Int. J. Adv. Eng. Pure Sci. 2022, 34(3): 472-478
DOI: 10.7240/jeps.1168047

RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Comparison of Different Cooling Systems in Plastic Injection Molding

Plastik Enjeksiyon Kalıplamada Farklı Soğutma Sistemlerinin Karşılaştırılması

Oğuz GİRİT[1]

[1]*Marmara University, Faculty of Technology, Department of Mechanical Engineering, 34854, İstanbul, Turkey*

Abstract
Injection molding is preferred for plastic products due to its high efficiency. However, one of the most important factors after injection is the cooling of the part. Therefore, the cooling process considers being an essential part of the total molding time. Generally, the cooling process in plastic injection molds is done by circulating the cooling liquid through the holes opened in the radial and axial direction on the mold. However, in cases where the cooling is not at the wanted level, the efficiency is increased by placing high thermal conductivity coefficients materials in the molds. With the development of manufacturing methods, conformal cooling systems with cooling channels that follow the molded part geometry have emerged as an alternative to this method. However, this is an expensive method, and studies are ongoing. In this study, the mold cooling times were analyzed and compared with the help of the MoldFlow analysis program on a sample part with a conventional cooling system, as a result of placing a conformal cooling system and a material (insert) with a high thermal conductivity coefficient in the mold.
Keywords: Plastic Injection, Conformal Cooling Channels, Cooling of Plastic Injection Molding, Analysis of Mold Cooling Times

Öz
Enjeksiyon kalıplama, plastik ürünler için yüksek verimlilik sebebiyle tercih edilmektedir. Enjeksiyon sonrasında en önemli unsurlardan birisi de parçanın soğutulmasıdır. Soğutma işlemi, toplam kalıplama süresinin önemli kısmını oluşturmaktadır. Genellikle plastik enjeksiyon kalıplarında soğutma işlemi kalıp üzerine radyal ve eksenel yönde açılan deliklerden soğutma sıvısı dolaştırılması ile yapılır fakat soğumanın istenilen düzeyde olmaması durumlarında kalıplara ısı iletkenlik kat sayısı yüksek olan malzemeler yerleştirilerek verim arttırılmaya çalışılır. İmalat yöntemlerinin gelişmesiyle bu metoda alternatif olarak kalıplanan parça geometrisini takip eden soğutma kanallarına sahip olan şekil uyumlu (konformal) soğutma sistemleri ortaya çıkmıştır. Ancak bu pahalı bir yöntemdir ve üzerinde çalışmalar devam etmektedir. Bu çalışmada, klasik soğutma sistemine sahip ve üretimi devam eden örnek bir parçada MoldFlow analiz programı yardımı ile klasik soğutma sistemi, şekil uyumlu (konformal) soğutma sistemi ve kalıba ısı iletkenlik katsayısı yüksek olan bir malzeme (insert) yerleştirilmesi sonucunda kalıp soğutma sürelerinin analizleri yapılarak karşılaştırılmıştır.
Anahtar Kelimeler: Plastik Enjeksiyon, Konformal Soğutma Kanalları, Plastik Enjeksiyonda Soğutma, Kalıp Soğutma Sürelerinin Analizi

I. INTRODUCTION

The plastic injection molding method, which is used to make plastic components with acceptable geometry, is one of the industry's most cost-effective procedures for mass manufacturing [1]. With an injection press, the plastic material is melted and injected into the mold cavity, filling the cavity geometry. The finished object is made by cooling the molten plastic substance that fills the shape.

The injection molding process consists of four major stages: injection, packing, chilling, and ejection of the item from the mold [2]. The cooling step accounts for 50 to 80 percent of the total cycle duration [3]. Although cooling time can account for more than 60% of the molding cycle, reducing cooling time would greatly enhance production rate and save costs [4]. Uncontrolled cooling time reduction, on the other hand, may result in severe shrinkage and warpage of the components [5]. As a result, several investigations are being conducted in order to minimize cooling time while maintaining part quality. The most crucial of them is altering the shape of the cooling channels [6].

In plastic injection molding, straight holes are drilled in the mold steels in the radial and axial directions to cool the molten plastic, and the cooling process is provided by circulating liquid (usually water) through these holes [7]. However, the number and diameter of these holes vary according to the part and mold design to be injected, and the wanted efficiency may not be achieved due to design restrictions [8].

Corresponding Author: Oğuz GİRİT, Tel: +90 532 4352100, e-posta: ogirit@marmara.edu.tr

Submitted: 29.08.2022, **Revised:** 23.09.2022, **Accepted:** 23.09.2022

There may be regions in a molded part that increase cooling times [9]. In this case, materials with high thermal conductivity coefficient inserts are usually placed in the mold areas, increasing the cooling time.

The conformal cooling system with cooling channels following the part's geometry has emerged with the development of additive manufacturing methods and the production of parts with complex geometries [10]. In this regard, with the study of Hong-Seok Park et al., it has been observed that there is a 30% time-saving in cooling time and improvements in part quality in a mold in which a conformal cooling system is used compared to a mold with a conventional cooling system [11].

Simulation studies and testing prototype conformal cooling patterns using various methodologies have been the focus of conformal cooling system research [12].

Konsulova-Bakalova used the thermal simulation program SolidWorks Simulation to examine conformal cooling channels with circular and elliptical sections. He found that the component's cooling time was improved utilizing conformal cooling channels, which resulted in a decrease in manufacturing cycle time and a rise in part quality [13].

Many studies have proposed strategies for designing cooling channel sections optimally in conformal cooling systems [14-15]. Furthermore, novel methods for improving heat transport have been developed and verified by analytical modeling and simulation [16].

In this study, numerical analyzes of the cooling systems of a sample product, which has a conventional cooling system and whose production continues, were made, and the results were interpreted.

II. MATERIAL AND METHOD

The product used in the analysis is shown in Figure 1. The product dimensions 505 x 178 x 337 mm and is 4 mm thick. There are 2° angles on the side surfaces of the product. Transparent Polycarbonate (PC) material is used for the product.

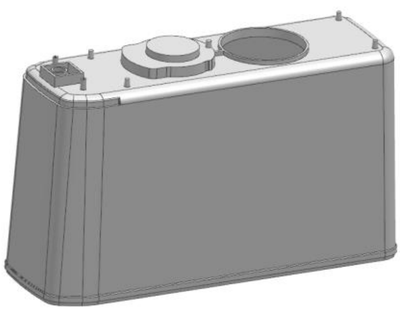

Figure 1. Product

There are four common types of conformal cooling channels in the literature: spiral conformal cooling channels [17-18], zigzag type conformal cooling channels [17], scaffold conformal cooling channels [19], and Voronoi diagram type [20].

Wang et al. The approach of forming spiral channels for conformal cooling systems [17] and the cooling channels obtained from spiral curves have concluded that the cooling liquid flow rate almost does not decrease [17]. Therefore, in this study, spiral conformal cooling channels were used.

The size of the cooling channels was established for the conformal cooling system analysis based on the wall thickness of the plastic portion [21]. For example, for a wall thickness of 4 mm, the channel diameter is 12 mm, the distance between the centers of the channels is 30 mm, and the distance between the channel center and the mold surface is 14 mm (Figure 2a). In conformal cooling channels, a design method is used in which the distance between the channels and the distance between the mold surface is kept constant [22]. In addition, many researchers are working on various algorithms to automate the cooling channel design in the conformal cooling system [23].

The mold materials and properties used in the shape-matched cooling system analysis are shown in Table 1.

Table 1. Used material properties of the conformal cooling system

Material	*Density g/cm³*	*Specific Heat J/Kg-K*	*Thermal conductivity W/ m-K*
Mold Steel	7,85	465	39,5

In the conventional cooling system and insert cooling analyses, the cooling channels were used when the mold was produced, as shown in Figure 2b.

To make a comparison, in the cooling system analysis in which material with a high thermal conductivity coefficient is used, the cooling channels are the same as the cooling channels used in the conventional cooling system. Therefore, only the insert material shown in Figure 3 has been changed. The properties of the insert material are shown in Table 3.

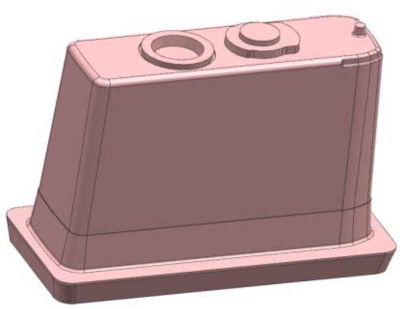

Figure 3. Insert

(a) (b)

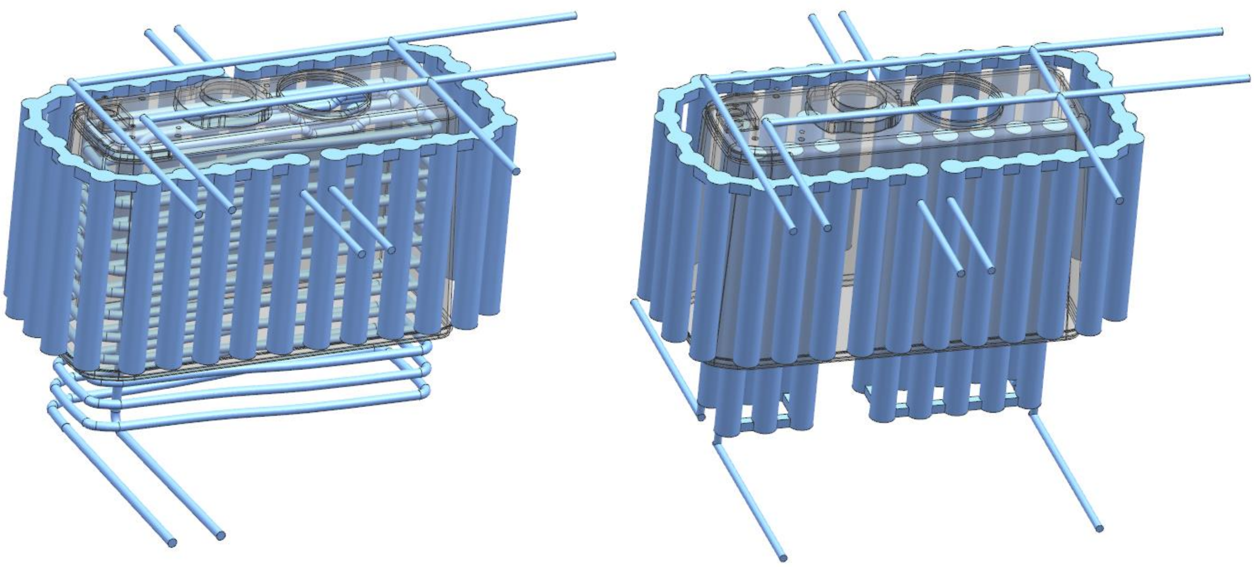

Figure 2. Conformal cooling system(a), Cooling system of produced product (b)

Table 2. Material properties of the insert

Material	*Density (g/cm³)*	*Specific Heat J/Kg-K*	*Thermal conductivity W/ m-K*
Beryllium-Copper (BeCu) Insert	8.415	360	130

The analysis results examined the cooling time and the amount of distortion on the plastic part.

2.1. Pre-Analysis

The final weight of the product is 80,215 grams. Plastic material properties are shown in Table 3.

Table 3. Material properties of the molded plastic

Number	*Characteristic feature*	*Value*
1	Solid density (g/cm³)	1.05
2	Melt density (g/cm³)	0.19
3	Thermal conductivity (W/m.°C)	0.25
4	Heat capacity (J/kg.°C)	2302

The mesh structure of the plastic product is shown in Figure 4. There are 166032 elements in the plastic product.

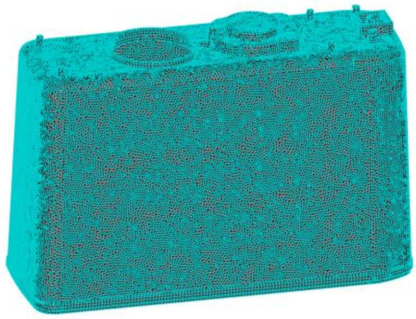

Figure 4. Mesh structure

In the first stage, a "Gate Location" analysis was performed to determine the injection point (Figure 5), and it is seen that the part base is suitable accordingly.

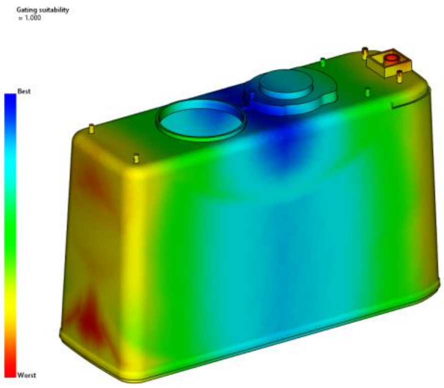

Figure 5. Gate location analysis

"Molding Window" analysis was performed to determine the injection time and melt temperature (Figure 6).

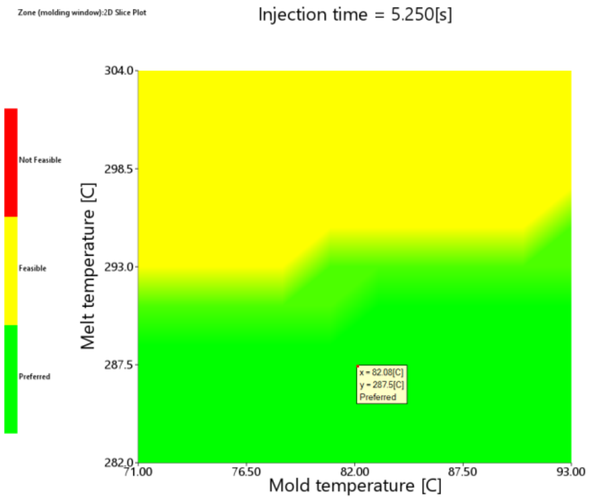

Figure 6. Molding window analysis

The injection time is shown on the x-axis and the melt temperature on the y-axis.

As shown in Figure 6, the analysis result is separated into three areas: green, yellow, and red. As a result, the melt temperature in the green zone, which is the ideal point, is 287.5 °C, the mold temperature is 82 °C, and the injection duration is 5.25 seconds.

As the third step, "Fill" analysis is performed to control the part's selected filling time and injection point. Finally, as shown in Figure 7, the part is filled.

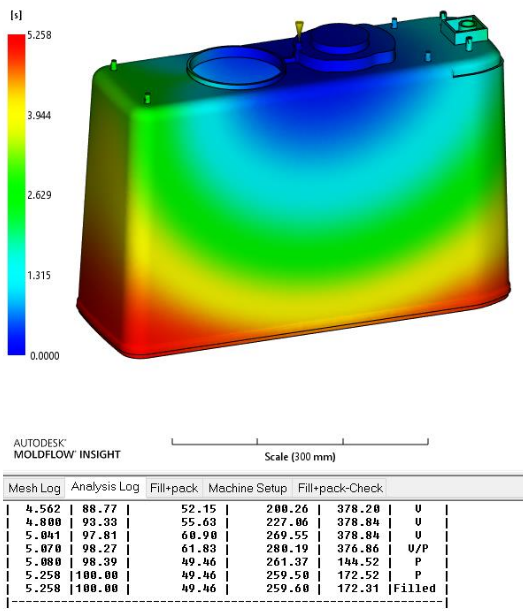

Figure 7. Fill analysis

As a result of these analyses, the cooling analyses' boundary conditions are shown in Table 4.

Table 4. Boundary conditions of the cooling analysis

Injection Temperature	287.5 °C
Ejection Temperature	160 °C
Mold Temperature	82 °C
Injection Time	5.25 s

In order to make the analysis compatible with the application, mold plates were added to the analysis (Figure 8).

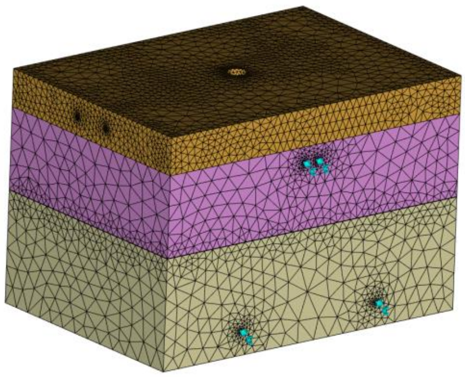

Figure 8. Mesh structure of the mold plates

III. RESULTS AND CONCLUSIONS

As a result of the analysis, the cooling times in different cooling systems and the temperature distribution resulting from this were determined. The temperature distribution at the time of removal in cooling systems is shown in Figure 9a for conformal, Figure 10a for insert, and Figure 11a for the conventional cooling system. The amount of warpage during and after the cooling process is shown in Figure 9b for conformal, Figure 10b for insert, and Figure 11b for the conventional cooling system. For all cooling systems, the temperature in all parts of the plastic part has dropped below the ejection temperature.

The cooling and cycle times and the multiplicative amounts obtained as a result of the analyzes for all cooling systems are shown in Table 5. In the analysis results, the molds with the longest cooling time than the shortest cooling time are respectively the conformal cooling system (25.96 s), the cooling system with the material with a high thermal conductivity coefficient (30 s), and the conventional cooling system (68.57 s). In terms of distortion, it was determined that the molds used a conformal cooling system (2,908 mm), a cooling system with high thermal conductivity coefficient material (3,876 mm), and a conventional cooling system (5.59 mm).

Table 5. Cooling Times and Warpages for cooling systems

Type of cooling system	*Cooling time, s*	*Warpage, mm*
Conformal	25,96	2,908
Insert	30	3,876
Conventional	68,57	5,59

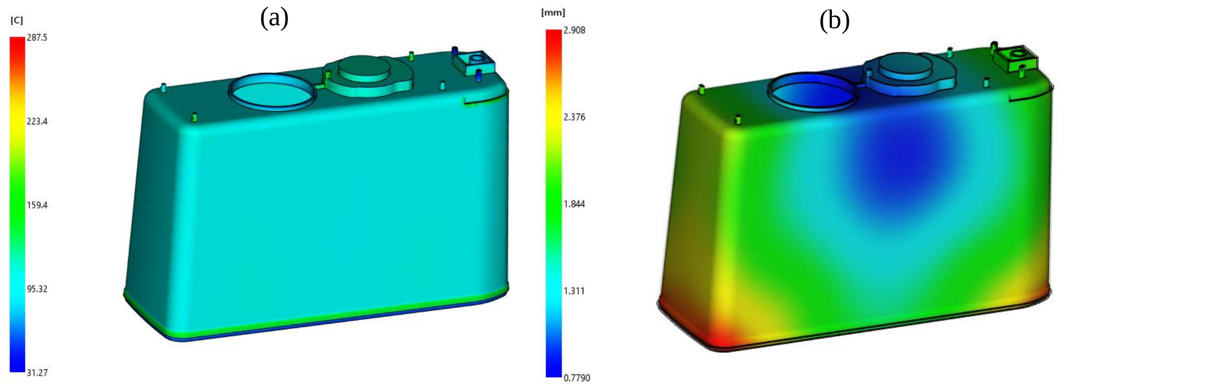

Figure 9. Ejection temperature at the ejection time of conformal cooling system (a), Warpage (b)

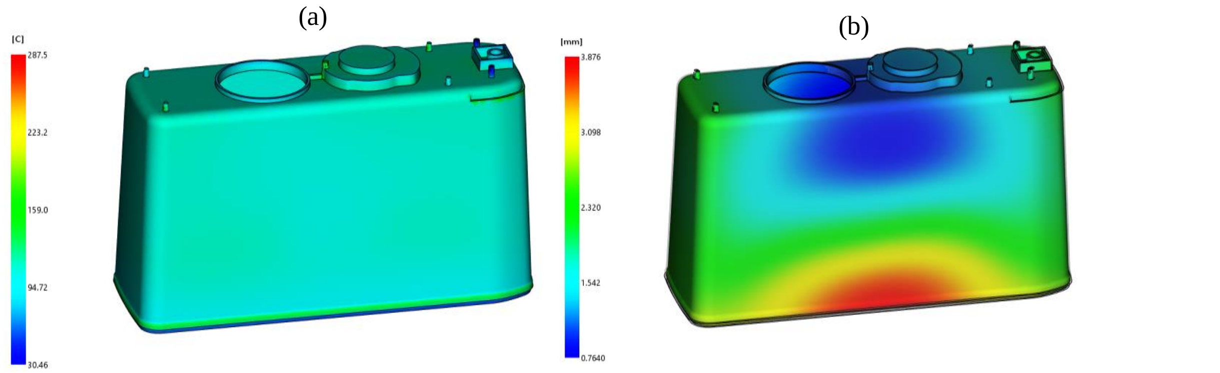

Figure 10. Ejection temperature at the ejection time of insert cooling system (a), Warpage (b)

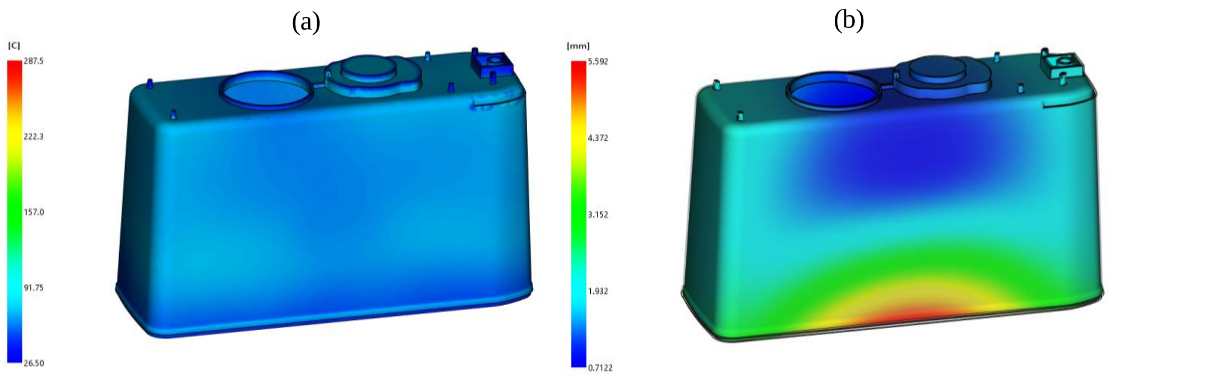

Figure 11. Ejection temperature at the ejection time of conventional cooling system (a), Warpage (b)

According to the analysis results, when the conformal cooling system and the conventional cooling system are compared, there is a 62% reduction in cooling time and a 47.97% reduction in the amount of warpage.

When the insert cooling system and the conventional cooling system are compared, there is a 56.25% reduction in cooling time and a 30.66% reduction in the amount of warpage.

When the conformal cooling system and the cooling systems with high thermal conductivity coefficients are compared, there is a reduction of 13.46% in the cooling time and 25% in the amount of warpage.

As a result of the analysis, it is seen that the conformal cooling system has the highest cooling efficiency, followed by the cooling system with the thermal conductivity coefficient.

The cooling efficiency and performance of the cooling systems used in plastic injection molding were compared with the analyzes made. Numerical analyzes were carried out with the Moldflow program using models prepared according to three different cooling systems. As a result of the analysis, the cooling times and the amount of warpage in the plastic part during and after the cooling were determined. Since the conventional cooling system analyses were made in a mold produced and currently used, the results obtained were compared and verified. This study can be improved by producing molds and experimental results to verify the conformal and insert cooling systems.

As a result of the analysis, the lowest values were found for the cooling time and the amount of warpage in the conformal cooling system. The results obtained in the cooling system with thermal conductivity coefficient are higher than the conventional cooling system, even if it is lower in performance and efficiency compared to the conformal cooling system.

The results obtained in the conformal cooling system depend on the homogeneous cooling of the part, flow rates, and pressure drops in the cooling ducts. It is evaluated that the efficiency in the cooling system with the thermal conductivity coefficient is due to the high thermal conductivity of the material used.

Although studies on conformal cooling systems that emerged with the development of manufacturing methods continue. The high production costs and low surface quality of the parts produced by additive manufacturing significantly reduce the usability of the parts in plastic injection molds. Various studies are underway to overcome these disadvantages [24,25]. Determining the thermal zones that increase the cooling times in the molded products and placing the materials with a high thermal conductivity coefficient increases the efficiency by reducing the cooling times significantly. The manufacturability of these parts is more convenient than the parts produced with additive manufacturing.

Studies to increase mold efficiency in plastic injection molding depend on the product geometry and material to be molded. Therefore, the solutions found for different product geometries and materials can vary according to each other.

ACKNOWLEDGMENT

I am grateful to Akın KANMAZ for aids.

REFERENCES

[1] Kim, H.K.; Sohn, J.S.; Ryu, Y.; Kim, S.W.; Cha, S.W. Warpage Reduction of Glass Fiber Reinforced Plastic Using Microcellular Foaming Process Applied Injection Molding. *Polymers* (2019), 11, 360.

[2] Shayfull, Z.; Sharif, S.; Zain, A.M.; Ghazali, M.F.; Saad, R.M. Potential of Conformal Cooling Channels in Rapid Heat Cycle Molding: A Review. Adv. *Polym. Technol.* (2014), 33.

[3] S.H.Masood and N.N.Trang, Thermal analysis of conformal cooling channels in injection moulding, *Proceedings of the 3rd BSME-ASME International Conference on Thermal Engineering*, Dhaka, Bangladesh, (2006).

[4] J.Shoemaker, Moldflow Design Guide: A resource for plastics Engineers, vol.10, *Hanser Publishers*, (2006).

[5] J.Meckley and R. Edwards, A Study on the design and effectiveness of corformal cooling channels in rapid tooling inserts, *The Technology Interface Journal*, vol. 10, no.1, (2009).

[6] Y. Wang, K.-M. Yu, C. C. L. Wang, and Y. Zhang, Automatic desing of conformal cooling circuits for raid tooling, *CAD Computer Aided Design* vol.43, no. 8, pp. 1001-1010, (2011).

[7] Wang G. L., Zhao G. Q. and Wang X. X., Heating/cooling channels design for an automotive interior part and its evaluation in rapid heat cycle molding, *Materials & Design*, 59: 310-322, (2014).

[8] Altaf K., Raghavan V. R. and Rani A. M. A., Comparative thermal analysis of circular and profiled cooling channels for injection mold tools, *Journal of Applied Sciences*, 11(11): 2068-2071, (2011).

[9] Berger, G.R.; Zorn, D.; Friesenbichler, W.; Bevc, F.; Bodor, C.J. Efficient cooling of hot spots in injection molding. A biomimetic cooling channel versus a heat-conductive mold material and a heat conductive plastics. *Polym. Eng. Sci.* (2019), 59, E180–E188.

[10] Rajamani, P.K.; Ageyeva, T.; Kovács, J.G. Personalized Mass Production by Hybridization of Additive Manufacturing and Injection Molding. *Polymers* (2021), 3, 309.

[11] H. S. Park, N. H. Pham, Design of conformal cooling channels for an automotive part, *International Journal of Automotive Technology* 10 (1) (2009), 87-93.

[12] A.Safifullah, Sç Masood, and I. Sbarski New cooling channel design for injection molding, in *Proceedings of the World Congress on Engineering*, (2009).

[13] Application of solidworks simulation for design of cooling system for injection molding, *International Virtual Journal*, In press.

[14] Lin ZC, Chou MH (2002) Design of the cooling channelsin monrectangular plastic flat injection mold, *J Manuf Sys* 21(3): 167-186.

[15] Ahari H,Kajepuor A, Bedi S (2011) Manufacturing optimization of laminated tooling with conformal cooling channels, *Rapid Prototype J* 17(6): 429-440.

[16] Altaf K, Raghavab VR,Rani AMA (2001) Comparative thermal analysis of circular and profiled cooling channel for injection mold tools, *J Appl Sci* 11 (11): 2068-2071.

[17] Y. Wang, K.-M. Yu, C. C. L. Wang, Spiral and conformal cooling in plastic injection molding. *Computer-Aided Design*, vol. 63 (2015), 1-11.

[18] H. S. Park, N. H. Pham, Design of conformal cooling channels for an automotive part.

International Journal of Automotive Technology, vol. 10, (2009), 87-93.

[19] Au, K. M. and K. M. Yu, A scaffolding architecture for conformal cooling design in rapid plastic injection moulding. *The International Journal of Advanced Manufacturing Technology*, vol. 34, (2007), 496-515.

[20] Y., Wang, K.-M. Yu, C. C. L. Wang, Y. Zhang, Automatic design of conformal cooling circuits for rapid tooling. *Computer-Aided Design*, vol. 43, (2011), 1001-1010.

[21] Jahan S. A., Wu T., Zhang Y., Zhang J., Tovar A. And Elmounayri H., Thermo-mechanical design optimization of conformal cooling channels using design of experiments approach, *Procedia Manufacturing*, 10: 898-911, (2017).

[22] Göktaş M., Güldaş A. and Bayraktar Ö., Cooling of plastic injection moulds using design adaptive cooling canals, *International Conference on Engineering and Natural Science s (ICENS 2016)*, Sarajevo, 1987-1993, (2016).

[23] J. M, Jauregui-Becker, G. Tosello, F. J. Van Houtena, H.N. Hansenb, Performance evaluation of a software engineering tool for automated design of cooling systems in injection moulding, *Procedia CIRP* 7, (2013), 270-275.

[24] Kuo, C.C.; Qiu, S.X.; Lee, G.Y. Characterizations of polymer injection molding tools with conformal cooling channels fabricated by direct and indirect rapid tooling technologies. *Int. J. Adv. Manuf. Technol.* (2021), 117, 343–360.

[25] Gibson, L.J.; Ashby, M.F. Cellular solids: Structure and properties. *Cambridge Univ. Press* (1997), 2, 510.