooling (CC) channels, a promising advancement over traditional cooling

systems in mold manufacturing. By systematically evaluating CC systems, the research highlights their ability to provide uniform and efficient cooling effects, leading to significant improvements in production quality and efficiency. The study classifies CC layouts into eight types, demonstrating their suitability for various part complexities and showcasing substantial benefits such as up to 70% reduction in cycle time and enhanced shape precision. Moreover, the paper discusses the best practices for utilizing CC channels in different mold materials and suggests hybrid fabrication techniques for achieving high dimensional accuracy. With the potential to replace conventional cooling molds, CC systems offer a path towards enhancing part quality, increasing production rates, and lowering costs, thereby extending their utility to advanced applications like gas turbine engines and gears.

8. Shubham Gupta, et al. “Simulation of Blow Molding Using Ansys Polyflow” The study focuses on simulating the blow molding process for hollow plastic materials (e.g., bottles) using ANSYS Polyflow, a computational fluid dynamics (CFD) tool. The goal is to analyze thickness distribution, stress profiles, and deformation dynamics during the molding process. The study successfully demonstrates ANSYS Polyflow’s capability in simulating blow molding, providing insights into thickness uniformity and stress distribution. The methodology can be extended for industrial optimization of bottle manufacturing.

9. H Haddad et al. “A study of blow moulding simulation and structural analysis for PET bottles” This study involves the order to increase PET (polyethylene terephthalate) bottle quality and decrease production time, it is crucial to simulate the injection stretch blow molding (ISBM) process. This study uses B-SIM simulation software to investigate finite element simulation of the ISBM process. Results about the impact of different process parameters on the distribution of wall thickness in PET bottles are obtained for a specific perform shape. After the simulation is finished, the simulated bottle is exported from B-SIM to the structural analysis program ANSYS Finite element analysis. To confirm the mechanical strength of PET bottles, top load and internal pressure analyses are performed. The findings show that PET bottles with the required strength may be produced by appropriately choosing process parameters and using B-SIM simulation.

10. A. Attar et al. “Manufacturing in blow molding: Time reduction and part quality improvement” In this study, a plastic dumbbell a component utilized in the recreational industry was developed using a concurrent engineering approach. Improving the thickness distribution and lowering the part's total weight were the design objectives. To aid in the part's development, preparatory experimental trials and simulations of the extrusion blow molding process were carried out concurrently. Following the completion of the component's numerical modeling, the production process was improved in accordance with the intended objective function, which is a uniform distribution of part thickness and/or minimal part weight. Through methodical adjustment of the working conditions, including the parison dimensions, the optimization was carried out in two successive steps: weight optimization and thickness optimization.

11. Agathoklis A. Krimpenis et al. “On Systematic CAD/CAM Modeling of Blow Molds for Plastic Bottles” Since many production problems and product shortcomings result from inaccurate and imprecise tooling, a methodical and detailed approach to the design and fabrication of blow molds for bottles made of PET and PP plastic material using CAD/CAM software tools is described. In addition to ensuring high mold accuracy, careful planning also reduces mold machining expenses, which are mostly caused by cutting tool wear and CNC machining time. The two main axes of blow mold design and production are (a) mold material and (b) machining parameter values. The former has a significant influence on mold manufacturing costs and the quality of the plastic bottles that are manufactured, while the latter is crucial for production rates and mold life-cycle.

12. C. GAUVIN, F. THIBAULT, and D. LAROCHE “Optimization of Blow Molded Part Performance Through Process Simulation” The best process operating conditions to create a blow-molded item with a certain performance are found in this study using a gradient-based numerical optimization approach. The part performance and processing conditions are related using finite element simulations. In order to satisfy mechanical performance limitations like maximum part

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deflection or maximum stress for an applied load, a performance optimization is first carried out to determine the minimal part thickness distribution that minimizes the part weight. Next, a process optimization determines the ideal operating parameters, such as the die gap opening profile, that minimize the component weight while adhering to the performance optimization's minimum thickness distribution. The findings demonstrate that the optimization strategy reduces the part weight with the fewest possible restrictions.

13. F. Thibault et al. "Preform Shape and Operating Condition Optimization for the Stretch Blow Molding Process" In this study, a novel design methodology was created to anticipate ideal preform geometry and ideal operating conditions for the stretch blow molding process automatically and successively. A constrained gradient-based optimization algorithm that automatically iterates across predictive finite element software is combined with the numerical approach. By successively adjusting the preform geometry (thickness and shape) and the operating parameters while adhering to process and design restrictions, the technique enables the targeting of a certain container thickness distribution. The preform geometry is mathematically parameterized for simplified treatment in order to optimize the preform shape, and a finite difference technique is used to assess the corresponding sensitivities. Additionally, a finite difference method is used to optimize the operating conditions. In order to solve the constrained optimization methods.

14. Cheng-Long Xiaoa & Han-Xiong Huang "Optimal design of heating system in rapid thermal cycling blow mold by a two-step method based on sequential quadratic programming" In certain applications, a high-gloss look is required, yet blow-molded parts composed of engineering resins typically have poor surface quality. This led to the development of a rapid thermal cycling extrusion blow molding (RTCEBM) technology, the presentation of the process principle, and an analysis of the optimization of its production procedure. A two-step optimization method based on the sequential quadratic programming (SQP) algorithm was proposed for designing the heating system in RTCEBM mold with the goal of achieving uniform temperature distribution on both mold cavity and core surfaces. The efficacy of this method was demonstrated by optimizing the electric-heating system for the RTCEBM mold of an automobile spoiler. Following optimization, the maximum core surface temperature differential drops from its starting value of 22.06°C by 77%.

15. Yogesh S. Khairnar et al. "A Review on Design of Plastic Injection Mould" Study says that plastic items are utilized for everything from industrial to home purposes due to their great strength and low weight, and they can be created at a low cost based on the needs of the consumer. A number of crucial elements must be taken into account while designing an injection mold, such as the type of mold, cooling channels, gate and runner placement and size, injection pressure, and mold material. The purpose of this study is to present a review of the literature on current developments in injection mold design for plastic molding.

16. Th. Schacht et al. "CAE/CAD in Injection Molding, Blow Molding, and Foam Molding-The Shortest Way to Mold Design" The paper explores the integration of Computer-Aided Engineering (CAE) and Computer-Aided Design (CAD) systems to optimize mold design for injection molding, blow molding, and foam molding processes. It emphasizes reducing reliance on trial-and-error methods, accelerating design timelines, and improving mold quality through computational tools. The study provides a practical framework for adopting CAE/CAD in plastics manufacturing, highlighting its role in improving efficiency, product quality, and competitiveness. It underscores the shift from experience-based design to data-driven optimization in industrial applications.

17. R.C.N. Barbosa "Injection mold design for a plastic component with blowing agent" Paper says the Finite Element Method (FEM) is being used by mold designers for optimization. The goal of this project is to create an injection mold using CBA. The goal of the three-dimensional (3D) mold design process is to forecast potential mold issues and outline the benefits of using CBA for injection. A pallet made of high-density polyethylene (HDPE) is the injected component. The CBA makes it possible to use smaller injection machines and produce parts with less warp in a quicker cycle.

18. Ming-Chang Jeng et al. "Rapid mold temperature control in injection molding by using steam heating" Following paper shows that In injection molding, the quick heating cycle provides the benefit of enhancing product quality. In this investigation, the same mold design was heated by steam and then cooled with cool water to create a dynamic mold surface temperature for control. The benefits of employing steam heating for injection molding were then assessed and contrasted with water heating through modeling and experimentation utilizing a TV housing mold and the steam system. It was also investigated how steam affected the part's quality. According to the results, using steam lowered the simple mold plate's heating time from 18 seconds to 8 seconds at a heating rate of 9 °C/s, and it also shortened the cooling time compared to using water heating.

19. A. Attar et al. ""Blow moulding manufacturing: cutting down on time and improving part quality" In this work, a plastic dumbbell—a component utilised in the recreational industry—was developed using a concurrent engineering approach. Improving the thickness distribution and lowering the total weight were the part's design objectives.Simulation of the extrusion blow moulding process and preliminary experimental trials were performed con currently to assist in the development of the part Following the completion of the component's numerical modelling, the production process was improved in accordance with the intended objective function, which is a uniform distribution of part thickness and/or minimal part weight. Through methodical adjustment of the working circumstances, including the parison dimensions, the optimisation was carried out in two successive steps: weight optimisation and thickness optimisation To show how the new model-based approach reduced the part development time, a process modelling methodology was used. Results showed that span time for the part development cycle could be reduced by approximately 60%, while the actual man-hour could be reduced by approximately 30% using a concurrent engineering approach.

20. Taylan Altan et al. "Manufacturing of Dies and Molds" Since almost all mass-produced discrete parts are made utilizing production procedures that use dies and molds, the design and fabrication of dies and molds represent an important link in the entire production chain. Therefore, the economics of creating a large number of components, subassemblies, and assemblies—particularly in the automobile industry—are impacted by the quality, cost, and lead times of dies and molds. As a result, die and mold manufacturers are compelled to create and apply the newest technologies in the following areas: EDM and ECM; machinery and cutting tools; surface coating and repair; optimized tool path generation for high speed cutting and hard machining; rapid prototyping, rapid tooling, and process modeling in part and process design.

3. CONCLUSIONS

The reviewed literature underscores the significant advancements in blow molding technology, particularly in mold design and process optimization, to enhance product quality and manufacturing efficiency. Key innovations such as conformal cooling channels (CCC) and rapid thermal cycling have proven effective in reducing cycle times and improving temperature uniformity, leading to higher-quality outputs. Additionally, systematic approaches like gradient-based optimization and concurrent engineering have streamlined production, ensuring uniform part thickness and reducing development time. The adoption of CAD/CAM systems has further enhanced mold accuracy and reduced costs, while careful selection of materials and machining parameters has maximized efficiency and product performance. These advancements collectively contribute to more efficient, cost-effective, and high-quality manufacturing solutions, positioning blow molding as a vital technology in modern production systems.

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