CAE Optimization and Mold Design of Air Auxiliary Molding of Automobile Door Handle

Hongxing Dong[1,*], Jianping Ren[2,3]

[1] *Hangzhou Polytechnic, Hangzhou 311402, Zhejiang, China*
[2] *Key Laboratory of Mold Intelligent Manufacturing of Taizhou, Taizhou 318020, Zhejiang, China*
[3]*School of Mechatronics and Mold Engineering, Taizhou Vocational College of Science & Technology, Taizhou, 318000, Zhejiang, P. R. China*
**Corresponding Author:*

Abstract:
To address the difficulty in forming automobile door handles for partially thick-walled plastic parts, Moldflow is utilized to simulate the Computer-Aided Engineering (CAE) of two molding techniques: conventional injection molding and air-assisted injection molding. The CAE analysis of conventional injection reveals that the main challenge in molding plastic parts is the shrinkage deformation caused by uneven wall thickness, resulting in size control issues and a shrinkage rate exceeding 7.2%. On the other hand, the CAE analysis demonstrates that air-assisted molding can reduce the shrinkage deformation rate to 0.33%. The corresponding air-assisted molding process parameters are as follows: mold temperature of 50℃, melt temperature of 230℃, filling time of 6s; injection pressure in three stages, namely 20MPa for 5s, 20MPa for 2s, and 10MPa for 2s; gas-assisted delay of 2s before injection, with gas injection conducted in three stages at 25MPa for 6s, 15MPa for 3s, and 5MPa for 3s, respectively. Based on these optimized parameters, a two-cavity gas-assisted two-plate plastic mold is designed. The inflatable element utilizes a cylindrical air needle suitable for thick-walled plastic parts, resulting in a simple and practical mold structure with high reliability. This design has significant reference value for future mold designs.

Keywords: gas auxiliary molding, CAE analysis, process optimization, injection molding, mold design

INTRODUCTION

Gas auxiliary molding (GAIM) operates by injecting high-pressure gas into molten plastic to create a vacuum section, push the melt material forward, and facilitate injection, pressure maintenance, and cooling processes[1-2]. The efficient pressure transmission of gas ensures consistent pressure distribution within the airway, thus eliminating internal stress, preventing product deformation, and reducing mold cavity pressure requirements. Consequently, the molding process does not necessitate high locking forces. Additionally, gas auxiliary injection molding leads to produce weight reduction, elimination of shrinkage, enhanced production efficiency, and increased design freedom[3-5]. Gas auxiliary molding is particularly beneficial for shaping thick-walled plastic parts, especially those with large screw column hole diameters, thick bars, wall thicknesses, and internal holes[6-8]. For instance, employing gas auxiliary injection molding in the production of a TV front frame can save 10%~20% of raw materials and significantly decrease locking force requirements. Gas auxiliary application in crafting refrigerator top cover plates effectively controls the quantity and reduces arch deformation from 1.7~2 mm to 0.5 mm. Similarly, the deformation of air conditioner components decreases from 3~4 mm to 1 mm, thus addressing issues of deformation and shrinkage that impact motor rotation and longevity. Gas auxiliary molding also enhances the design and production of thick wall long handle type plastic parts, allowing for the creation of seamless products without the need for separate mold sets and assembly processes. To achieve optimum gas auxiliary molding, the injection and inflation process parameters must be carefully calibrated.

Traditionally, adjusting molding density, air vent configuration, injection parameters, and gas filling processes was required, but this approach was time-consuming and costly. However, employing computer-aided engineering (CAE) analysis through Moldflow simulation technology streamlines the parameter acquisition process, significantly improving production efficiency and reducing costs[9-10]. Thus, integrating CAE analysis technology into gas auxiliary molding practices has become a vital strategy in addressing production challenges, such as those encountered in molding new energy vehicle handles[11-12]. By optimizing gas auxiliary molding processes through CAE simulation and mold design based on real-world applications, this paper underscores the importance of leveraging innovative technologies for achieving efficient and cost-effective plastic part manufacturing.

METHODS

Plastic Parts of Car Handle

The structure of the handle handle is shown in Figure 1, the plastic parts are mainly composed of the middle handle and the support and handle at both ends. When considering the molding requirements for these plastic parts, several key criteria must be met. Firstly, the plastic parts must exhibit good strength to ensure durability. Additionally, it is essential to minimize molding deformation during the fabrication process. Furthermore, the aesthetic aspect is crucial, necessitating a bright appearance on both the front and inner sides, free from any defects. To enhance production efficiency, the processing time for each plastic part should be minimized. Low molding injection pressure is desirable, requiring a simple mold structure and ensuring a long mold life. Moreover, it is imperative to save molding material where possible. Hence, the recommended material for these plastic parts is ABS (UMG ABS GSM), aligning with the specified requirements.

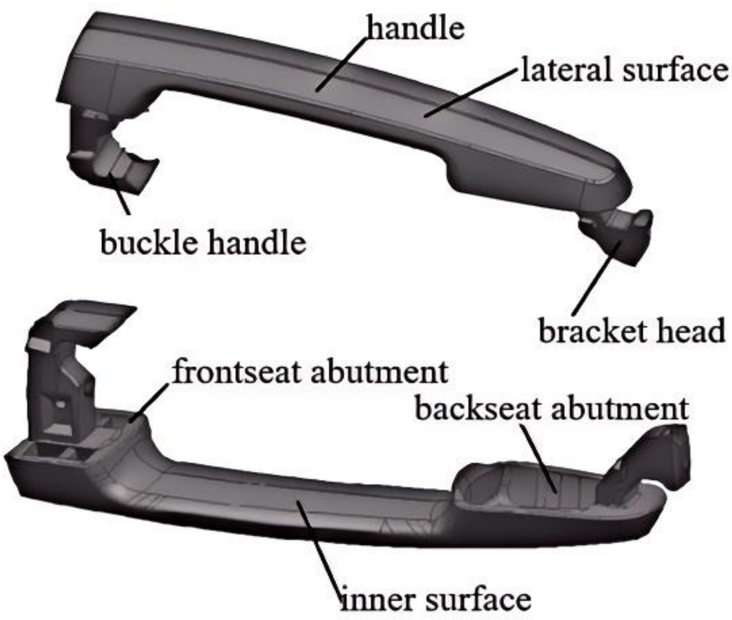

Figure 1. View of exterior axis and exterior axis of handle plastic product structure

Selection of Forming Method

The structural size of the handle plastic parts is demonstrated in Figure 2, with dimensions of 92mm × 30mm ×21mm, resembling a barbell shape that is wider at both ends and narrows in the middle. Specifically, the middle handle has a width of 15mm, while the two ends measure 21mm and 18mm, respectively. Given the frequent usage of these plastic components, there exists a paramount need for a robust strength design. Consequently, one effective strategy for enhancing strength involves adjusting the wall thickness. Accordingly, the plastic handle features a 6mm thickness, which is further heightened at the backseat base. Notably, the S1 area exhibits a relatively thinner wall thickness, exemplifying the marked unevenness in thickness as a pronounced trait of these plastic parts. Evidently, during the injection molding process, utilizing a simplistic approach may result in substantial shrinkage and deformation due to the inconsistent wall thickness. This could potentially render the plastic parts unusable. A more optimal alternative involves the utilization of the gas auxiliary molding method, which serves to mitigate shrinkage and deformation issues, thereby safeguarding both the strength and dimensional accuracy of the plastic parts.

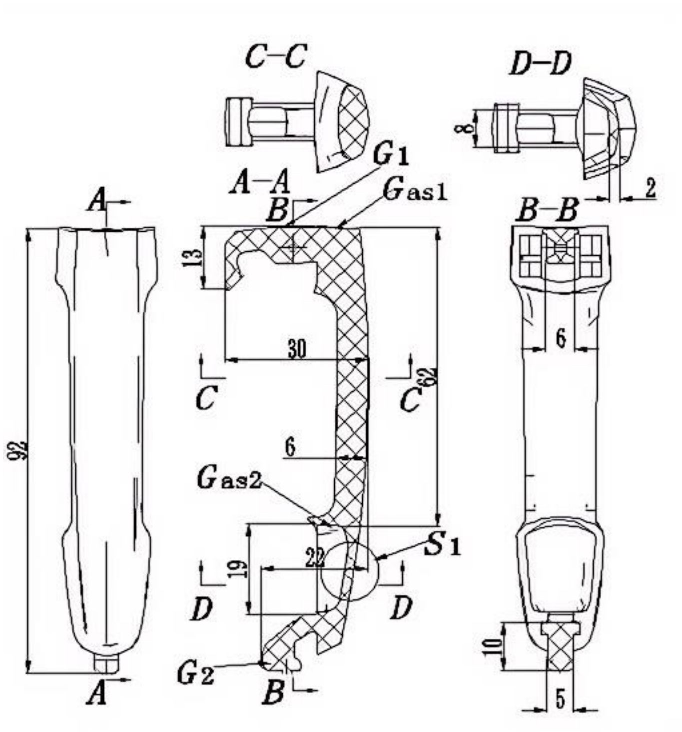

Figure 2. Analysis of plastic piece molding mode: G1 and G2-gate; Gas1 and Gas2-gas auxiliary molding air inlet; S1-thin wall area

Selection of Gas Auxiliary Forming Gate and Air Outlet

The essence of gas auxiliary molding in the case of thick-walled plastic parts is to ensure proper swelling of the thick wall area, hollowing of the wall, and minimal shrinkage and deformation. This is achieved by solid plastic filling in the localized internal conditions of the plastic parts. The improvement of shrinkage deformation involves two main methods: enhancing gas channel inflation pressure and pressure preservation in the gas channel area and maintaining injection pressure in the pressure preservation channel area. It is optimal for the forward direction of gas injection during gas auxiliary forming to align with the molten material flow direction, facilitating gas penetration and achieving a high hollowing rate to ensure effective thin-wall forming of the plastic parts. The choice of gate and air inlet position significantly impacts the size of the formed area on the plastic parts. For instance, selecting G1 as the pouring gate necessitates positioning the air-filling opening on the same side as the G1 gate, specifically at Gas 1. However, due to the thin wall thickness of the S1 area, the auxiliary gas may not penetrate S1 and beyond, resulting in a short inflatable airway distance and limited filling of the S1 area and the bracket head area. Consequently, this setup reduces the effectiveness of gas auxiliary molding in improving shrinkage and deformation. Conversely, utilizing G2 gate injection and Gas2 for inflation enables the filling of the S1 area and subsequent pressure deformation, enhancing the reduction of shrinkage and deformation in both the S1 area and beyond. This alternative approach effectively enhances the ability of gas auxiliary molding to address shrinkage and deformation issues in plastic parts.

In the formation of gas auxiliary, one of the initial factors to be regulated is the injection volume. It is crucial to consider both the structural integrity of the plastic components and the surface quality requirements of the wall molding. Employing the "full shot method" is recommended for achieving optimal molding outcomes. This method involves gradually filling the plastic cavity through the filling tail overflow mouth and overflow groove. Initially, the injection process is slow to allow for the gradual filling of the cavity, followed by the introduction of gas auxiliary filling. The surplus molten material is directed through the overflow groove into the gas auxiliary filling airway to ensure complete cavity filling and proper shrinkage. By adhering to this approach, the end product's quality is enhanced. Hence, the key control parameter during injection molding is to switch the filling pressure at 95% of the cavity volume, precisely at the moment when the overflow mouth reaches its full capacity.

High-speed injection molding is beneficial for the rapid filling of the mold cavity, gas penetration, and assisting in mold filling[13-14]. The process involves controlling the injection speed and pressure maintenance. Gas is pushed into the cavity to maintain pressure, akin to the pressure stage in traditional injection molding. Generally, gas-assisted injection molding can reduce the pressure required from the injection molding machine. However, in cases involving thin-walled areas like S1 in the product structure, maintaining a certain injection molding pressure is still necessary to ensure product quality. It is crucial to consider the support head near the G2 gate when sealing the gas port, as excessive pressure can cause the gas needle to seal, preventing gas recovery in the cavity and potentially causing a blowout when the mold opens. When using gas-assisted molding, the initial filling is controlled by a period of 6 seconds, with pressure retention set at 30MPa for 10 seconds.

In molding plastic parts using ABS material, various parameters play critical roles in determining the final product quality[15-16]. Firstly, gas injection pressure and gas injection speed at the Gas 2 air vent significantly influence material fluidity. Higher gas pressure facilitates better penetration, while lower air injection pressure results in inadequate filling, high pressure, rapid inflation, and plastic solidification without proper melting and cooling. The optimal molten index value for ABS material lies between 1g to 5g per 10 minutes, recommending an air pressure range of 20 to 25 MPa. Therefore, the inflation pressure of Gas 2 is precisely set at 20MPa for 3s for this particular molding process. Another crucial factor to consider is the setting of the airport opening delay time. The timing of the air injection port opening must be carefully calibrated. An overly swift opening may cause rapid gas divergence post-injection, leading to reduced plastic part integrity, and resulting in low hollowing rates. Conversely, a delayed opening may cause plastic accumulation issues. Hence, a deliberate initial delay time of 3s is assigned to the Gas 2 airport in this molding process. Consequently, the plastic parts are produced using G2 gate injection, with a Gas 2 air vent utilized for the auxiliary inflatable molding scheme. This decision is based on a thorough analysis of computer-aided engineering (CAE) results and process optimization parameters.

CAE Model with Auxiliary Injection

The CAE model developed through plastic molding is illustrated in Figure 3a. This model employs a tetrahedral grid with a total of 740,342 tetrahedra and 135,750 connecting nodes. The tetrahedral volume measures 163.2 cm3, with a flow channel volume of 14.1 cm3. The model's maximum aspect ratio is 6.4, with a minimum of 1.2 and a mean of 2.35. Additionally, the maximum dihedral angle is 174.2. Gas auxiliary molding typically involves four standard techniques, including under injection forming, auxiliary cavity forming, melt reflux molding, and movable core forming. In this context, the method of auxiliary cavity forming is implemented, necessitating the inclusion of an overflow port at the stem's end, along with a corresponding overflow tank. The gate is positioned at G2 as depicted in Figure 2, while the mold chamber follows a configuration of one mode and two chambers, as shown in Figure 3a. The cylindrical gate at position G2 has dimensions of Ø1.5mm and a flow channel diameter of Ø8mm. The inlet configuration is illustrated in Gas2 (Figure 3b).

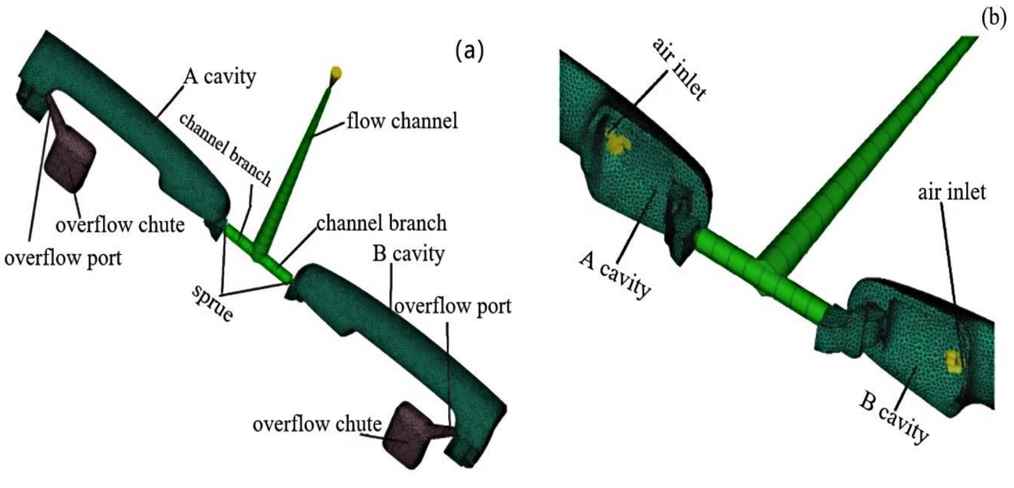

Figure 3. The CAE model setup:(a) CAE model; (b) air inlet setting

CAE Analysis with Non-Auxiliary Injection

The CAE simulation for plastic parts filled with non-auxiliary injection involves a tetrahedral mesh in the model with no overflow port and overflow tank. The analysis method utilized is the combination of filling and pressure preservation, with the following process parameters: mold temperature set at 50℃, melt temperature at 230℃, automatic filling control, and automatic filling-pressure preservation switch. Pressure preservation is set to 80% of the maximum pressure for 10 seconds, with a cooling time of 20 seconds. In the absence of auxiliary forming, the plastic parts exhibit a filling time of 13.3 seconds. However, the single cavity injection time is slightly prolonged, as depicted in Figure 4a, with a filling pressure of approximately 48MPa. The injection molding machine's requirements are not excessively high, and the pressure difference between the filling beginning and ending remains within 5MPa. The occurrence of edge flying on the plastic parts is minimized, as illustrated in Figure 4b, along with a minimal temperature difference at the flow front. The temperature difference within the mold cavity is within 5℃, demonstrating good material flow mobility in the cavity, as shown in Figure 4c. Conversely, an uneven distribution of plastic parts is observed, with a significant shrinkage rate at the central handle position reaching about 7.2%. The thicker the part, the greater the contraction, with the shrinkage rate at the bracket head and buckle handle ends around 5% and 6%, respectively. The thick wall thickness of the plastic parts contributes to difficulty in minimizing deformation in the finished products, especially in the presence of uneven wall thickness. Therefore, the introduction of gas auxiliary molding is essential to address plastic part deformation effectively.

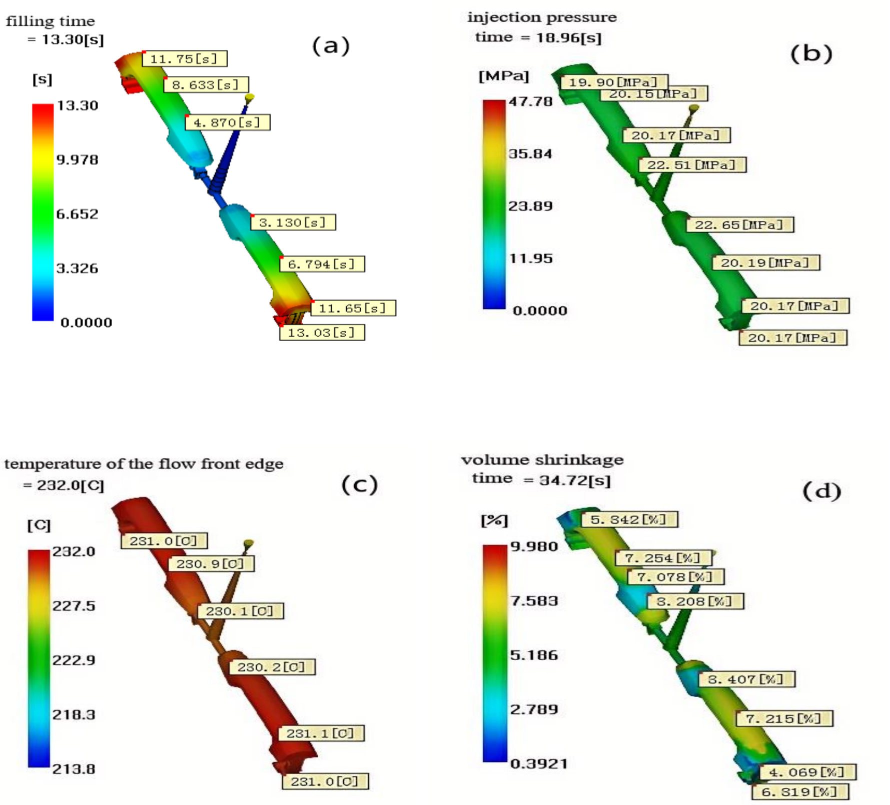

Figure 4. CAE analysis results of non-auxiliary injection molding:(a) filling time; (b) injection pressure; (c) temperature of the flow front edge in the mold chamber; (d) volume shrinkage

RESULTS AND DISCUSSION

CAE Optimization Analysis of Gas Auxiliary Molding

Initial gas auxiliary molding

To address the issue of significant shrinkage rates observed in plastic parts, our approach involves enhancing the shrinkage deformation within the handle using alternative methods. Additionally, adjustments have been made to enhance the pressure protection parameters within the plastic components, specifically aiming to reduce shrinkage deformation near the support head adjacent to the gate. Consequently, the configuration of process parameters for gas-assisted molding is structured as follows. Initially, the key process parameters were set as follows: mold temperature at 50℃, melt temperature at 230℃, and cooling time of 10 seconds. After an in-depth analysis conducted using Moldflow, the outcomes are depicted in Figures 5a to 5d. The results demonstrate a notable reduction in the filling time of the plastic parts post the gas-assisted molding implementation. Notably, within the range of 5-6 seconds, the filling pressure within the designated mold cavity has decreased to approximately 10MPa, while the overall filling pressure has lowered to around 36MPa. Consequently, the volume shrinkage rate has been minimized to 0.7-1.25%, effectively managing the temperature differential of the material flow within 5MPa. By carefully regulating the injection cylinder temperature, material flow for the handle shape, and inflation pressure, subsequent pressure protection for the support head of the component is facilitated. The utilization of gas-assisted injection has significantly enhanced the injection performance of the mold cavity, resulting in the effective control of plastic parts' deformation.

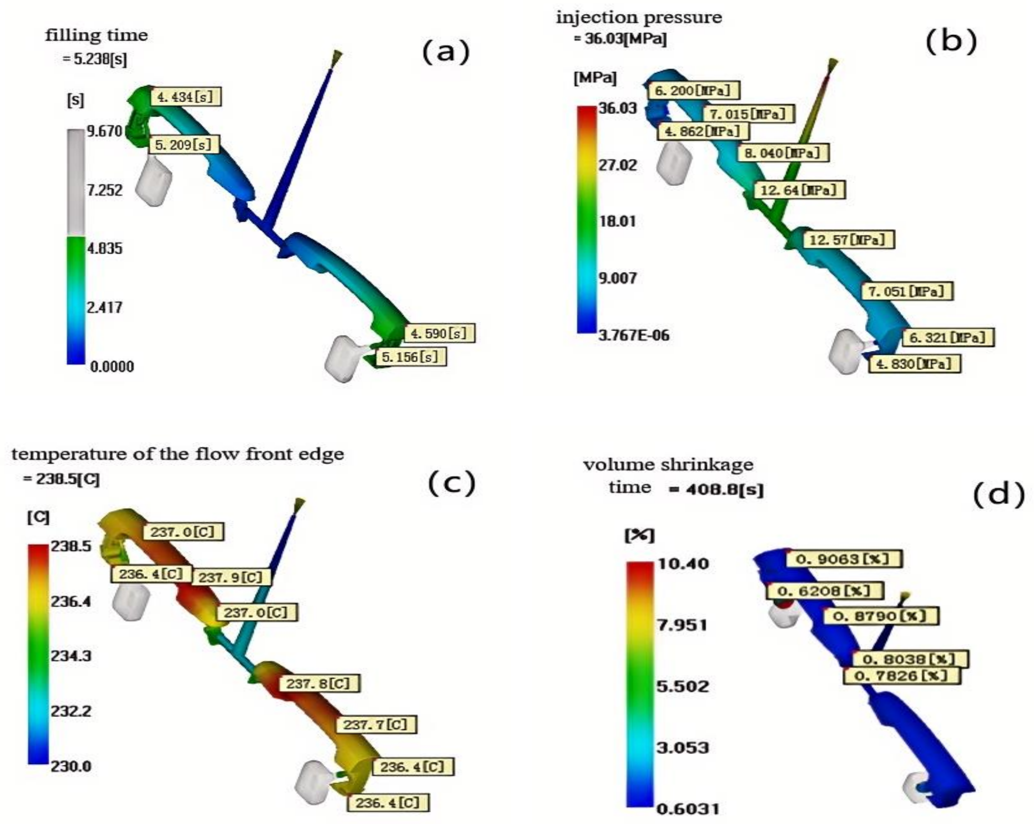

Figure 5. Results of gas-assisted initial CAE analysis:(a) filling time; (b) injection pressure; (c)temperature of the flow front edge in the mold chamber; (d) volume shrinkage

Optimization of gas-assisted injection process parameters

To further reduce the shrinkage rate of plastic parts, the injection and pressure retaining processes, as well as the gas filling process, were optimized. The pressure retention strategy was enhanced by dividing it into three sections: P1 at 10MPa for 2s, P2 at 20MPa for 5s, and P3 at 30MPa for 8s. Additionally, auxiliary gas filling involved pressures of P4 (5MPa for 3s), P5 (15MPa for 6s), and P6 (25MPa for 9s). These parameters were adjusted using an orthogonal test scheme with a table layout specified as L27(313). The filling time was set at 6s, with a gas-auxiliary delay of 2s and corresponding levels at 4s, 6s, and 8s. The optimized process scheme was determined as follows: P1=20MPa, T1=5s; P2=20MPa, T2=2s; P3=10MPa, T3=2s; P4=25MPa, T4=6s; P5=15MPa, T5=3s; P6=5MPa, T6=3s; and t=6s. The results of this improved parameter combination are illustrated in Figure 6.

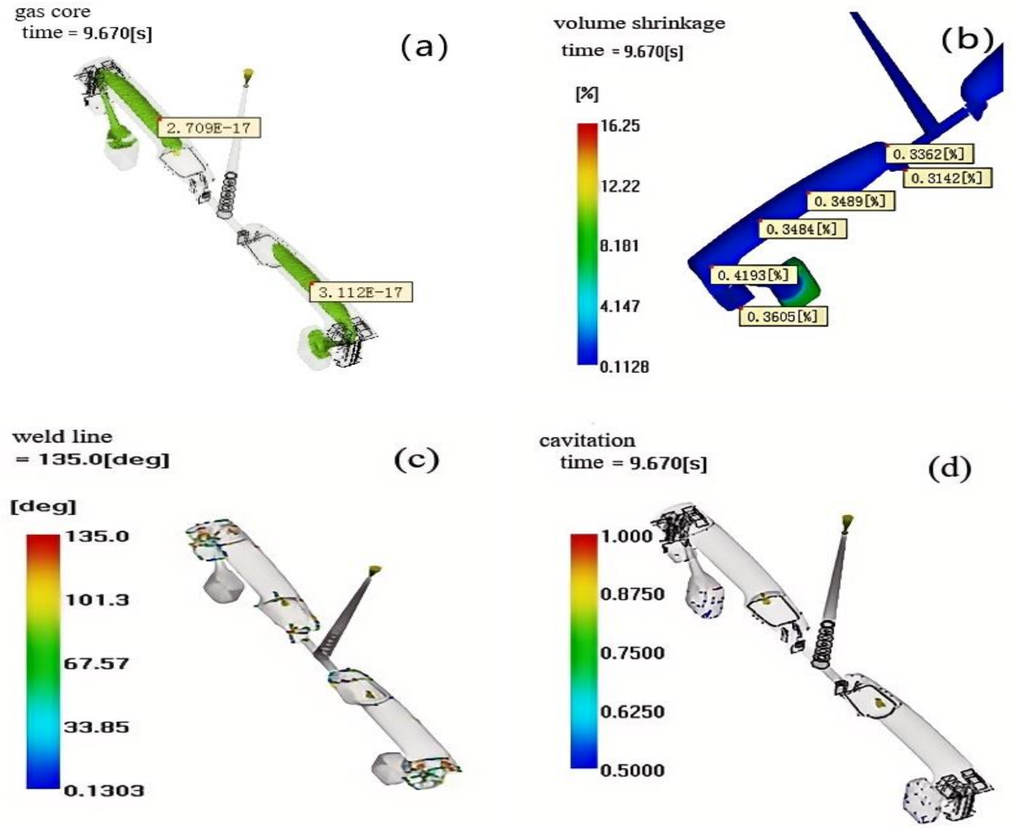

Figure 6. Gas-auxiliary CAE analysis optimization results:(a) gas core; (b) volume shrinkage; (c) weld line; (d)cavitation

Based on the results of Figure 6, it is evident that the gas core extension near the stem's end indicates a strong gas penetration capability, suitable for assisting in filling the handle and matching gas pressure requirements. The overall volume shrinkage rate of the plastic parts has been effectively minimized to below 0.45%. Specifically, the bracket head's shrinkage rate achieved through injection molding and pressure preservation is approximately 0.33%, while the handle and handle end exhibit rates of about 0.34% and 0.40%, respectively. Additionally, the fusion lines displayed in Figure 6c predominantly consist of angles exceeding 135 degrees, which signifies optimal fusion. In the event of successful fusion, any air pockets typically manifest in the overflow tank initially, posing minimal risk to the plastic parts' integrity. Based on the CAE optimization findings, it is apparent that the refined injection molding combined with gas auxiliary molding process parameters can effectively facilitate gas-assisted injection molding for plastic parts[17-18].

Die Auxiliary Equipment and Gas Auxiliary Equipment

Air auxiliary equipment

The gas auxiliary equipment includes a nitrogen auxiliary device, specifically the gas auxiliary control unit. Nitrogen is the gas utilized in gas auxiliary injection molding, with a maximum pressure of 35MPa and a nitrogen purity of 98%. The gas auxiliary control unit serves as a critical component in the equipment, responsible for managing both the gas injection time and pressure. It features a sophisticated multi-group gas circuit design, enabling simultaneous control over multiple injection molding machines. Additionally, the gas auxiliary control unit is designed with a gas recovery function to minimize gas consumption efficiently. The overall structure of the mold can be observed in Figures 7a and 7b.

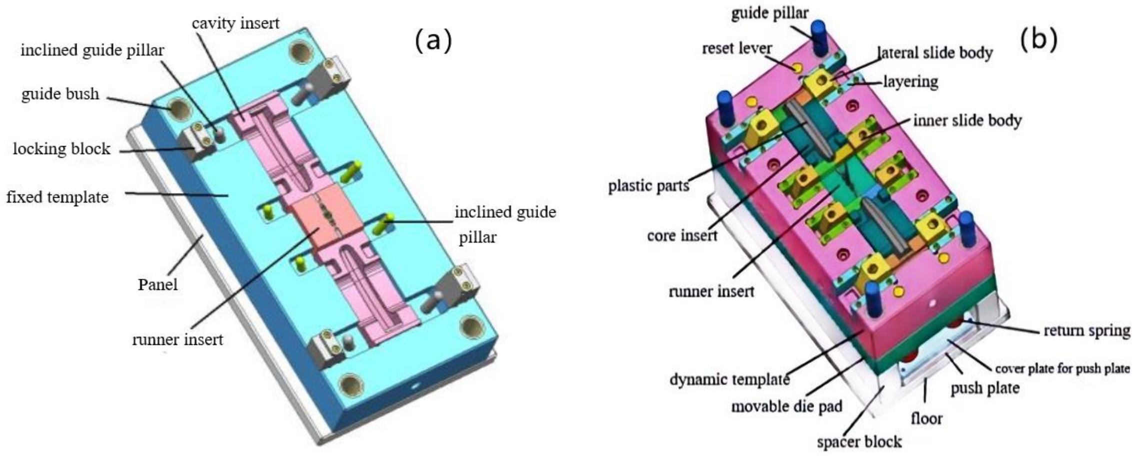

Figure 7. Optimization results of gas auxiliary CAE analysis:(a) fixed die setting; (b) dynamic die

Air auxiliary mold

The structural design of the mold shown in Figures 7a and 7b can be described as follows: The typing selection of the main classification line (shown in Figure 8a) plays a crucial role in determining the characteristics of the plastic mold. Under this classification, several key issues need to be considered. Firstly, in the A-A vertical section, the handle end features two inclined grooves on both sides, denoted by the directions F3 and F4. The main direction, established by the mold line, necessitates the implementation of a specific clip at these two locations, requiring the installation of an inclined core mechanism. Secondly, a lateral through hole is present in the middle section of the handle, which also necessitates a side core. Additionally, the internal handle and overflow tank dictate that the core must be split according to the inner type surface illustrated in the drawing, aligning with directions F1 and F2. Similarly, for the upper section of the plastic part and the support head, the core must be split laterally based on the orientations outlined in F1 and F2. To ensure optimal gas auxiliary forming at one end of the bracket, a two-stage pouring system is adopted. The initial stage involves latent gate pouring, followed by pouring in a side gate form. Furthermore, the mold chamber consists of one mold and two chambers, with a single type surface exposed. The pouring system incorporates a cold flow channel pouring system depicted in Figure 3a, with each mold chamber being cooled using Ø 8mm water-cooled pipes. To facilitate the removal of the core and mold, four slider mechanisms are integrated into the outer wall of the plastic parts. Additionally, thimbles are positioned at the top of the plastic parts, as depicted in Figure 8b. A notable distinction from traditional injection molds is the inclusion of an intake element, specifically the air channel of the air needle, which is accessible through the moving model core insert. This channel is externally connected to the gas generation device illustrated in Figure 7a.

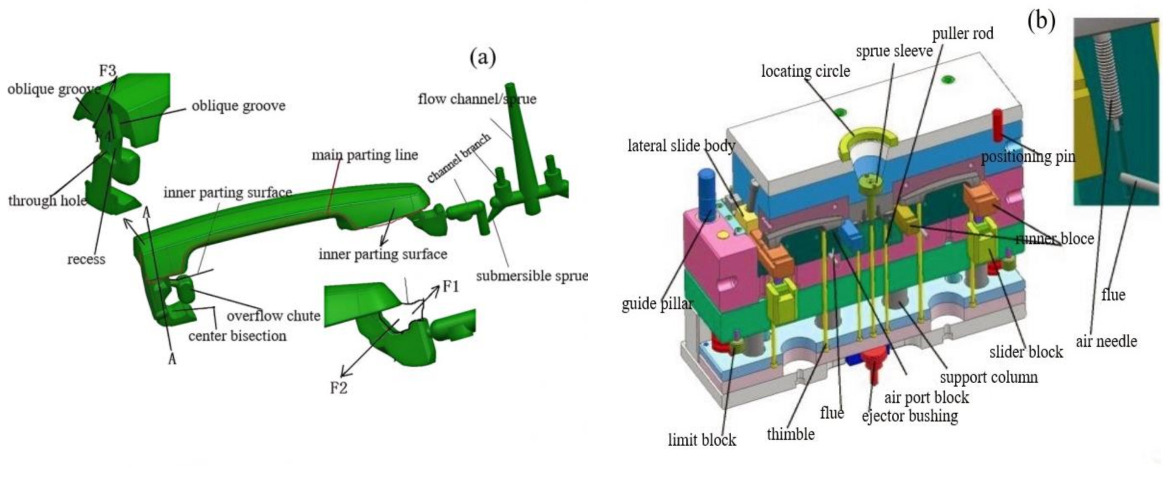

Figure 8. Die structure design:(a) typing setting (b) mold mechanism installation

The layout of an air auxiliary mold in the mold involves key components such as the air needle and the release mechanism. The air needle mechanism for the single cavity includes components such as the airway, air needle and air mouth block[19-20]. The airway of the air needle is connected to the gas generator externally through an opening on the moving model core insert. The gas needle, a critical component of the gas auxiliary mold, directly impacts process stability and product quality. In this case, the mold utilizes the QZ-H1 nitrogen needle, known for its thick wall for plastic intake, threaded core surface installation for easy removal, and maintenance-free operation. Moreover, the gas needle offers a larger gas output, low nitrogen purity, and avoids blockage by nitrogen oil. Furthermore, the outer Hard slider mechanism is employed to manage the end of the plastic piece. For side core forming, specifically in unilateral structures, a composite slider core pumping mechanism is utilized. This mechanism operates in two steps for core extraction. The first step involves inclined core pumping, extracting the core from the inclined groove in the plastic parts as depicted in Figure 8a. The subsequent step consists of outer slider core pumping to handle the side core's position as illustrated in Figure 8b.

CONCLUSIONS

The first step in addressing the issue of thick wall thickness, significant shrinkage deformation, and challenging size control of plastic parts involves the design of a two-cavity gas auxiliary molding mold alongside the primary mold. Utilizing the Moldflow gas auxiliary CAE analysis module, simulations are conducted to analyze the gas auxiliary and non-auxiliary states of the plastic parts. The CAE analysis of the non-auxiliary injection molding process highlights the complexity arising from the thick wall thickness of the plastic parts, where the shrinkage rate exceeds 7.2%, leading to difficulties in controlling the parts' dimensions during molding. Subsequent analysis of the gas auxiliary molding process indicates that it effectively decreases the shrinkage rate in the thick wall area to approximately 1%. Through further optimization and an orthogonal combination of gas auxiliary process parameters followed by CAE simulation, the shrinkage rate can be further reduced to around 0.33%. Noteworthy gas auxiliary molding process parameters include a mold temperature of 50℃, melt temperature of 230℃, filling time of 6s, and injection molding pressure preservation divided into three stages (20MPa for 5s, 20MPa for 2s, and 10MPa for 2s). Additionally, a 2s gas auxiliary delay is introduced, along with gas injection in three sections at varying pressures and durations (25MPa for 6s, 15MPa for 3s, and 5MPa for 3s). The optimization analysis of gas auxiliary molding through CAE provides essential guidance for designing efficient gas auxiliary molding mold structures, aiming to prevent design oversights and enhance overall mold production efficiency. The gas auxiliary mold, featuring a universal two-plate mold structure, incorporates a single cavity with four side sliders for side extraction core die implementation, top, and needle release functionalities. This mold design integrates an inflatable element that uses a cylindrical air needle suitable for thick-wall plastic parts core surface threading, emphasizing simplicity, practicality, high reliability, and extended service life, thus offering valuable insights for future mold design enhancements.

REFERENCES

[1] Juan David Escobar-García, Cristina Prieto, Maria Pardo-Figuerez, Jose M. Lagaron, Molecules, 28, 4137(2023).
[2] Kuang Tangqing, Wang Jia min, Liu Hesheng, Yuan Zhihuan, Polymers, 15,9, (2023).
[3] Kirk Robert J. Tendulkar Minesh R., Kolliopoulos Panayiotis K., Wang Yijie, Shi Xutao, Koelling Kurt W. ,Polymer Engineering and Science, 61, 7, 1956-1970(2021).
[4] Taidong Li, Jiquan Li, Frederik Desplentere, Xinxin Xia, Xiang Peng, Shaofei Jiang, Journal of Polymer Engineering, 39, 587(2019).
[5] Minh, Pham Son,Uyen, Tran Minh The, Do, Thanh Trung, Nguyen, Van-Thuc; Nguyen, Van Thanh Tien ,Polymers, 15,11(2023).
[6] Zhou Haiying, Liu Hesheng, Kuang Tangqing, Jiang Qingsong, Chen Zhixin, Li Weipei, Zhang Yun, Advances in Polymer Technology, 2020(2020).
[7] Park, Hyungpil,Cha, Baeg-Soon, Rhee, Byungohk,Advances in Materials Science and Engineering, 2015(2015)
[8] Kim Donghan, Ahn Seokyoung,Lee Kye Hwan, Nambiar Rajiv, Chung Sang Won, Park Seong Jin, German Randall M.,Powder Technology, 239,389-402(2013).

[9]Khan Nisar Ahamad, Sankar Mamilla Ravi, Kumar Ajay,Springer Proceedings in Materials, 52, 63-83(2024).
[10] Hwang Soonhwan, Kim Jongsun,Journal of Mechanical Science and Technology, 33,8,3803-3812 (2019).
[11] Zhang Guoqiang, Xie Meiting, Wang Wenjuan, Zhai Jiqiang,Applied Mechanics and Materials, 201-202, 808-811(2012).
[12] Mao Hua-Jie, Zhang Bo, Wang Jian-Yang, Hua Lin,Suxing Gongcheng Xuebao/Journal of Plasticity Engineering, 12,96-99(2005) .
[13] Liu Yang, Peng Li, Lin Jielong, Zhou Yong, Wang Dujin, Han Charles C., Ye Nanbiao, Huang Xianbo, Dong Xia,ACS Applied Polymer Materials, 5, 4127-4135(2023).
[14] Matsui Yuki,Ohishi Kiyoshi,Yokokura Yuki, Morita Hiroshi, Hotta Daigo,IEEE/ASME International Conference on Advanced Intelligent Mechatronics, AIM, 201, 1221-1226(2019).
[15] Gong Ke,Liu Handai, Huang Cheng, Cao Zhi, Fuenmayor Evert, Major Ian, Polymers, 14, 23,(2022).
[16] Şahin Tülin, Çavdar Karaçam Songül, Tunçman Duygu, Şahin Şenol, Ergen Şefika Arzu, Çolpan Öksüz Didem, ALMisned Ghada,Tekin H.O. ,Radiation Physics and Chemistry, 223(2024).
[17] Hentati Fatma, Hadriche Ismail, Masmoudi Neila, Bradai Chedly, International Journal of Advanced Manufacturing Technology, 104, 9-12, 4353-4363(2019).
[18] Jayswal Shubham, Jangade Harsh, Abhishek Kumar, Ramkumar P.L. Advances in Intelligent Systems and Computing, 757,385-393(2019).
[19] Ali, Z. Türeyen E.B., Karpat Y., Çakmakci M. ,Procedia CIRP, 42, 87-90(2016).
[20] Schwenk Terry L. ,Annual Technical Conference - ANTEC, Conference Proceedings, 5, 2547-2550(2009)