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A Comparative Study of Conventional and Conformal Cooling Systems for Injection Moulding of Acrylonitrile Butadiene Styrene Material

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Abstract

Injection moulding is one the most familiar processes for manufacturing of plastic parts by injecting molten thermoplastic polymers into a metal mould. In injection moulding process, the cooling channel performance is one of the most crucial factors because it has significant effect on both production rate and the quality of the plastic part. This study investigates the comparative performance of conventional and conformal cooling systems in the injection moulding process using acrylonitrile butadiene styrene (ABS) material of stainless steel mould. The study evaluates the effectiveness of different cooling channel configurations through simulation analysis using Solidworks Plastics 2022. Three conformal cooling channel diameters (4 mm, 6 mm, and 8 mm) were compared against a conventional cooling system with a 6 mm diameter channel. The study specifically examined cooling time, shrinkage and weight of the moulded parts as key performance indicators. Results demonstrated that the 4 mm diameter conformal cooling channel achieved the best performance, reducing cooling time by 4.5% (from 4.49 seconds to 4.29 seconds) and decreasing volumetric shrinkage by 19.0% (from 0.4148% to 0.3361%) compared to the conventional system. Part mass remained relatively consistent across all configurations, with variations less than 0.2%. The 6 mm and 8 mm diameter conformal channels also showed improvements over the conventional system, though less pronounced than the 4 mm configuration. These findings suggest that properly designed conformal cooling channels, particularly those with smaller diameters, can significantly improve injection moulding efficiency and product quality.

1. Introduction

Plastic injection moulding technology has revolutionized the manufacturing industry, enabling the mass production of intricate plastic components with remarkable precision. Among the critical aspects of this process, the design and optimization of cooling systems play a pivotal role in determining production efficiency and product quality. Decades of research have underscored the importance of effective cooling systems in minimizing cycle time, reducing defects like warpage and shrinkage, and enhancing dimensional stability [1]. Research on innovative cooling techniques, such as conformal cooling systems, has gained significant momentum, offering transformative solutions for challenges posed by conventional straight-drilled channels [2].

Experts assume uniform cooling across the mould cavity is essential for consistent part quality [3]. Several studies show that conventional cooling channels, which are widely used, often fail to provide uniform heat dissipation for parts with complex geometries [4]. This inadequacy has sparked a longstanding interest in conformal cooling systems designed to follow the contours of the mould cavity and ensure more even thermal distribution. Researchers have demonstrated that conformal cooling channels can reduce cycle times and enhance the quality of moulded parts [5]. However, while some studies emphasize the advantages of conformal cooling, such as shorter cycle times, others highlight challenges like increased manufacturing complexity and cost [6].

Despite these advancements, several questions remain unresolved. Overall, it has remained unclear whether the benefits of conformal cooling are universally applicable across different polymer types, mould materials, and channel geometries. It remains an open question whether conformal cooling channels can consistently outperform conventional systems across all key performance metrics, such as cooling time, shrinkage, and part weight.

The present study aims to conduct a detailed comparative analysis of conventional and conformal cooling systems for the injection moulding of Acrylonitrile Butadiene Styrene (ABS) material of stainless steel mould. Hypothetically, conformal cooling channels, particularly with optimized diameters and layouts, will outperform conventional channels regarding cooling efficiency and part quality, and conformal channels with smaller diameters will yield the most significant improvements in cooling time and reduction of defects. This study provides valuable insights for manufacturers seeking to enhance productivity and reduce costs in injection moulding processes.

2. Methodology

2.1 Conventional Cooling System

The plastic cup with runner and conventional cooling systems, including coolant input and output was used in this study. The diameter of the straight cooling channel diameter was 6 mm. For the baffle, the diameter was 7 mm, while the blade thickness (T) and tip height (H) were 1 mm. The conventional cooling channel layout is shown in Figure 1.

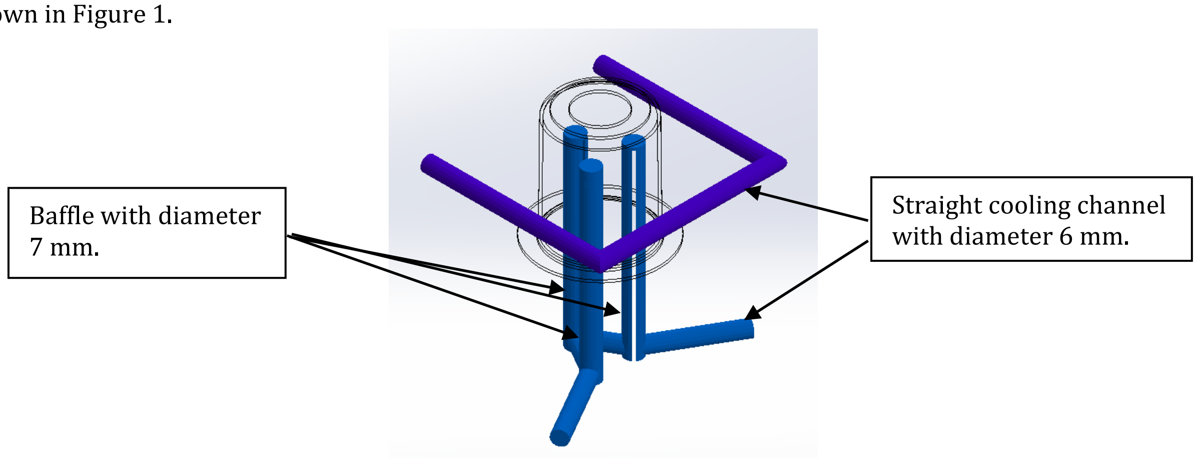


***Fig. 1*:** Conventional cooling channel

2.2 Conformal Cooling System

The hole diameter of the cooling channel, the distance between the channel, and the distance between the centre of the channel and the cavity wall were identified as the parameters for the design of the conformal cooling channel. According to the design guideline of the cooling channel [7], since the wall thickness of the plastic cup was 1 mm, the diameter of the cooling channel was designed as 4 mm, 6 mm, and 8 mm. The distance between the centre of the channel and the cavity wall was chosen to be 1.5 times of the cooling channel diameter, resulting in distances of 6 mm, 9 mm, and 12 mm, while the distance between the cooling channels was selected to be 2 times of the cooling channel diameter, which amounted to 8 mm, 12 mm, and 16 mm, as shown in Table 1. For the configurations with 4 mm and 6 mm diameters, the cooling channel for the coolant output in the core was designed to pass through the middle of the cooling channel. However, for the 8 mm diameter configuration, it was noted that the spiral diameter at the core was too small for the 4 mm diameter cooling channel to pass through the middle; therefore, the cooling channel for the coolant output was designed to maintain 2 mm from the channel wall to the cavity wall. For the configurations with 6 mm and 8 mm diameters, the cooling channel diameter before the coolant output in the core was set as 4 mm to avoid overlapping between the cooling channels, as shown in Figure 2.

***Table 1*:** Design value of conformal cooling channel

Diameter of the cooling channel (mm)	Distance between the centre of the channel and the cavity wall (mm)	Distance between cooling channel (mm)
4	6	8
6	9	12
8	12	16

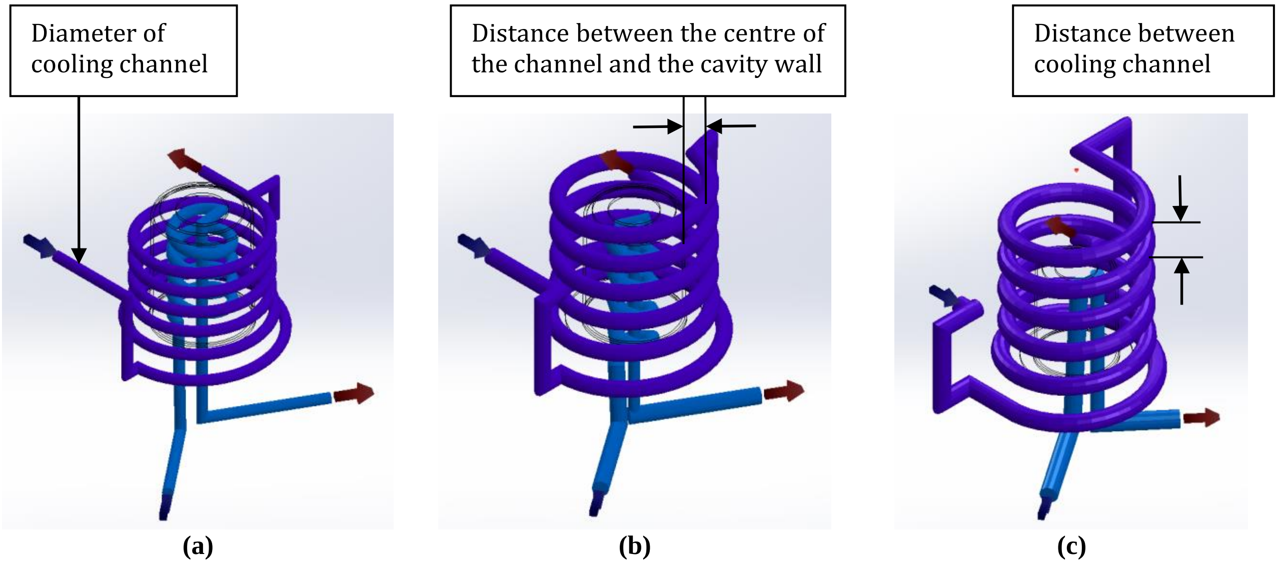


***Fig. 2*:** Conformal cooling channel in core and cavity with coolant input and output (a) 4 mm diameter; (b) 6 mm diameter; (c) 8 mm diameter

2.3 Simulation Setup

The plastic material was specified as ABS: CHIMEI / POLYLAC PA-757. The mould material was chosen as SS 316L. The coolant was set as water. For the coolant input, the coolant inlet and outlet were selected and the flow rate of coolant was set as 916.7 cc/s and inlet temperature was 30°C. The process parameters of fill, cool and pack used in the simulation are as shown in Table 2, Table 3 and Table 4.

***Table 2*:** Parameter of fill settings

Parameters	Value
Filling time (s)	0.37
Melt temperature (˚C)	210
Mould temperature (˚C)	50
Injection pressure limit (MPa)	210

***Table 3*:** Parameter of cool settings

Parameters	Value
Mould open time (s)	5
Eject temperature (˚C)	74.19

***Table 4*:** Parameter of pack settings

Parameters	Value
Pressure holding time (s)	2.032
Pure cooling time (s)	1.539

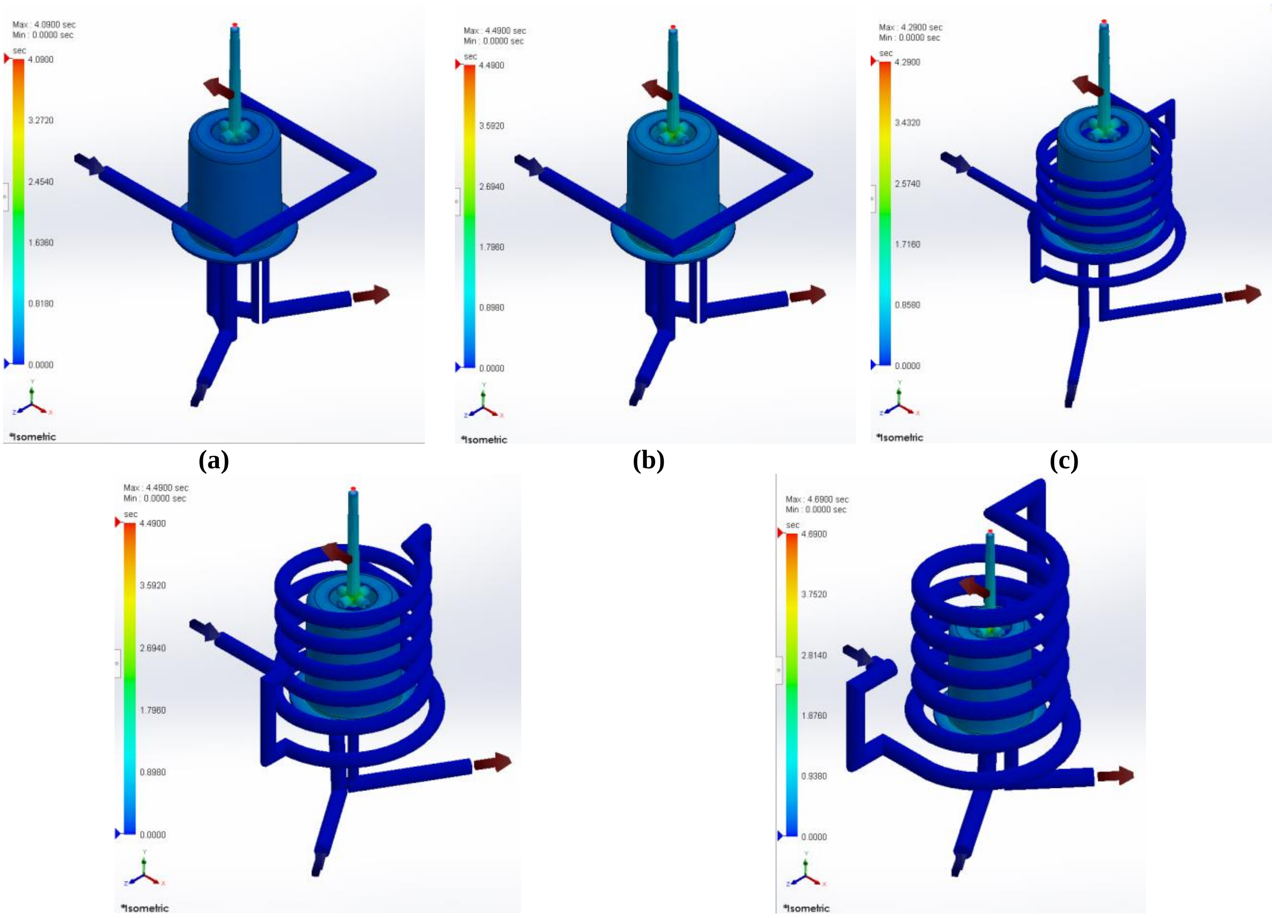
3. Results and Discussion

3.1 Cooling Time

The cooling time of different configurations of cooling channel as shown in Table 5. The cooling time image of different configurations of cooling channel captured in Solidworks Plastic as shown in Figure 3. The reduction in cooling time with 4 mm diameter conformal cooling system of SS 316L mould compared to the 6 mm diameter conventional cooling system of SS 316L mould, indicates that conformal cooling channels cooled the passageway which follows the profile of the mould cavity or core to perform uniform cooling process effectively. For 8 mm diameter conformal cooling channel, the design might not have accounted for high-heat areas or might have channels too far from the part surface for effective cooling. An excessively large or small diameter could lead to inefficiencies. Larger diameters might slow down the coolant flow, reducing heat transfer efficiency, while very small channels could increase flow resistance, potentially not distributing coolant effectively [8]. Larger diameter may lead to inadequate flow rate, that might not support the necessary flow dynamics. If the flow rate of the coolant through the conformal channels is too low, it might not carry away heat efficiently [9].

Table 5**:** Cooling time of different configurations of cooling channel

Configurations of cooling channel	Cooling time (s)
6 mm diameter conventional (P21)	4.09
6 mm diameter conventional (SS 316L)	4.49
4 mm diameter conformal (SS 316L)	4.29
6 mm diameter conformal (SS 316L)	4.49
8 mm diameter conformal (SS 316L)	4.69



(a) (b) (c)

(d) (e)

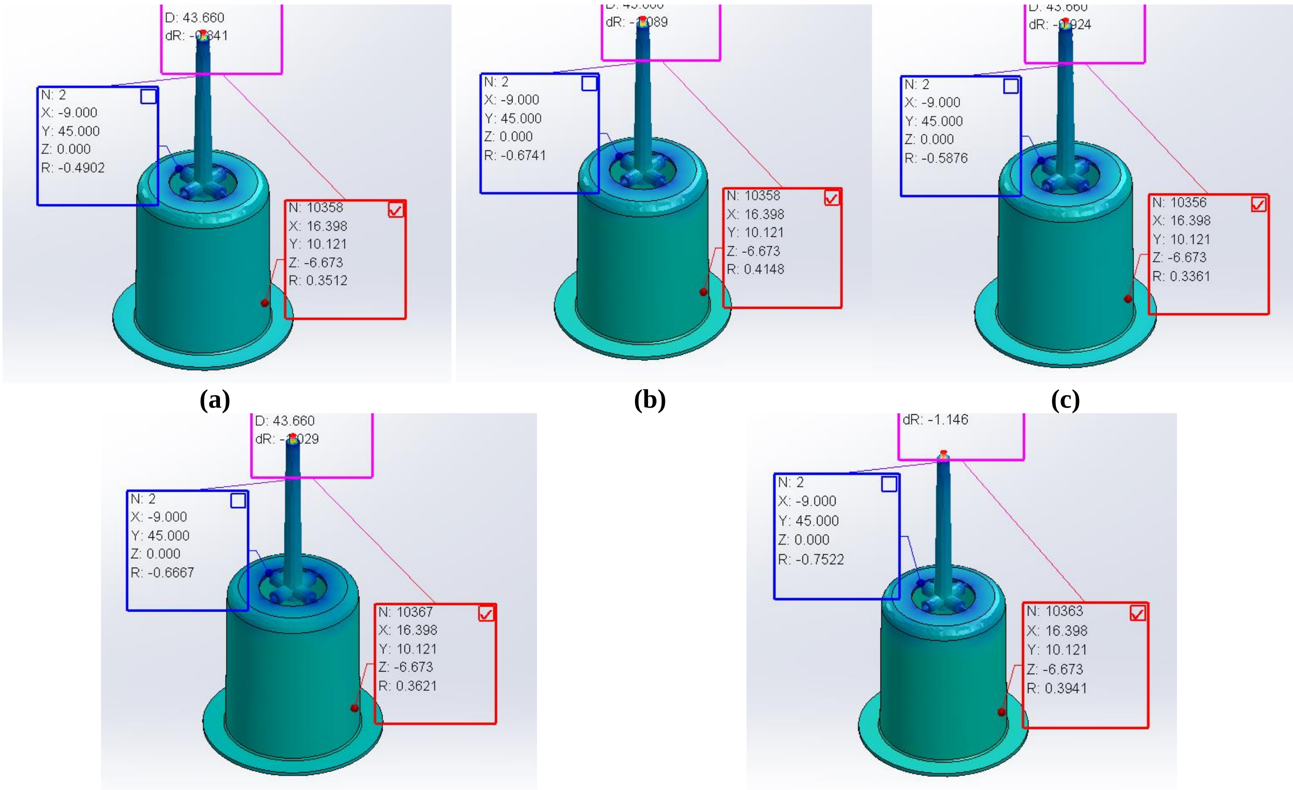
Fig. 3**:** Cooling time of different configuration of cooling channel (a) 6 mm diameter conventional (P21) = 4.09 seconds; (b) 6 mm diameter conventional (SS 316L) = 4.49 seconds; (c) 4 mm diameter conformal (SS 316L) = 4.29 seconds; (d) 6 mm diameter conformal (SS 316L) = 4.49 seconds; (e) 8 mm diameter conformal (SS 316L) = 4.69 seconds

3.2 Shrinkage

The shrinkage of different configurations of cooling channel as shown in Table 6. The shrinkage image of different configurations of cooling channel captured in Solidworks Plastic as shown in Figure 4. The result in shrinkage with conformal cooling system of SS 316L mould compared to the 6 mm diameter conventional cooling system of SS 316L mould shows that conformal cooling channels result in lower volumetric shrinkage, which suggests better control over the cooling process, leading to parts with more consistent dimensions and less likelihood of defects like warpage or sink marks [10]. Conformal cooling channels are designed to closely follow the contour of the part, allows for more uniform heat extraction across the part, minimizing temperature variations that lead to uneven shrinkage. Conformal cooling allows for better control over the temperature gradients within the mould. This improved thermal management helps to reduce residual stresses and shrinkage [11].

Table 6**:** Shrinkage of different configurations of cooling channel

Configurations of cooling channel	Shrinkage (%)
6 mm diameter conventional (P21)	0.3512
6 mm diameter conventional (SS 316L)	0.4148
4 mm diameter conformal (SS 316L)	0.3361
6 mm diameter conformal (SS 316L)	0.3621
8 mm diameter conformal (SS 316L)	0.3941



(d) (e)

Fig. 4**:** Shrinkage of different configuration of cooling channel (a) 6 mm diameter conventional (P21) = 0.3512%; (b) 6 mm diameter conventional (SS 316L) = 0.4148%; (c) 4 mm diameter conformal (SS 316L) = 0.3361%; (d) 6 mm diameter conformal (SS 316L) = 0.3621%; (e) 8 mm diameter conformal (SS 316L) = 0.3941%

3.3 Weight

The weight of different configurations of cooling channel as shown in Table 7. The weight image of different configurations of cooling channel captured in Solidworks Plastic as shown in Figure 5. The slight variations in part mass between the conventional and conformal cooling system of SS 316L mould could be attributed to different cooling efficiencies affecting the packing of the molten plastic in the mould. The 4 mm and 6 mm conformal cooling channel with SS 316L mould shows a minor decrease in mass compared to the conventional cooling channel with SS 316L mould, suggesting optimal cooling might lead to less overpacking, thus using less material and save the cost [12]. With an 8 mm diameter conformal cooling channel, the coolant might not flow as effectively as in smaller channels. Larger channels could result in a lower coolant velocity, which might not carry away heat as efficiently. This could lead to slower cooling, allowing more time for additional material to be packed into the mould before the part solidifies [13].

Table 7: Weight of different configurations of cooling channel

Configurations of cooling channel	Weight (g)
6 mm diameter conventional (P21)	6.168
6 mm diameter conventional (SS 316L)	6.195
4 mm diameter conformal (SS 316L)	6.182
6 mm diameter conformal (SS 316L)	6.192
8 mm diameter conformal (SS 316L)	6.202

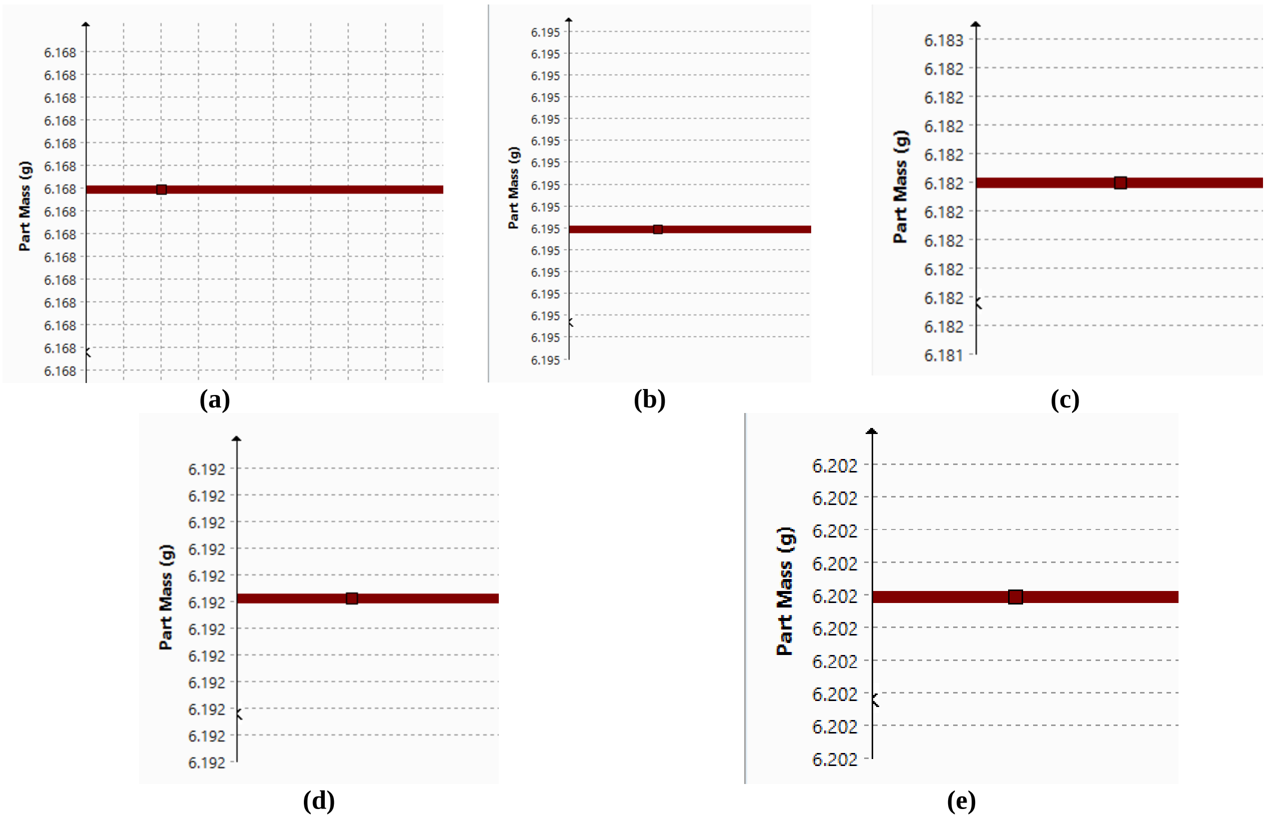


Fig. 5: Weight of different configuration of cooling channel (a) 6 mm diameter conventional (P21) = 6.168 grams; (b) 6 mm diameter conventional (SS 316L) = 6.195 grams; (c) 4 mm diameter conformal (SS 316L) = 6.182 grams; (d) 6 mm diameter conformal (SS 316L) = 6.192 grams; (e) 8 mm diameter conformal (SS 316L) = 6.202 grams

4. Conclusion

This study successfully demonstrated the comparative performance of conventional and conformal cooling systems in the injection moulding of Acrylonitrile Butadiene Styrene (ABS) material. The results highlighted that conformal cooling channels, particularly those with a 4 mm diameter, outperformed conventional straight drilled channels by reducing cooling time by 4.5%, volumetric shrinkage by 19.0% and weight by 0.2%. These improvements translate to shorter cycle times, enhanced productivity, and superior part quality with fewer defects like warpage and sink marks. The study provides valuable insights into the advantages of conformal cooling systems and their potential to transform injection moulding processes by improving efficiency and product quality.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

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