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A Simulation Study of Conformal Cooling Channels in Plastic Injection Molding

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Abstract

In injection molding 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. In order to reduce the cycle time, and control the uniform distribution of temperature, it is necessary to create conformal cooling channels, which conform to the shape of the mold cavity and core. This paper presents a simulation study of different types of cooling channels in an injection molded plastic part and compares the performance in terms of time to ejection temperature, shrinkage, temperature profile, and part warpage to determine which configuration is more appropriate to provide uniform cooling with minimum cycle time. Autodesk Moldflow Insight (AMI) simulation software is used to examine the results of the cooling channels performance.

Keywords:Injection Molding, conformal cooling, simulation, moldflow, cycle time

1. Introduction

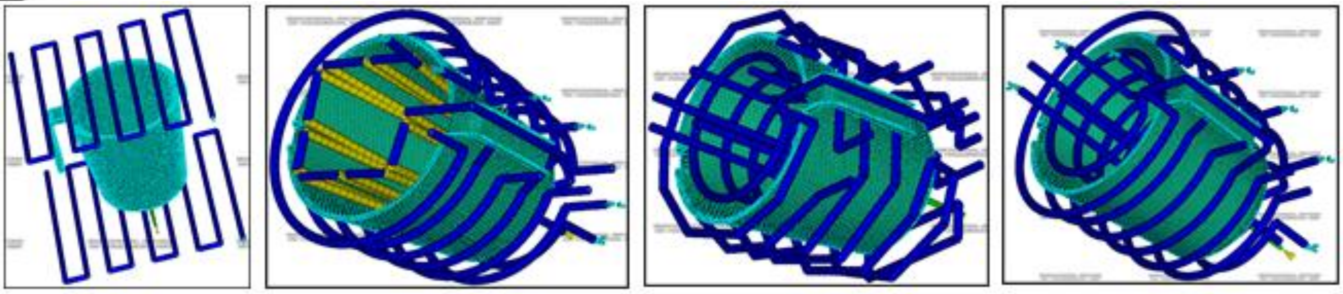
Plastic injection molding process is the most common process for economically mass producing of plastic parts of various complex geometries and shapes [1]. Some of the major problems facing injection molders today are how to reduce cycle time, part warpage and shrinkage alongside lowest costs. However, using computer simulation software AMI, it is possible to design and simulate different cooling configuration of the plastic part and investigate the proper cooling system for the plastic part.

Most of the researches on conventional cooling systems for injection molding have been directed toward optimal cooling system design to improve the effectiveness and efficiency of cooling. Au and Yu [2] presented a scaffolding architecture for conformal cooling design for rapid plastic injection molding. Research in conformal cooling system has mainly focused on simulation studies and testing of prototype conformal cooling molds using various techniques [3]. Sach et al. [4] described the production of injection molding tooling with conformal cooling channels using the Three Dimensional Printing (3DP) process. They compared the effectiveness of conformal cooling and conventional cooling of core and cavity by experimental testing and also by finite difference approach. They concluded that the conformal mold was able to maintain a more uniform temperature. Saifullah et al. [5] presented bi-metallic conformal cooling for injection mold where simulation and experimental results show that bi-metallic conformal cooling channel design gives better cycle time, which ultimately increases production rate as well as fatigue life of the mold. In this paper, a comparative analysis of various cooling system configurations has been done in terms of time to ejection temperature (time to freeze), shrinkage, temperature profile, warpage, sink marks with the aim of determining which cooling system configuration is appropriate for this part providing uniform cooling, minimum cycle time, less warpage and shrinkage. The results from the simulation studies show that conformal cooling is the best cooling system for the plastic part.

2. DesignofPartandCoolingChannels

In this study, a plastic part has been designed using Pro/Engineer Wildfire 5 as shown in figure 1. Part is of 2 mm in thickness and 182 mm in height. The IGES (Initial Graphics Exchange Specification) CAD model of the plastic part has been imported to AMI to perform analysis.

Figure 1: CAD Model of the plastic part



(a) (b) (c) (d)

Figure 2: Cooling channel types: (a) Normal, (b) conformal combination with baffle, (c) conventional combination with conformal and (d) conformal

Polypropylene has been assigned as a material for plastic part. Melt temperature and mold surface temperature have been maintained at 225°C and 38°C respectively. The best gate location analysis has been done and it is foundto be located in the middle of the base of the plastic part. Water was selected as the coolant liquid for all analysis because it has high cooling property, economically viable and environmentally friendly. Figure 2 shows the four types of cooling channels considered in this analysis. All cooling channels had the same diameter of 10 mm. For these channels, depth of the cooling channels from cavity surface and distance between cooling channels centres were 25 mm and 40 mm respectively. The coolant Reynolds number was calculated to be 9750 and temperature at coolant inlet was 20°C, which indicates that flow of water was fully turbulent.

3. PlasticSimulationStudy

Autodesk Moldflow Insight has been used to design the cooling channels and perform *Cool +Flow+ Pack + Warp* analysis. Dual Domain Meshing (Fusion mesh) was used with number of elements being 30770. The quality of the mesh was improved with manual meshing techniques. The maximum aspect ratio was improved significantly from 20 to 10. Similarly match percentage has improved from 81.4% to 91.6% as well as reciprocal percentage has improved from 7.2% to 88.3%.

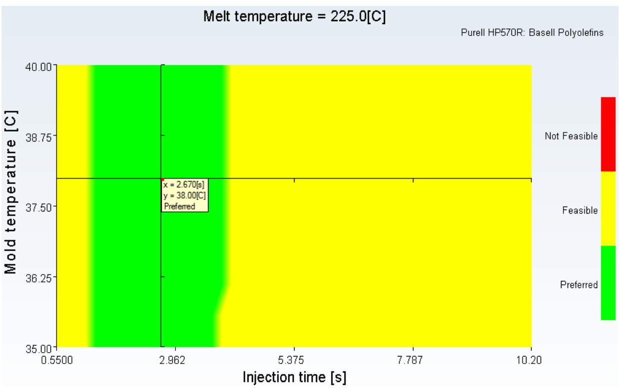
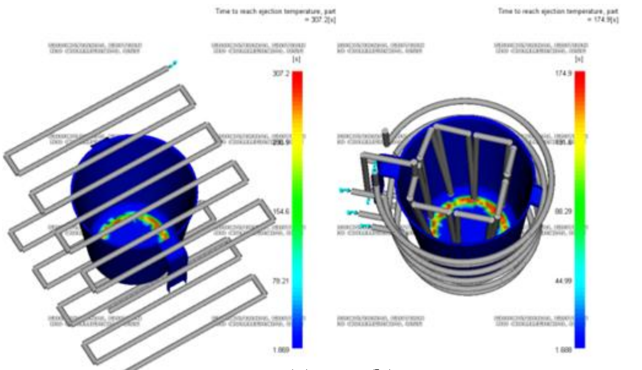


Figure 3: Molding Windows

Molding Windows is quick analysis to evaluate the best material conditions that are needed to produce the part. The purpose of Molding Windows is to determine the best processing conditions and evaluate the sensitivity of the part to the molding process and evaluate gate locations and gain a measure of part design quality to improve manufacturability. It also helps to determine variation in mold temperature, melt temperature, injection to produce high quality of the part.Figure 3shows the zone plot for Polypropylene material Purell HP570R. The X-axis is melt temperature andinjection time. The Y-axis mold temperature. The zone plot has three areas, which are green, yellow and red. From figure 3 it is clear that the zone plot selected is within green area (Preferred). This means we are able to mold the part and the quality will be high and hence the part will be acceptable by customers after producing.

4. Results and Discussion

The simulation results in terms of time to reach part ejection temperature (time to freeze) indicates that normal cooling channels took around 75 seconds to reach ejection temperature for most of the plastic parts as shown by blue colours in figure 4 (a). It shows that this cooling channel is the slowest cooling system because it requires more time than other systems. It takes more time because of its structure that consists of straight drilled holes in the mold. These holes have some limitations in terms of geometric complexity, non-uniform cooling between the surfaces of the part and cooling fluid mobility within the injection mold [1].

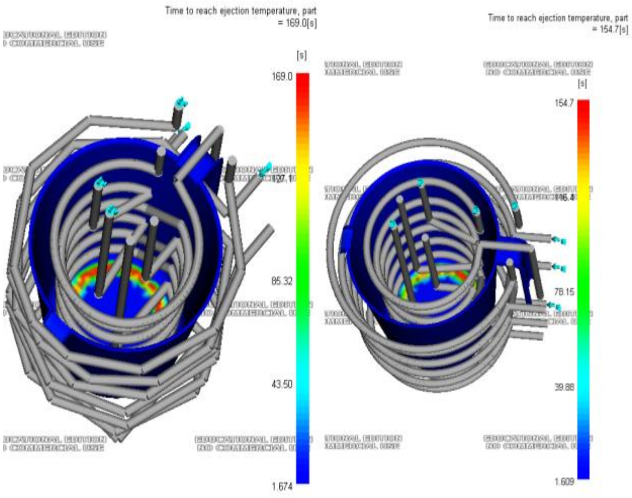


(a) (b)

Figure 4: Time to reach part ejection temperature (Time to freeze part) with (a) normal, (b) conformal combination with baffle, cooling channels

However, time to reach part ejection temperature decreased to around 44 seconds with the use of conformal cooling channel combination with baffle showing significant improvement as can be seen in blue shades in Figure 4 (b) and faster by nearly 43% in comparison with that of normal straight channels which use the same pitch distance and the same channel diameter.

With the use of conventional cooling in combination with conformal cooling channel in the core, the value of time to reach part ejection temperature reduces to around 43 seconds as can be seen in blue in figure5 (a). The cooling time (time to freeze) further reduced to around 37 seconds for the fully conformal cooling system as can be seen in blue figure5 (b) thus cooling the product the fastest, by 49.6% faster than normal cooling channel, and up to 12% faster than conformal cooling channel in combination with baffle, that is the lowest value when compared to the rest of the cooling channel used in the analysis. This is due to conformal cooling lines follow the part geometry in the mold and because of optimum placement resulting in uniform mold temperatures. In conformal cooling, results show that the predicted temperature difference across the part thickness is drastically reduced and becomes more uniform than other cooling channels such as normal, conventional and conformal channels in combination with baffle line layout. In addition, in a conformal cooling channel, the mold surface temperature is fairly uniform around the part.

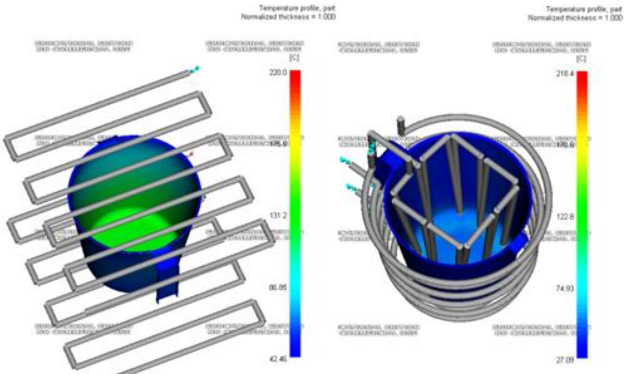


(a) (b)

Figure 5: Time to reach part ejection temperature with (a) conventional combination with conformal, (b) conformal, cooling channel

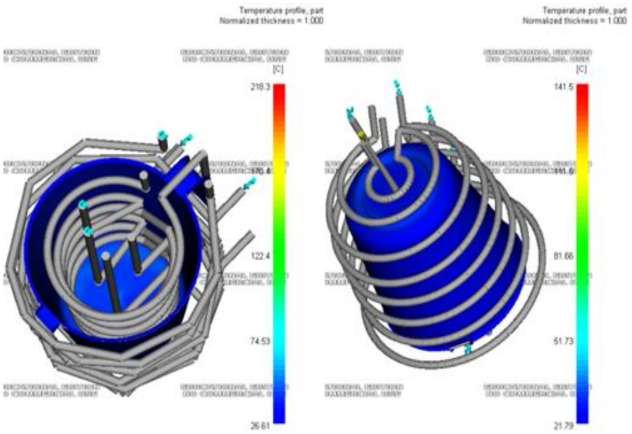
To demonstrate the temperature distribution, figure6(a) shows temperature profile for normal cooling channel. Since mold surface temperature is 38°C in all types of cooling channels, as a result, the normal cooling channel has non-uniformity of temperature distribution within the range from 42.46°C to 131.2°C as shown in figure6 (a), which means that lowest value (42.46°C) is more than mold surface temperature which is 38°C. In contrast, small temperature variation from 27.09°C-74.39°C is with the use of conformal cooling combination with baffle as can be seen in figure6 (b).

In conventional cooling in combination with conformal, temperature distribution lies within the range from 26.61°C to 74.53°C as shown in figure7 (a). These cooling channels cannot provide the uniformity for all portions of part. On other hand, the temperature is uniformity distributed for all portions of part 21.79 °C with the use of conformal cooling channel as described in figure7 (b). Furthermore, we notice that the highest temperature in the whole analysis is reduced by more than 36%. Therefore, it can be concluded that this result gives clear evidence that conformal cooling channel provides better temperature consistency and uniformity than other cooling channels even in complex part.



(a) (b)

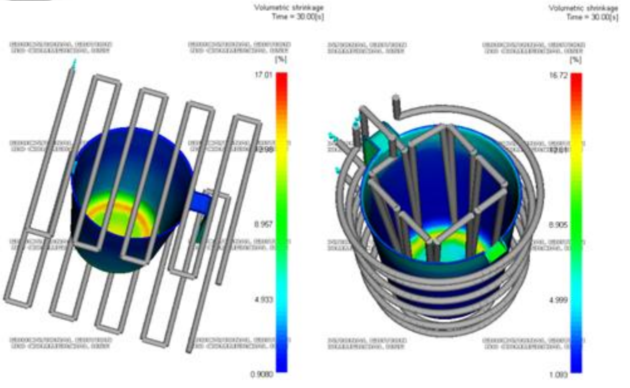
Figure 6: Temperature profile of part with (a) normal, (b) conformal combination with baffle, cooling channels



(a) (b)

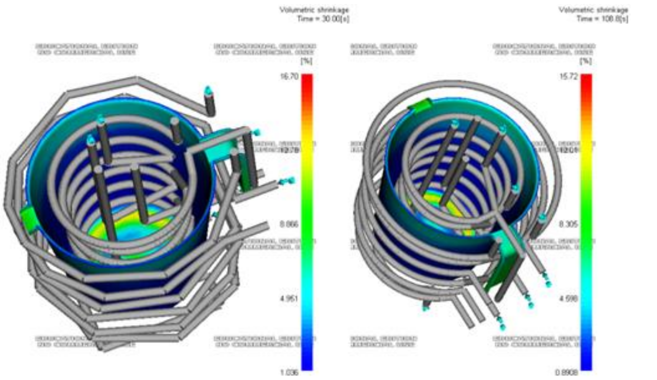
Figure 7: Temperature profile of part with (a) conventional combination with conformal, (b) fully conformal cooling channels

Volumetric shrinkage is inherent in the injection molding process, where the molded plastic part shrinks with cooling and solidifying of material. Shrinkage can sometime be to the extent of 20 percent by volume. Figure 8 (a) shows that in normal cooling channel, volumetric shrinkage is 17.01%, which is highest among all types of channels. This rapid increase of volumetric shrinkage and its spread around the part center is due to premature pressure removal [1]. This high value of shrinkage can be reduced by changing the sharp corners to radius and improve some part features. On the other hand, the value of shrinkage has been decreased to 16.72% with the use of a conformal cooling combination with baffle as shown in figure 8 (b). It shows that with the help of adding baffles to the conformal cooling channel, volumetric shrinkage can be reduced and made more uniform. In case of conventional cooling combination with conformal as can be seen in figure 9 (a), the result shows that volumetric shrinkage has been reduced slightly to 16.70 %. Apart from this, in the conformal cooling channel, the value of volumetric shrinkage has been decreased to 15.72% that is the lowest percentage among all cooling channels as shown in figure 9 (b). It points out that volumetric shrinkages are distributed more consistently and show more uniformity in conformal cooling channels [1]. Therefore, on the basis of these results from the analysis, it can be concluded that the mold using conformal cooling channels produces better quality of plastic parts in comparison of other cooling channels layouts.



(a) (b)

Figure 8: Volumetric shrinkage of part with (a) normal, (b) conformal combination with baffle, cooling channels

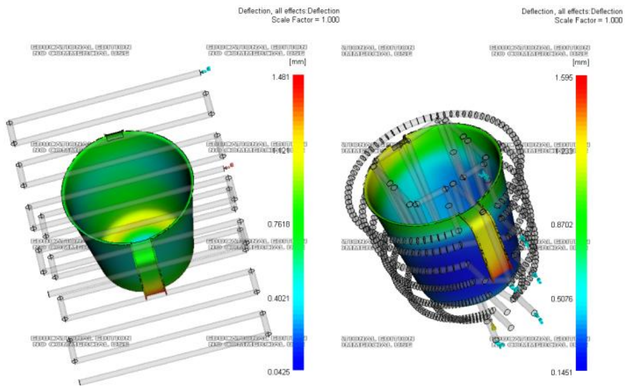


(a) (b)

Figure 9: Volumetric shrinkage of part with (a) conventional combination with conformal, (b) conformal, cooling channels

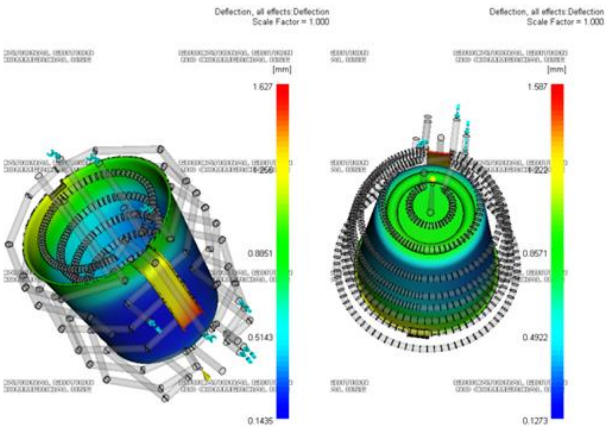
The result of warpage analysis shows that minimum warpage (deflection) of 1.481 mm was occurring with the use of normal cooling channels as can be seen in figure 10 (a), which is the lowest value as compared to other cooling channels. With the use of conformal cooling channel combination with baffle, the value of warpage increases to 1.595 mm as can be seen in figure 10 (b), because there was excessive and uniform cooling between the surfaces of the part. On the other hand, warpage increases significantly to 1.627 mm with the use of conventional cooling channels in combination with conformal as shown in figure 11 (a). It is because there was non-uniform cooling between the surfaces of the part. Furthermore, the results in figure 12 (b) shows that with the use of conformal cooling channel, the warpagereduced to 1.587 mm that was less as compared to both conventional cooling combinations with conformal and conformal cooling combination with baffle.

However, in comparison between the conformal cooling channel and normal cooling channel, the value of warpage (deflection) in conformal cooling channel is slightly higher than that of normal cooling channels, due to normal cooling design solves the part distortion problem in a better way in some cases depending on the complexity and geometry of the part, such as the part in our case study. However, in conformal cooling channel, this slight increase in warpage is not a big issue that could influence the main function of cooling due to having more advantageous conditions of lowest time required to freeze, lowest volumetric shrinkage and lowest sink mark. These advantages orgains of using conformal cooling channel outweigh the losses or disadvantages of such modest increase in warpage.



(a) (b)

Figure 10: Warpage on part with (a) normal, (b) conformal combination with baffle, cooling channels

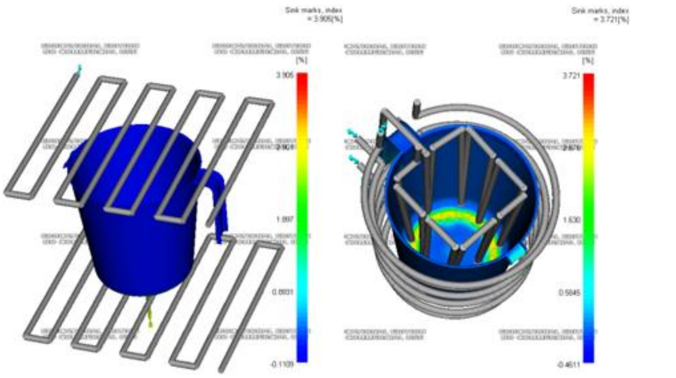


(a) (b)

Figure 11: Warpage on part with (a) conventional combination with conformal, (b) conformal, cooling channels

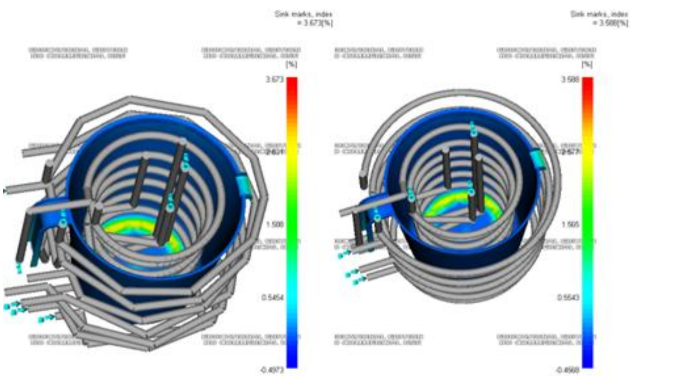
A sink mark or void occurs as a local surface depression or a vacuum bubble in the molding interior due to material shrinkage without enough compensation [6]. Sink marks occur at regions with high local shrinkage. Sink marks typically occur in moldings with thicker areas. Also, it happens because there may be possibility of unbalanced heat removal in cooling. The presence and location of sink mark or voids is detected by the appearance of marks on the surface. The results of this analysis show that in normal cooling channel, there was 3.905% deep sink marks on the outer surfaces as can be seen in figure 12 (a). However, this high percentage of sink mark can be controlled by increasing packing time and packing pressure or by reducing the part thickness. On the other hand, with the use of conformal cooling combination with baffle, the sink mark percentage decreased to 3.721% as shown in figure 12 (b).

Figure 13 (a) shows that, with the use of conventional cooling in combination with conformal cooling, the sink mark was further reduced to 3.673%, thus providing less sink marks than with normal and conformal combination with baffle cooling channels. Moreover, with a fully conformal cooling channel, the percentage of sink mark was 3.588% as can be seen in figure 13 (b) that was the lowest value when compared to the rest of the cooling channels used in the analysis. In this case, conformal cooling channel showed less sink mark due to having less volumetric shrinkage among all other types of cooling channels. Therefore, it can be stated that sink mark behavior depends on value of volumetric shrinkage.



(a) (b)

Figure 12: Sink Marks on part with (a) normal, (b) conformal combination with baffle, cooling channels



(a) (b)

Figure 13: Sink Marks on part with (a) conventional combination with conformal, (b) fully conformal cooling channels

Figure 14 and figure 15 summarize the results obtained from Autodesk Moldflow Insight analysis. Figure 14 shows the comparison for time to freeze and maximum temperature profile. Figure 15 shows the comparison of volumetric shrinkage, sink marks and the warpage values for all four cases of cooling channels.

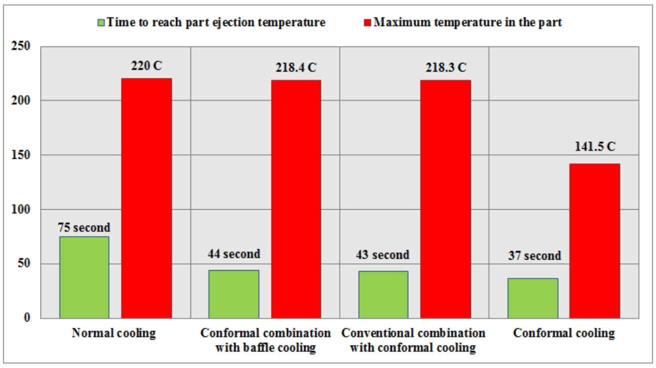


Figure 14: Comparison of time to reach ejection temperature and maximum temperature

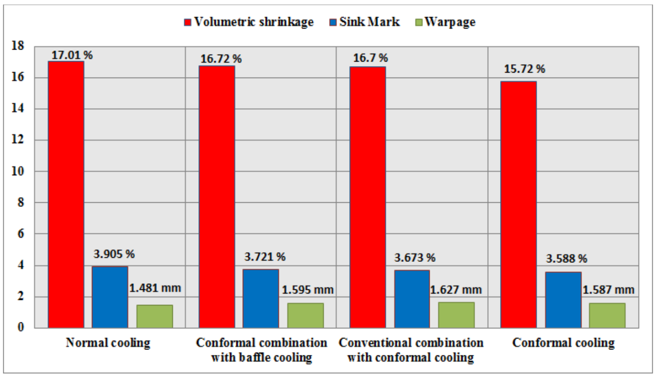


Figure 15: Comparison of volumetric shrinkage, sink mark and warpage

5. Conclusion

On the basis of comparison of the results shown in Fig 14 and Fig 15, it can be concluded that conformal cooling channel is the most suitable cooling system for the plastic part among other cooling channels. It leads to better cooling properties due to exhibiting the lower volumetric shrinkage and the lower sink mark percentage. It also provides the lowest time to reach the ejection temperature, which translates to lower cooling time and reduced overall cycle time. In addition, the analysis also shows that fully conformal cooling (both in cavity and core) also reduces the warpage in the parts compared to the case of conventional (in cavity) with conformal (in core) and also compared to the case of conformal (in cavity) with baffles (in core). The conformal cooling channel shows uniform cooling that makes it most favorable cooling system. Conformal cooling channels requires less cooling time and provides near uniform cooling of parts because these cooling lines are located to follow the part geometry in the mold. Use of an injection molding analysis software provides valuable information for plastic product and mold design in reducing time and cost of production especially for complex parts.

6. References

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