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ANALYSIS OF MULTICAVITY CAPMOULD USING ANSYS FLUENT

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ABSTRACT:
The design and analysis of multicavity cap moulds using ANSYS Fluent for the simulation of the injection molding process. The study investigates three distinct multicavity cap designs: 2-cavity threaded, 8-cavity threaded, and 8-cavity flip-top moulds, commonly used in manufacturing caps for packaging, pharmaceuticals, and consumer goods. The primary aim is to optimize the molding process by evaluating key parameters such as melt flow, temperature distribution, cooling efficiency, and pressure drop during both the injection and cooling phases. Using SolidWorks, 3D models of the cap moulds are created and analyzed through CFD simulations in ANSYS Fluent to study the fluid dynamics, heat transfer, and material behavior within the mould. The simulations help in understanding fill patterns, melt front progression, and the impact of cooling channel layouts on temperature uniformity across the cavities. The performance of each mould configuration is evaluated in terms of cycle time, energy consumption, and potential defect formation (such as warping, short shots, and air traps), offering insights into optimizing the mould design for improved efficiency and part quality. The findings highlight the importance of integrated CFD analysis in multicavity mold design, emphasizing the role of cooling system optimization to reduce defects and improve overall efficiency in industrial manufacturing processes

Keywords: Cap mold, Multicavity, Ansys fluent

1. INTRODUCTION

Injection molding remains one of the most essential and versatile manufacturing processes for the mass production of plastic components due to its high speed, repeatability, and suitability for complex part geometries. Its widespread use spans industries such as automotive, aerospace, electronics, consumer products, and medical devices. As the demand for higher productivity and cost-effectiveness increases, the use of multicavity molds has become increasingly prevalent. Multicavity molds allow the simultaneous production of multiple identical parts in a single shot, significantly reducing cycle time and per-part production cost. However, the complexity of mold design and flow behavior increases substantially with the number of cavities, introducing new engineering challenges. A critical issue in multicavity molding is achieving uniform filling of all cavities. Ideally, the molten plastic should reach each cavity at the same time, temperature, and pressure. However, due to uneven runner layouts, inconsistent gate sizes, flow length variations, and localized pressure drops, imbalances often occur. These imbalances result in variations in part weight, dimensional errors, short shots, or defects like warpage and sink marks. The issue is further complicated when variable injection pressures are involved, as different flow resistances across cavities can magnify inconsistencies in filling. Thus, understanding and controlling the flow behavior within the mold becomes vital for product consistency and process efficiency. To analyze and overcome these challenges, simulation-based approaches such as ANSYS Moldflow have become indispensable. ANSYS Moldflow enables comprehensive visualization of the injection molding process, offering insights into flow front progression, temperature gradients, pressure distribution, shear rates, cooling performance, and potential defect zones. Through simulation, engineers can identify areas prone to filling delays, optimize runner and gate designs, and fine-tune process parameters like injection speed, packing pressure, and cooling time. This reduces the reliance on physical trial-and-error testing, shortens development time, minimizes material waste, and improves overall product quality.

2.LITERATURE REVIEW

This literature review covers the key studies related to the use of ANSYS Fluent in simulating and analyzing multicavity cap moulds, focusing on the thermal analysis, flow dynamics, material behavior, and optimization of the moulding process. **Sung et al. (2009)** explored the influence of mould design on mold filling and cooling efficiency. They concluded that optimizing cavity layout and cooling channels can minimize cycle time and improve the overall quality of molded products. **Yuan and Lee (2012)** discussed how different cavity layouts and cooling configurations affect temperature distribution in multicavity moulds. Their study highlighted the importance of uniform cooling to avoid defects like warping, sink marks, and air traps. **Tian et al. (2014)** used ANSYS Fluent to analyze the cooling efficiency of multicavity moulds. Their study demonstrated that optimized cooling channels could reduce the cooling time and improve part quality by maintaining a more uniform temperature distribution across cavities. **Kumar et al. (2017)** applied ANSYS Fluent for thermal analysis in multicavity moulds, examining the heat flux distribution and temperature gradients within the mould during the injection process. The study concluded that an adaptive cooling system can enhance mold performance by reducing localized overheating and ensuring uniform cooling across multiple cavities. **Zhou, Y., Zhang et al. (2015)** employed ANSYS Fluent to simulate the injection molding process in multicavity molds. They analyzed the melt front propagation and how variations in cavity geometry impact the fill time and melt flow uniformity. Their findings suggested that optimizing the gate locations and flow paths is essential for reducing pressure drop and ensuring uniform filling of all cavities **Chand and Shinde (2018)** studied the melt flow and solidification process using ANSYS Fluent, focusing on optimizing multicavity mold designs for uniform material distribution. The results showed that melt viscosity and temperature variations could significantly affect the final product's geometrical accuracy and surface finish. **Li et al. (2015)** used ANSYS Fluent to model the solidification behavior in injection molding. They found that rapid cooling and thermal gradients could cause shrinkage and warpage in the final part. The study emphasized the need for controlled cooling rates to avoid these issues in multicavity mold systems. **Tang et al. (2020)** explored how adaptive mesh refinement in ANSYS Fluent can improve the accuracy of simulations in complex multicavity moulds. They demonstrated that the mesh quality directly affects the simulation precision and the ability to predict mold filling dynamics and cooling efficiency. **Nazar, L., & Kotas, R. (2014).** A detailed investigation into the application of ANSYS Fluent for simulating and optimizing fluid dynamics, pressure, and temperature distributions in multicavity molds used in the injection molding process **Srinivasan, V., & Chowdhury, B. (2019).** This research utilizes CFD simulations in ANSYS Fluent to study the fluid flow, cooling rates, and thermal uniformity in multicavity molds for injection molding, providing insights into the optimization of mold designs. **Rao, S., & Rajendran, S. (2017).** This paper investigates the melt flow and cooling processes in multicavity injection molding using ANSYS Fluent. The authors demonstrate how simulations can predict temperature variations and flow distribution, improving the uniformity of material distribution and cooling efficiency in the mold. **Xie, Y., & Zhang, X. (2019).** This study explores the effect of mold temperature and flow rate on the melt flow and solidification process using ANSYS Fluent. It highlights the relationship between temperature gradients and melt viscosity, focusing on how these factors influence the final part quality, including shrinkage and surface defects.

Tian, J., & Liu, J. (2014). This study discusses the use of ANSYS Fluent for modeling both cooling and solidification in injection molding processes. The paper highlights the critical influence of cooling rates and the design of cooling systems in achieving uniform material distribution and reducing shrinkage in the final product. **Song, H., & Lee, C. (2018)** to analyze the melt flow and cooling behavior in multicavity injection molds. The study shows how flow maldistribution and inconsistent cooling can lead to product defects and discusses strategies for improving the thermal management of the mold. **Gao, Y., & Zhou, Z. (2020).** This paper examines the impact of nanoparticles in the coolant fluid used in injection molding, using ANSYS Fluent for the simulation. The study highlights how adding nanoparticles like Al_2O_3 or CuO can enhance thermal conductivity and optimize heat transfer during the solidification process in multicavity molds

3.METHODOLOGY

In this study, methodology employed to analyze the heat transfer, flow dynamics, and performance characteristics of 2-cavity, 8-cavity threaded cap, and 8-cavity flip-top cap moulds. The analysis was conducted using ANSYS Fluent and ANSYS CFD to predict critical parameters such as heat flux, velocity, pressure distribution, and temperature profiles. When producing cap molds using HDPE (High-Density Polyethylene) as the material for the caps and P20 steel as the mold material.

Table 1: HDPE material properties

S.NO	PROPERTY	VALUES
1	Density	0.98 (g/mm^3)
2	Young’s modulus	0.55 à 1 GPa
3	Yield strength	30 MPa
4	Thermal conductivity	0.52 (W m-1 K -1)
5	Poisons ratio	0.46
6	Coefficient of friction	0.29
7	Liquid limit (%)	74.18
8	Plastic limit (%)	32.3
9	Plastic index (%)	41.81

Table 2: P20 material properties

S.NO	Property	Values
1	Density	7.9 g/cm^3
2	Tensile Strength	1000-1200 MPa
3	Yield strength	800-1000 MPa
4	Thermal conductivity	29.0 - 34.0 W/m-K
5	Poisons ratio	0.27
6	Elongation	10-15%.
7	Compressive Strength	862 MPa
8	Elastic modulus	190-210 GPa

Design and Production Considerations

Tolerance Specifications:

Apply specific tolerances to each feature based on the design specifications. These may include:

- **Dimensional Tolerances:** Typically, tolerances can range from ±0.01 mm to ±0.05 mm depending on the feature's criticality.

- **Geometric Tolerances:** Apply geometric tolerances such as flatness, roundness, and concentricity, particularly for features like threads and sealing surfaces.
- **Surface Finish:** Measure the surface finish where applicable, as it can affect the sealing performance and appearance.

Tolerances for Cap Molds:

- Dimensional Tolerances: Typically, ±0.01 mm to ±0.05 mm, depending on the feature's criticality.

Boundary conditions:

2 Cavity Threaded Cap

- Temperature: 250 °C
- Pressure: 100 MPa
- Simulation Time: 20 sec
- Warpage: 0.07mm (Upper Section)
- Velocity: 20 mm/s
- Thermal conductivity ~ **0.1 to 0.22 W/m·K**

8 Cavity Threaded & Flip-Top Cap

- Temperature: 220 °C
- Pressure: 120 MPa
- Simulation Time: 25 sec
- Flip-Top Latching Variance: 0.08mm
- Thermal conductivity ~ **0.1 to 0.22 W/m·K**

Table 3: Tolerance Analysis - Core/Cavity Dimensions

Tolerance (mm)	Filling Time (s)	Pressure (MPa)	Warpage (mm)
±0.01	4.2	120	0.05
±0.02	4.5	130	0.08
±0.03	4.8	150	0.10

Significant deviation in filling time and pressure is observed as the tolerance increases. The warpage increases proportionally. The ±0.01 tolerance is recommended for part consistency and quality.

2 Cavity Threaded Cap Mould

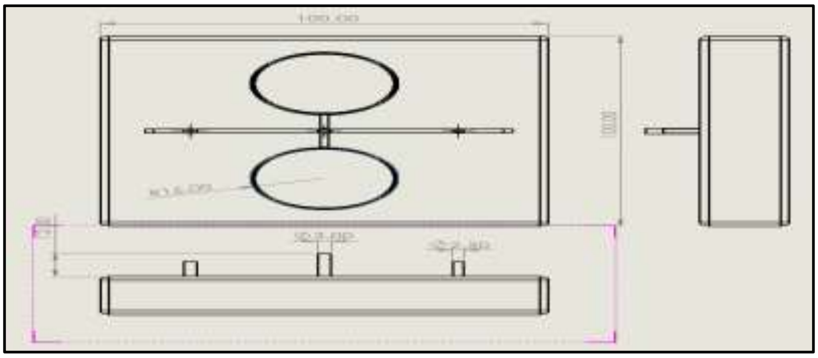

Figure 1: 2 cavity mold Isometric model

8 Cavity Threaded Cap Mould

In an 8-Cavity Threaded Cap Mould, the minimum heat flux in ANSYS CFD analysis depends on several factors like cooling channel design, polymer material, and cycle time requirements. For a threaded cap mould with multiple cavities, heat flux distribution is crucial for ensuring uniform cooling and preventing defects.

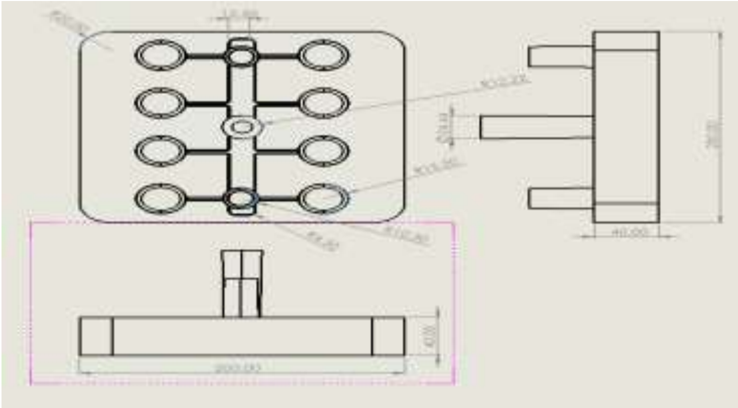

Figure 2: 8 cavity mold Geometry model

Figure 3: 8 Cavity cap mould model

8 Cavity Flip top Cap Mould:

This refers to a specialized tool designed to mass-produce flip-top caps, those convenient caps with a hinged lid that "flips" open and closed. The "8-cavity" designation means the mold can produce eight of these caps simultaneously with each injection molding cycle.

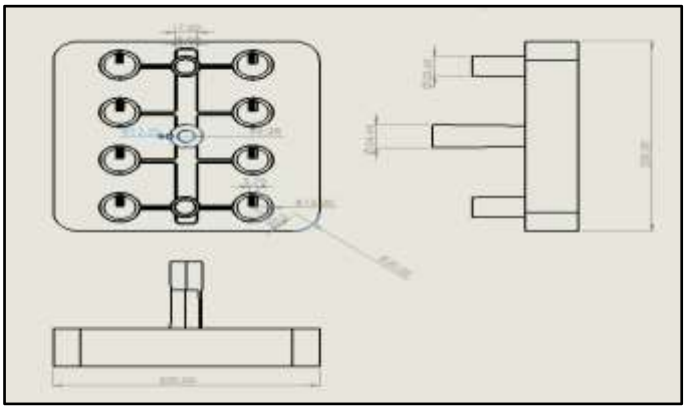

Figure 4: 8 Cavity flip top mold Geometry model

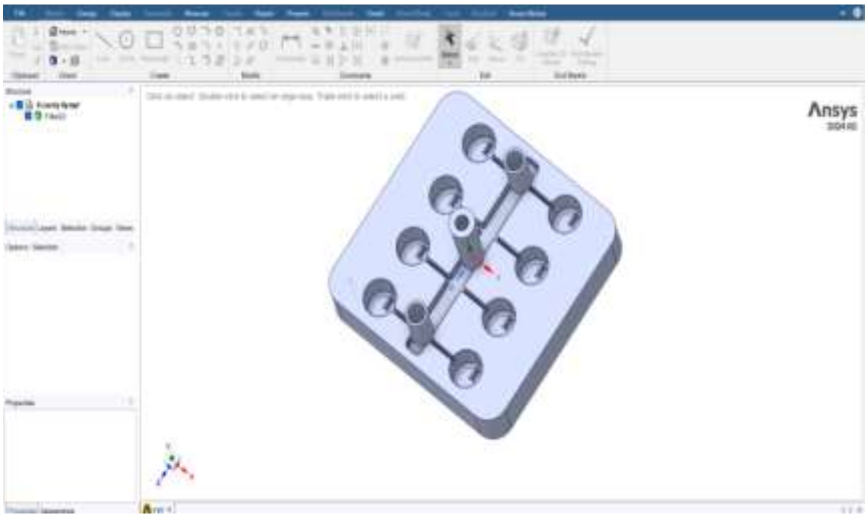

Figure 5: Imported 8 cavity Flip top Cap mold

4.SIMULATION RESULTS

The mold flow analysis conducted in ANSYS to evaluate the effect of various tolerances on the 2-cavity threaded cap mold and the 8-cavity threaded and flip-top cap mold. The analysis focuses on identifying critical tolerances that impact part quality, cycle time, and overall manufacturing feasibility.

2 Cavity Threaded Cap Mould

To conducting a fluid flow analysis of a 2-cavity threaded cap mold specifically designed for HDPE (high-density polyethylene) material using Ansys 2024 R1.

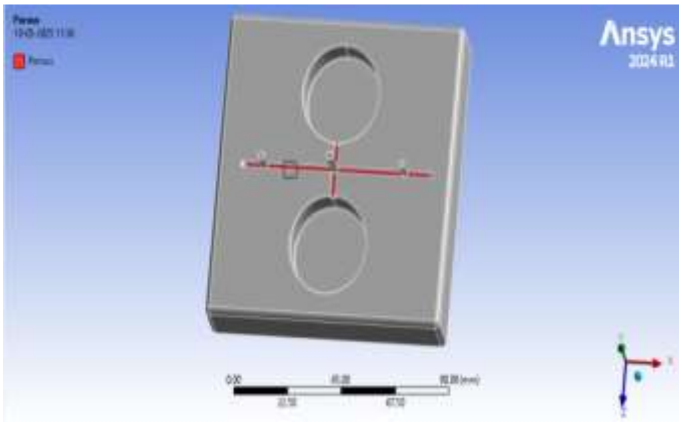

Figure 6: 2 cavity model flow porous

This ANSYS 2024 R1 model visualization highlights porous regions within the 2-cavity threaded cap mold's runner system. The marked red areas denote zones where fluid flow resistance may occur, indicating potential molding concerns

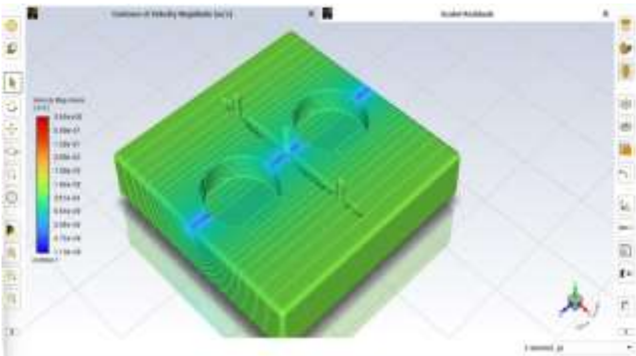

Figure 7: 2 cavity mold velocity streamlines

Above figure 7 shows the velocity streamlines of HDPE flow within the 2-cavity mold, providing valuable insights into the flow pattern and velocity distribution. The color-coded streamlines and the "Scaled Residuals" window indicate that the simulation has converged and provides meaningful results

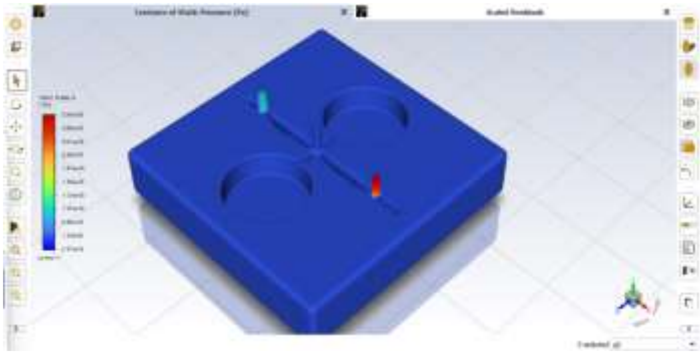

Figure 8: 2 cavity mold Pressure streamline

Above figure 8 shows the static pressure distribution in the 2-cavity mold, highlighting the maximum pressure regions. The color-coded contours and the "Scaled Residuals" window indicate that the simulation has converged and provides meaningful results shows the range of static pressure values in Pascals (Pa), from 3.57e-04 Pa (dark blue) to 2.99e+05 Pa (dark red).

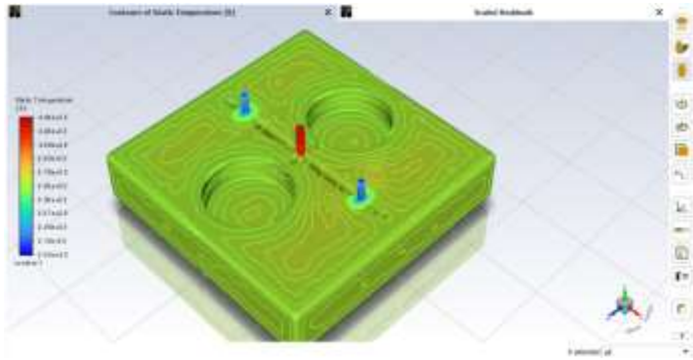

Figure 9: 2 cavity mold Temperature streamline

Above figure 9 shows the 2-cavity mold Temperature streamline for HDPE fluid flow the range of static temperature values, from 3.00e+02 K to 4.40e+02 K

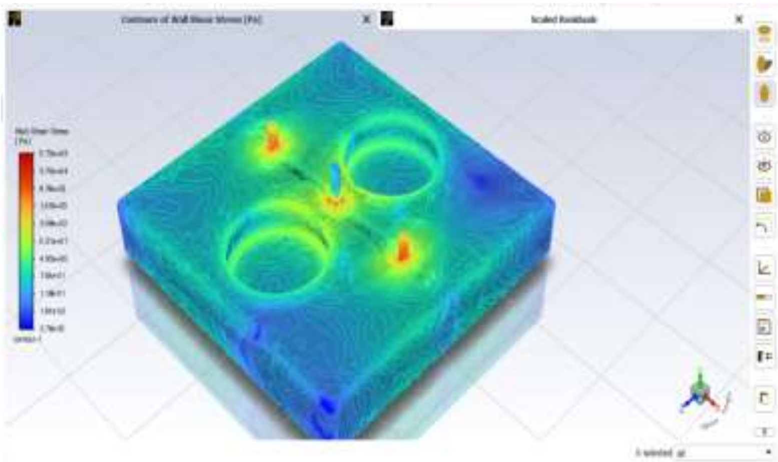

Figure 10: Wall Shear Stress

Above figure 10 shows the 2-cavity mold analysis for HDPE fluid, specifically focusing on Wall Shear Stress. the range of wall shear stress values, from 2.79e-03 Pa to 3.70e+05 Pa The high shear stress observed at the flow inlet suggests that the gate design could be optimized to reduce the shear stress. This could involve increasing the gate size or changing the gate geometry.

8 Cavity Threaded Cap Mold

The 8-cavity model imported from SolidWorks into Ansys 2024 R1. The imported geometry can now be used for various analyses in Ansys to optimize the mold design and ensure efficient production.

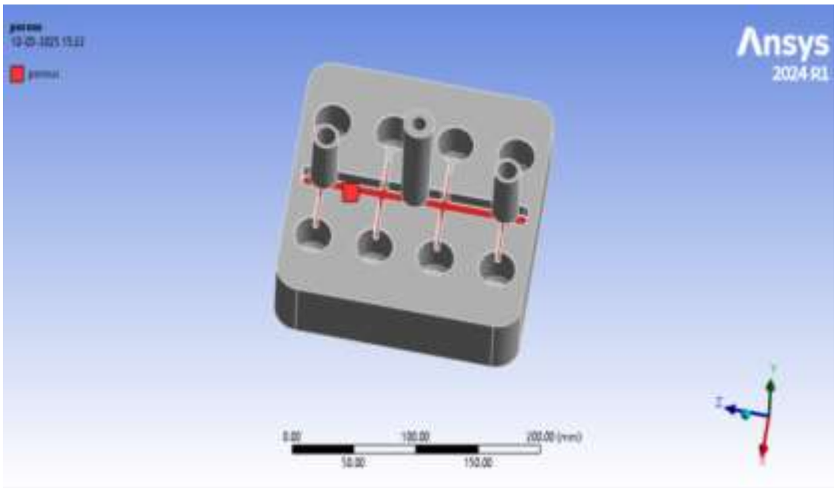

Figure 11: 8 cavity cap mold model flow porous

Above figure 11 shows the porous region encompasses the central runner and a portion of the branch runner, indicating that the focus is on modeling the flow behavior within this part of the system. The Ansys interface indicates that the model is being prepared for a fluid flow simulation. The "porous" designation suggests that boundary conditions and parameters for the porous medium are being defined.

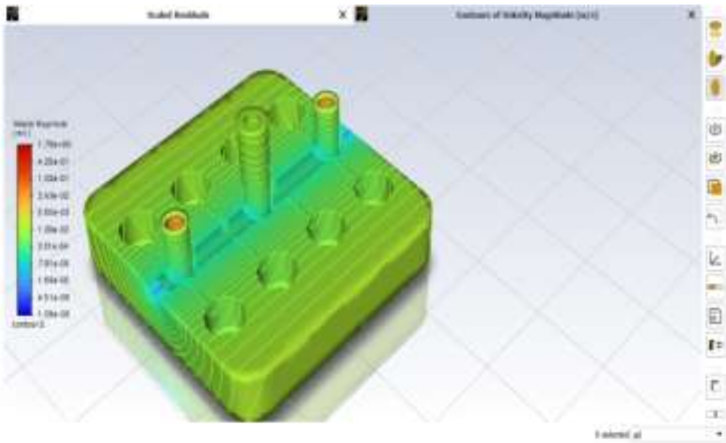

Figure 12: 8 cavity mold velocity streamline

The figure 12 shows the velocity distribution in the 8-cavity mold for HDPE fluid flow. The color-coded contours and the "Scaled Residuals" window indicate that the simulation has converged and provides meaningful results. shows the range of velocity magnitudes, from 1.08e-06 m/s to 1.78e+00 m/s

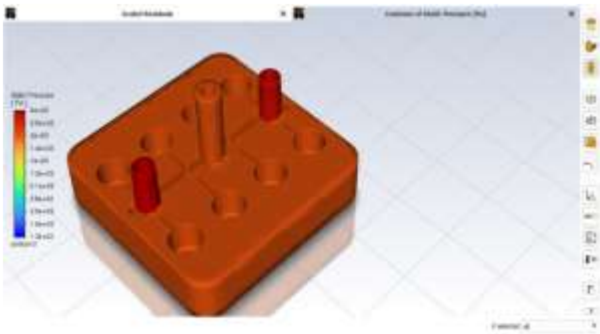

Figure 13: 8 cavity mold Pressure streamline

Above figure 13 shows the low-pressure regions are located in the wider sections of the runners and in the cavities, indicating the pressure drop as the material flows through the mold. the range of static pressure values, from 1.3e+02 Pa (dark blue) to 4e+03 Pa

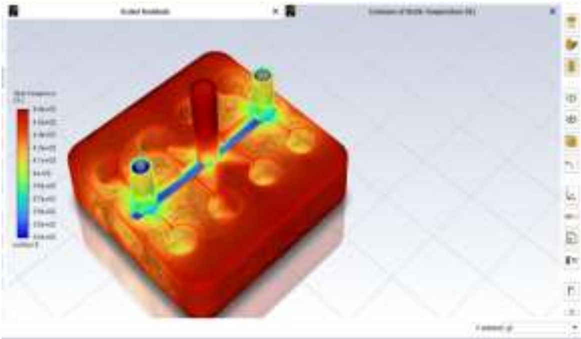

Figure 14: 8 cavity mold Temperature streamline [k]

The figure 14 shows the temperature distribution in the 8-cavity mold. The color-coded contours and the "Scaled Residuals" window indicate that the simulation has converged and provides meaningful results range of static temperature values, from 3.4e+02 K to 4.6e+02 K

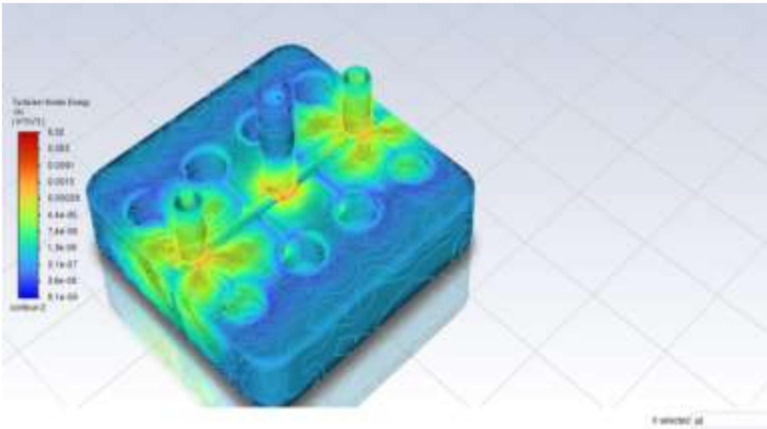

Figure 15: Turbulent Kinetic Energy (k)

The figure 15 shows the turbulent kinetic energy distribution in the 8-cavity cap mold for HDPE fluid flow. The color-coded contours and contour lines provide valuable insights into the flow behavior and turbulence intensity. The simulation results can be used to optimize the mold design and process parameters to minimize defects and improve the quality of the molded parts the range of turbulent kinetic energy values, from 6.1e-09 m^2/s^2 (dark blue) to 0.32 m^2/s^2

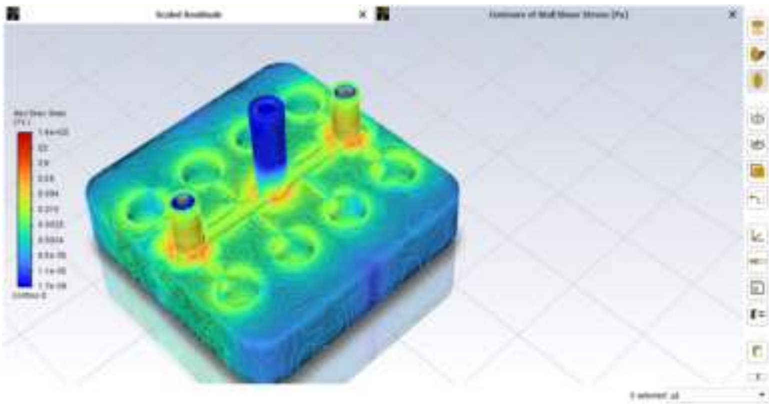

Figure 16: Wall shear Stress (Pa)

The figure 16 shows the wall shear stress distribution in the 8-cavity flip-top cap mold for HDPE fluid flow. The color-coded contours and the "Scaled Residuals" window indicate that the simulation has converged and provides meaningful results. The wall shear stress values range from 1.7e-06 Pa to 1.4e+02 Pa. This range suggests that the shear stress is relatively low in this simulation.

8 Cavity Flip top Cap Mold Flow analysis:

The 8-cavity flip-top cap mold using HDPE fluid flow simulation in Ansys has provided valuable insights into the filling process, potential challenges, and opportunities for optimization. By leveraging these insights, you can improve the mold design, optimize the process parameters, and achieve efficient, high-quality production of flip-top caps

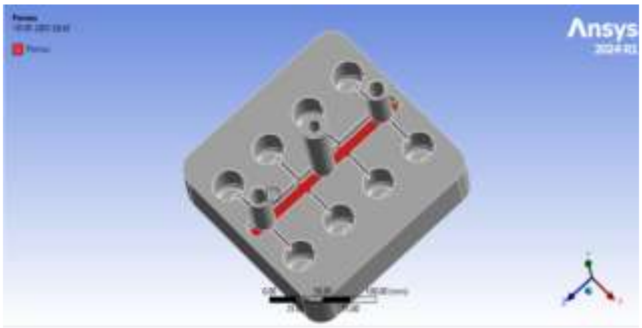

Figure 17: 8 cavity Flip top cap mold porous

Above figure 17 shows The Ansys interface indicates that the model is being prepared for a fluid flow simulation. The "Porous" designation suggests that boundary conditions and parameters for the porous medium are being defined.

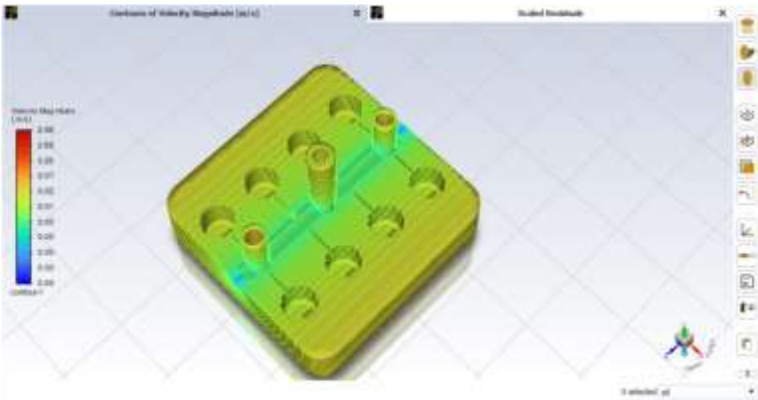

Figure 18: 8 cavity Flip top cap mold Velocity streamline

The figure 18 shows the velocity distribution in the 8-cavity flip-top cap mold for HDPE fluid flow. The color-coded contours and the "Scaled Residuals" window indicate that the simulation has converged and provides meaningful results shows the range of velocity magnitudes, from 0.00 m/s to 2.98 m/s.

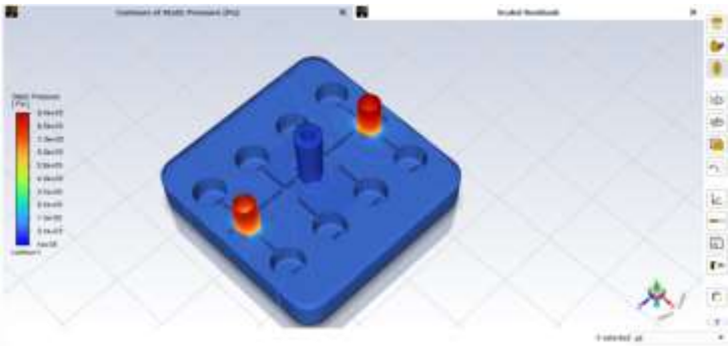

Figure 19: 8 cavity Flip top cap mold Pressure streamline

Above figure 19 shows the 8-cavity flip-top cap mold Pressure streamline for HDPE filling. The image shows the static pressure distribution in the 8-cavity flip-top cap mold for HDPE filling. The color-coded contours and the "Scaled Residuals" window indicate that the simulation has converged and provides meaningful results.

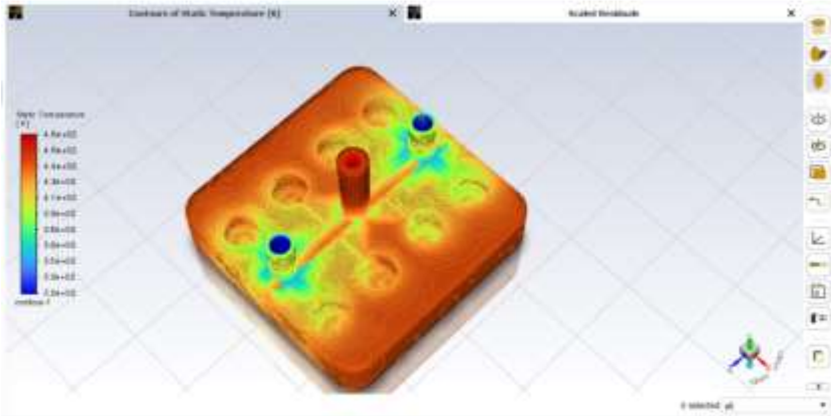

Figure 20: 8 cavity Flip top cap mold Temperature streamline

Above figure 20 shows the 8-cavity flip-top cap mold Temperature streamline for HDPE fluid flow. The temperature gradually decreases as the HDPE flows through the runners and into the cavities, as indicated by the changing color gradient. the range of static temperature values, from 3.2e+02 K to 4.8e+02 K

Turbulent Kinetic Energy (k):

It represents the intensity of turbulence in a fluid flow system. It quantifies the energy contained within turbulent eddies and is a critical parameter in CFD (Computational Fluid Dynamics) simulations for mold filling, cooling efficiency, and flow stability.

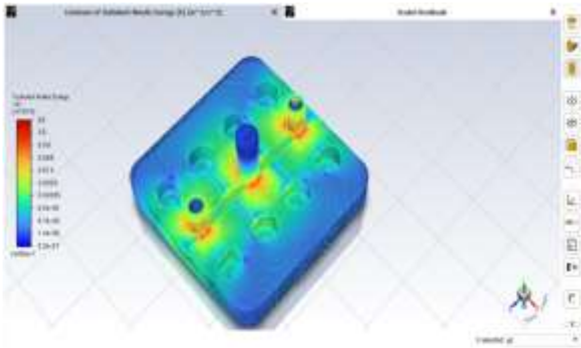

Figure 21: Turbulent Kinetic Energy (k)

Above figure 21 to observe the Turbulent Kinetic Energy (k) distribution across the mold geometry. Turbulent kinetic energy reflects the intensity of turbulence and is crucial for understanding flow stability, mixing behavior, and energy dissipation. Marked in red regions, reaching values up to 3.5 m^2/s^2.

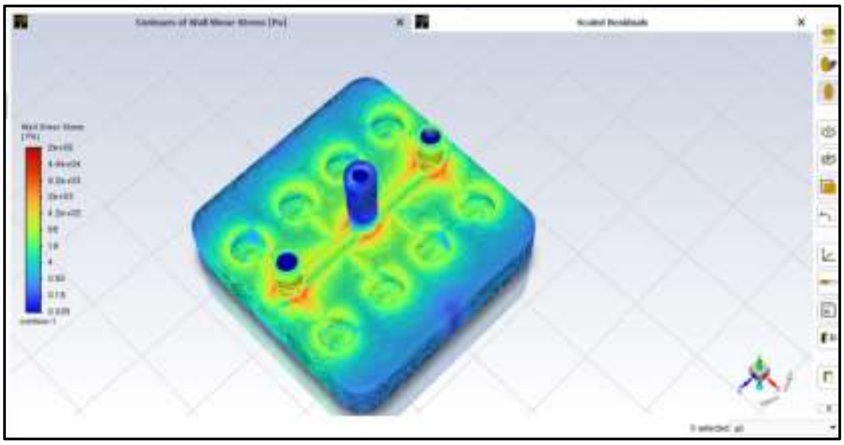

Figure 22: Wall shear Stress (Pa)

Above figure 22 to observe the Wall Shear Stress (Pa) distribution across the mold geometry Indicated in red regions, showing values up to 2 x 10^5 Pa High shear stress areas are prone to excessive heat generation, material degradation, or potential surface defects. These regions may need design improvements like smoother flow transitions or optimized runner positions.

Table 4: Comparison of different cap molds fluid flow results

Mold cap Type	Velocity streamline (m/s)	Pressure streamline [Pa]	Temperature streamline [K]	Turbulent Kinetic Energy (k)	Wall shear Stress (Pa)
2 Cavity Threaded	2.45	3.36	4.40	1.48	3.70
8 Cavity Threaded	1.78	4.01	4.62	0.32	1.41
8 Cavity Flip Top	2.98	9.31	4.80	0.22	2.01

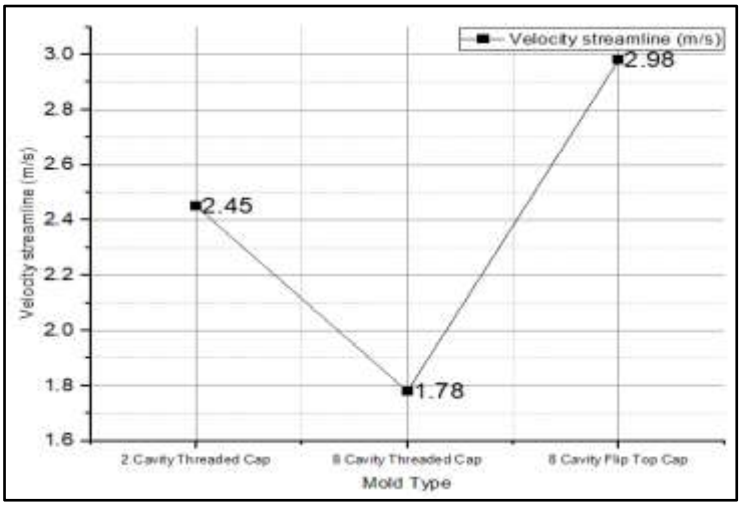

Figure 23: Validation of different mold cap Velocity streamlines (m/s)

- The significant drop from 2 Cavity Threaded Cap to 8 Cavity Threaded Cap suggests a more balanced and distributed flow, likely leading to reduced turbulence.
- The sharp rise in velocity for the 8 Cavity Flip Top Cap could indicate restricted flow areas, leading to higher localized speeds, which might cause increased shear stress or temperature buildup.
- The variations in velocity could impact mold filling efficiency, material distribution, and potential defects like air entrapment or warping.

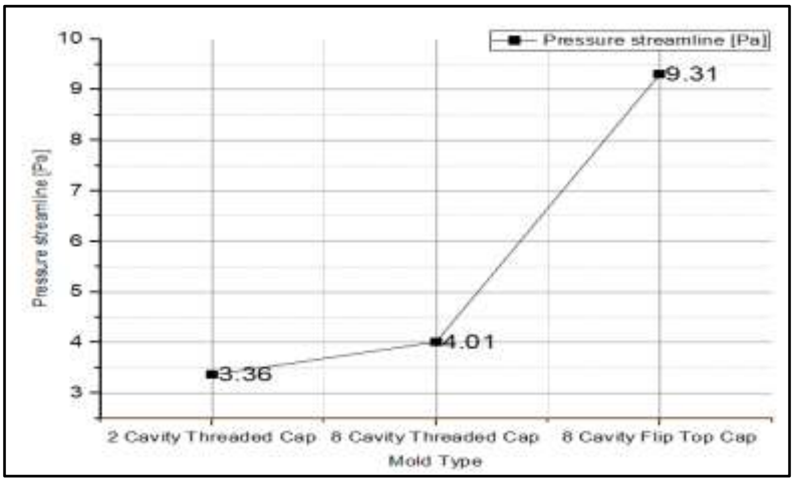

Figure 24: Validation of different mold cap Pressure streamlines [Pa]

- The modest increase in pressure from the 2 Cavity to 8 Cavity Threaded Cap suggests improved flow distribution with only minor resistance changes.
- The sharp pressure rise in the 8 Cavity Flip Top Cap likely points to design constraints such as narrower channels, complex flow paths, or sudden directional changes, contributing to pressure buildup.
- Elevated pressure can impact filling uniformity, increase material shear stress, and may require optimized gate or runner design to improve flow efficiency.

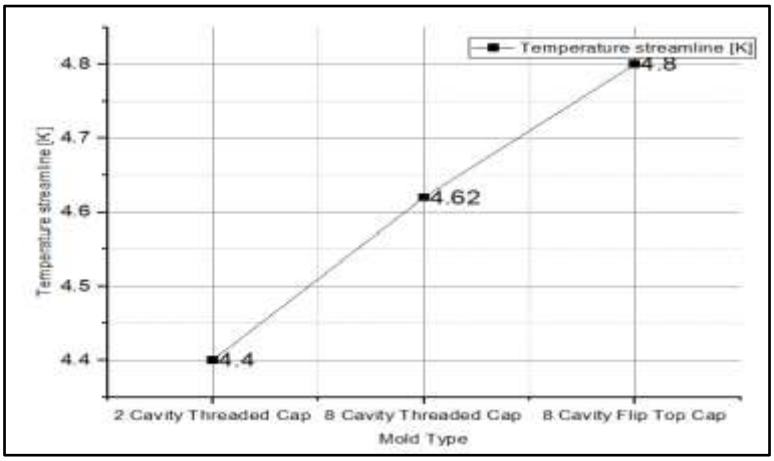

Figure 25: Validation of different mold cap Temperature streamlines [K]

- The increasing temperature trend from 2 Cavity to 8 Cavity Flip Top Cap may indicate higher heat buildup or less effective heat dissipation in designs with more complex geometries or restricted flow patterns.
- The rise in temperature for the 8 Cavity Flip Top Cap suggests potential thermal concentration points that could impact material cooling rates and influence shrinkage or warping in the final molded product.

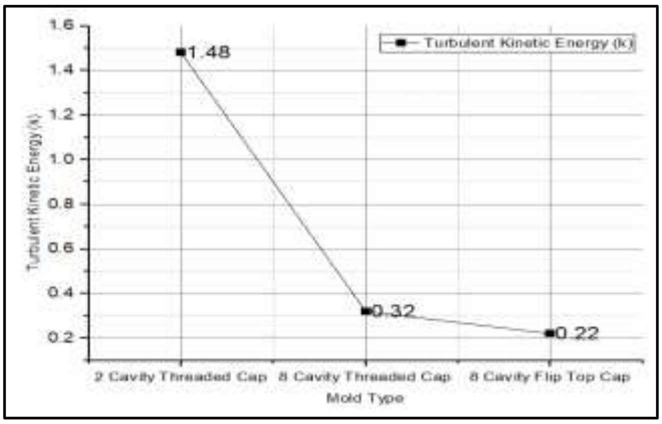

Figure 26: Validation of different mold caps Turbulent Kinetic Energy (k)

- The sharp decrease in Turbulent Kinetic Energy (k) from the 2 Cavity Threaded Cap to the 8 Cavity designs suggests that increasing the number of cavities helps in reducing turbulence, likely leading to a smoother and more efficient filling process.
- The 8 Cavity Flip Top Cap has slightly lower turbulence than the 8 Cavity Threaded Cap, which could imply better flow distribution or fewer abrupt directional changes in the mold.

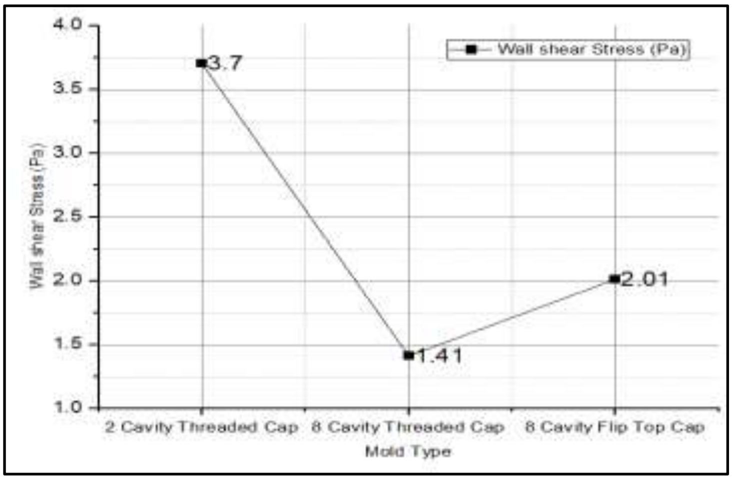

Figure 27: Validation of different mold caps Wall shear Stress (Pa)

- The significant drop from the 2 Cavity Threaded Cap to the 8 Cavity Threaded Cap indicates improved flow behavior, potentially due to optimized runner design or increased cavity count reducing flow resistance.
- The increase in wall shear stress for the 8 Cavity Flip Top Cap may suggest design complexities, sharp corners, or higher-pressure zones affecting the flow pattern.

CONCLUSIONS

The CFD analysis of multicavity cap moulds using ANSYS Fluent has provided significant insights into the optimization of the injection moulding process. The study explored three distinct cavity designs: 2-cavity threaded, 8-cavity threaded, and 8-cavity flip-top moulds, widely used in manufacturing caps for packaging, pharmaceuticals, and consumer goods. The analysis focused on key parameters, including melt flow, temperature distribution, cooling efficiency, and pressure drop during both the injection and cooling phases. The findings revealed that the melt flow and temperature distribution were significantly influenced by the cavity configuration. The 8-cavity flip-top mould exhibited the most efficient cooling performance, with better uniformity in filling patterns and reduced temperature gradients across cavities. On the other hand, the 2-cavity threaded mould demonstrated a more predictable fill pattern but faced challenges in melt front progression, which affected cycle times and overall energy consumption. The 8-cavity threaded mould struck a balance between efficiency and complexity, offering reasonable performance in both filling and cooling aspects. In conclusion, CFD simulations in ANSYS Fluent proved to be an invaluable tool for understanding the impact of cavity design on the injection moulding process. By optimizing the melt flow, cooling channels, and temperature control, significant improvements in part quality, cycle time, and energy efficiency were achieved. The results emphasized the need for tailored mould configurations based on specific application requirements to minimize defects such as warping, short shots, and air traps.

Future Scope:

Future research can focus on improving sustainability by reducing energy consumption and material waste in the injection moulding process. Green technologies such as recyclable polymers and low-energy moulding processes could be integrated into the design optimization phase. the understanding and performance of multicavity cap molds in the injection moulding industry could be significantly advanced, leading to more efficient production, improved part quality, and sustainability in manufacturing processes.

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