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A Simulation Study of advanced cooling strategies to optimize part quality

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ABSTRACT

In thermoplastic injection moulding process, the cooling strategies are one of the most essential aspects to take in to account, because it has significant influence on both production capacity and the quality of the plastic part. With increasingly demand of electrical products i.e. fittings, junction boxes and distribution equipment's, injection moulding remains the most prevalent method for producing plastic parts. The main objective of this study was to determine an optimum and efficient strategy where conformal cooling channels are investigated to have both cooling time (Cool Analysis) and improve quality of the part (Warp Analysis) means of performing finite element analysis (FEA) and heat transfer analysis. Design of mould component was carried out using commercial CAD software Unigraphics Nx 8.0. For FEA commercial CAE software called Solidworks Plastics 2015 is used. The analysis show that the component with conformal cooling channels exhibited a more uniform surface temperature, significantly reduced cycle time and less warpage, when compared to a traditionally cooled mould design.

***Keywords**: Thermoplastics; Finite element analysis; Distribution equipments; Heat transfer analysis.*

1.Introduction

The injection moulding process is one of the most common manufacturing technique to produce thermoplastic parts in the plastic industry. In this process granular plastic resin and suitable additives are melted and then forced into a mould/die, where the material forms its final shape. Injection moulding process is well known for manufacturing various shapes and complex geometries at low cóst. This is a cyclic process which involves four essential stages: the filling of the moulding cavity, the melt packing, the solidification of the part and the ejection [1]. The cost-efficiency of the process is dependent on the time spent in the moulding cycle. Correspondingly, the cooling phase is one of the most significant steps, science it determines the rate at which the parts are produced [2]. Proper thermal heat balance of injection moulding process is not only necessary to increase part quality but also influences production rate, the most used cooling involves the manufacturing traditional straight line cooling system which detains some limitation in cooling for proper thermal heat balance/heat extraction. Most of the researches on traditional straight cooling systems for injection moulding have been directed toward optimal cooling system design to improve the effectiveness and efficiency of cooling [3]. Conformal cooling is a promising alternative with growing acceptance. Cooling channels follow with the part's contours to increase the heat adsorption away from molten plastic to facilitate faster and more uniform cooling [4]. Such temperature control in moulding has capacity to produce parts with low residual stresses and warpage (i.e. better quality) and reduce overall mould cycle time [5].

The first part of this investigation is to find the appropriate material by considering various chemical and physical properties to meet requirements of the selected electrical component (VTPM Cover).Successively, a study on exact material selection i.e. Polypropylene (PP), Acrylonitrile butadiene styrene (ABS) & Poly Carbonate (PC) was performed and finally it is concluded that PC is the material to manufacture the component. Then a comparative study on traditional cooling systems and conformal cooling system is conducted to analyze the best possible solution for the component to enhance quality and machinability criteria.

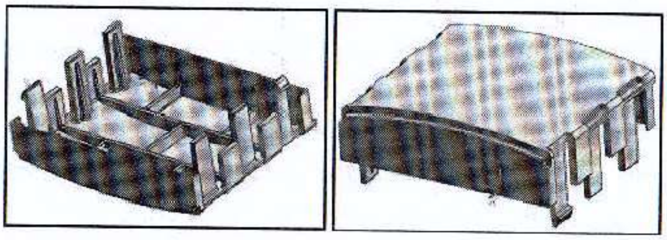
2. Literature Review

For determining the optimal conformal cooling channel configuration, parametric analyses were carried out to propose with in the engineering design. Mostly all of the analysis carried out intended for part to cooldown in the minimum time with uniform part temperature (i.e. quality) to have less warpage and shrinkage. Alban Agazzi et al. have proposed a new approach of cooling channel design for determination of the cooling system of a 3D industrial part. Based on morphological concepts, the idea of regulation of the temperatures of the polymer and the mould by a cooling surface is introduced [1]. A 3D CAD model of core and cavity of typical component was developed that required moulding the part [2]. These core and cavity halves were used in the FEA and thermal analyses, first determining the best location for the gate and later the cooling channels, both factors were seen to influence cycle time. A reduction in time spent on cooling the part before ejected would drastically increase the production rate; hence reduce cost [2]. There is of various cooling channel system configuration which is carried out in terms of time to ejection temperature (time to freeze), shrinkage, temperature profile, warpage, sink marks, to determine uniform cooling, minimum cycle time, less warpage and shrinkage [3]. It is described that three dimensional printing technology is a desktop manufacturing process that allows to create internal geometry with complex cooling passage [4,5]. A finite difference simulation was used to study conformal cooling channel design. A direct comparison of the mould surface temperature of a 3D Printed mould with conformal channels and a mould with conventional straight channels was done [5]. The design of a plastic injection mould for producing warpage testing specimen and performing thermal analysis for the mould to access on the effect of thermal residual stress in the mould. They believed that warpage is the main problem that exists in thin shell feature [6].

The literature research revealed that a considerable effort has been carried out concerned to the conformal cooling channel design to determine best cooling strategy, the latter is clearly an evidence of how important this traditional system is in when concerning the overall mould efficiency and operability and therefore a proposed methodology should be addressed in order to establish the detrimental factors and performance efficiency of both the system design and the part quality signatures.

3. Component design and analysis

In this article, a thermoplastic part has been designed using Unigraphics Nx-8.0. (Advanced high- end CAD/ CAM/CAE Software package by Siemens), as shown in Fig. 1. The wall thickness of the component is 2mm



(a) (b)

Fig. 1. CAD Model of thermoplastic component

with overall dimensions approximately 9.50*54.40*22.30mm (length, width, height). The STEP (Standard for the Exchange of Product model

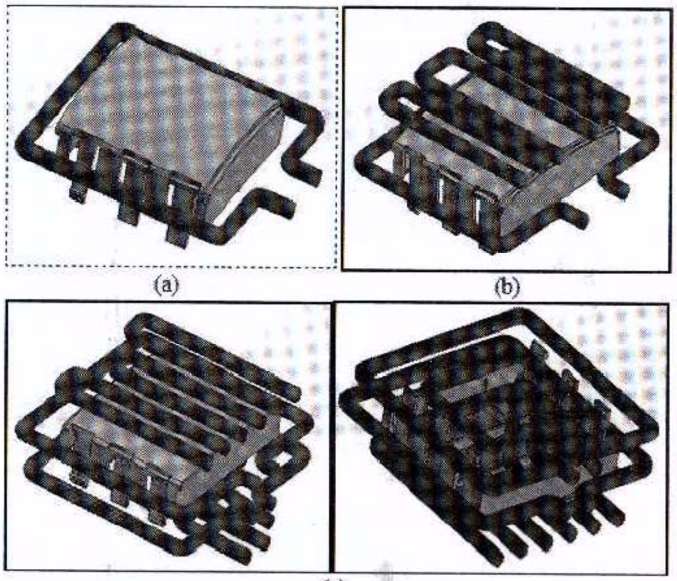


Fig.2. Cooling channel design (a) Traditional straight line cooling channel (configuration 1), (b) Traditional straight line cooling channel (configuration 2), (c) Conformal cooling channel.

data) of a 3D CAD model of the component has been imported to Solidworks Plastics (Advanced CAE analysis Software by Dassault System) for analysis purpose.

Poly carbonate (Generic material of PC) and Steel (420SS) has been assigned for thermoplastic component and injection mould die respectively, shown in Table 1. Melt temperature and mould surface temperature have been kept at 305 C and 95 C respectively. Water was used as a cooling fluid for the analysis because it was considered the appropriate media, also it is economical and environment friendly; the minimum coolant temperature was kept at 85 C, Fig. 2 shows the three systems of cooling channels that are considered in this analysis. All cooling channels were moulded to have the same diameter of 5 mm. In this channel design the average distance to the wall cavity and the center line distance between the cooling channels were 8 mm and 12 mm, respectively. The coolant Reynolds number was calculated to be 14855 ensuring the fully developed turbulent flow throughout all cooling channels.

Solid works Plastics has been used to design cooling channels to achieve cool, flow, pack, and warp analysis. Hybrid meshing was used with average number of mesh elements being 651087, the mesh quality was improved by using manual mesh techniques. Hence the maximum aspect ratio was enhanced significantly from 26 to 12.5 %, in order to generate proper discretization domain.

4. Results and Disscussion

The analysis carried to establish the most suitable cooling strategy has accomplished the study of three different cooling strategies namely traditional cooling (configuration 1), traditional cooling (configuration 2)

Table 1. Mould Polymer and Mould Material Properties

Mould Polymer Properties (Generic Poly carbonate)	**Mould Material Properties (Steel 420SS)**
Specific Heat: Constant - 1900 J / (Kg-K) Thermal Conductivity: Constant - 0.24 W/(m-K)	Specific Heat: Constant - 4.62e+006 erg/(g-C) Thermal Conductivity: Constant - 2.5e+006 erg / (sec-cm-K)
Elastic Modulus: Constant - 2.3e+010 Poisson's Ratio: Constant - 0.4	Density: Constant - 7.73 g/cm^3 Shear Modulus: Constant - 7.9e+011 dyne/cm^2
Thermal Ex. Co-efficient: Constant - 7.3e-005 °C Melt Flow Rate - 20 cm^3/10min % of Fiber - NULL Max. Shear Rate - 40000 1/s Max. Shear Stress - 500000 Pa Stress optical coefficient - 8.2e-011 to 8.2e-013 1/Pa	Thermal Ex. Co-efficient: Constant - 1.3e-005 Young's Modulus: Constant - 2.1e+012 dyne/cm^2 Poisson's Ratio: Constant - 0.28

and conformal cooling channel design. The analysis outcome shows that the time required for the part to complete cooling and proper ejection to occur in the traditional cooling channel (configuration 1), took around 22.09 seconds, as shown in Fig. 3 (a). It shows that this cooling configuration takes more time, because it consists of a straight line cooling channel structure. This strategy has some restrictions in terms of geometric complexity thus introducing non-uniform cooling and then poor part quality.

However, time required for the cooling reduced to around 12.49 seconds with the use of traditional cooling channel (configuration 2), as shown in Fig. 3 (b). Also the results show that there is significant improvement in what concern reduction of cooling time by using the same channel diameter with different cooling configuration. The cooling time is further reduced to about 9.09 seconds using the conformal cooling channel design, as shown in Fig. 3 (c) moreover, it

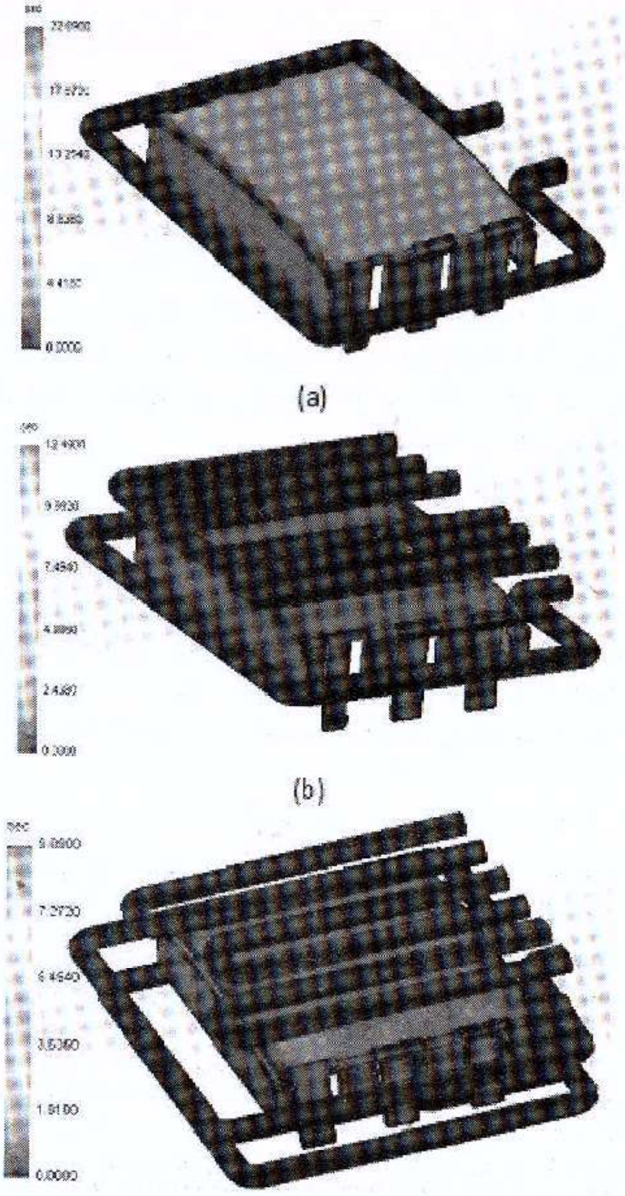


Fig.3. Time required for the complete cooling (a) Traditional straight line cooling channel (configuration 1), (b) Traditional straight line cooling channel (configuration 2), (c) Conformal cooling channel design.

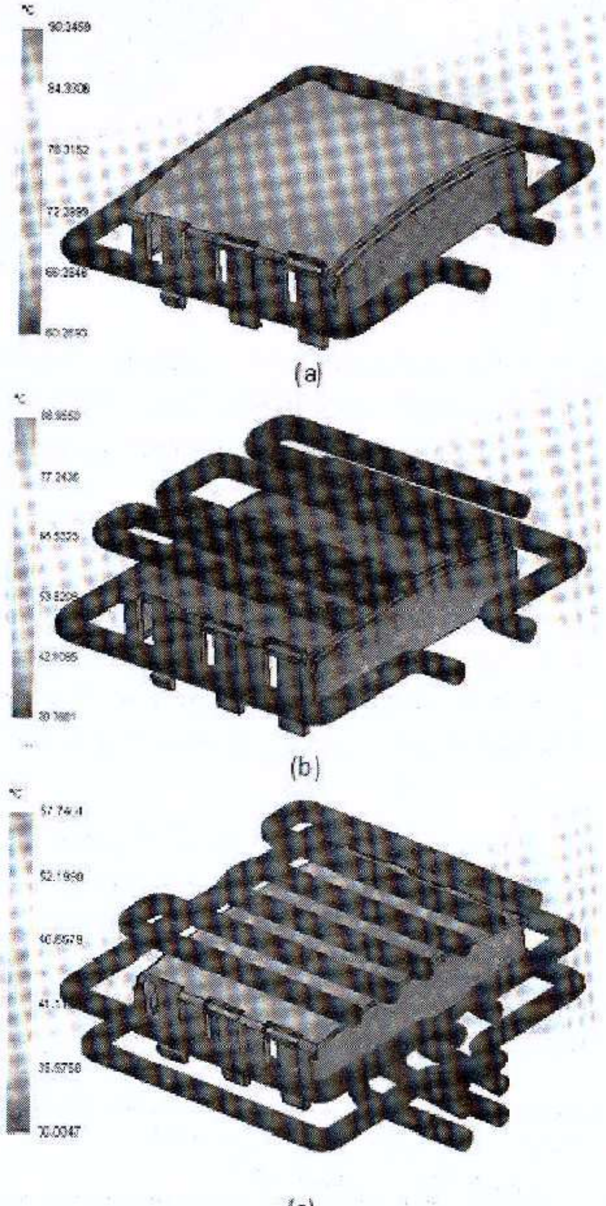


Fig.4. Mould surface temperature at the end of cooling (a) Traditional straight line cooling channel (configuration 1), (b) Traditional straight line cooling channel (configuration 2), (c) Conformal cooling channel design.

should be referred that is assume the lowest value when compared to the remaining of the analysis results.

The latter, is believed to occur of the conformal cooling channels follows the part contours enabling a faster and more uniform heat removal from the areas of the mould with a higher thermal load. These results show that temperature across the part thickness is exceptionally reduced as compared to the traditional cooling (configurations 1 and 2), thus emphasizing the conformal cooling potential as a strategy for minimizing residual stresses within the part subjected to service load.

Furthermore, by using the conformal cooling channel design the mould temperature range at the end of cooling is more uniform in each side of the component shown in Fig. 4. The results show that there is a mould temperature variation range between 30.03 C to 57.74 C with the use of conformal cooling channel design. On the other hand, in traditional cooling channel (configuration 1 and 2) the mould temperature lies between 60.26 C to 90.34 C and 30.39 C to 88.95 C respectively, as shown in Fig. 3 (a, b). These traditional straight channels are unable to provide temperature uniformity all around the component, a fact that may affect the overall quality of the manufactured component and will contribute significantly to mould thermal fatigue and thus reducing its overall durability. On the other hand, the temperature is uniformly dispersed with the use of conformal cooling channel design, as shown in Fig. 4 (c). Therefore it can be concluded that conformal cooling channels provide better temperature reliability and uniformity than the traditional cooling configurations especially for the complex geometrical components.

As warp analysis result show minimum warpage (Total deflection) is about 0.43mm with box effect (uniformity) that was occurring with the use of conformal cooling channel, as shown in Fig. 5 (c). Moreover, it can be said that it is a minimum value as compared to the other cooling configurations. The warpage rate rises to 0.76mm in traditional cooling channel (configuration 1) and it can be seen in Fig. 5 (a). On the other hand warpage is increased extensively to 1.02mm with the use of traditional cooling channel (configuration 2), as shown in Fig. 5 (a). The latter is consistent with inappropriate cooling between the surfaces of the component that lead to non-uniform deflection/warpage. Result show that with the use of conformal cooling channel designs it is possible to have less warpage as compared to the other cooling configuration.

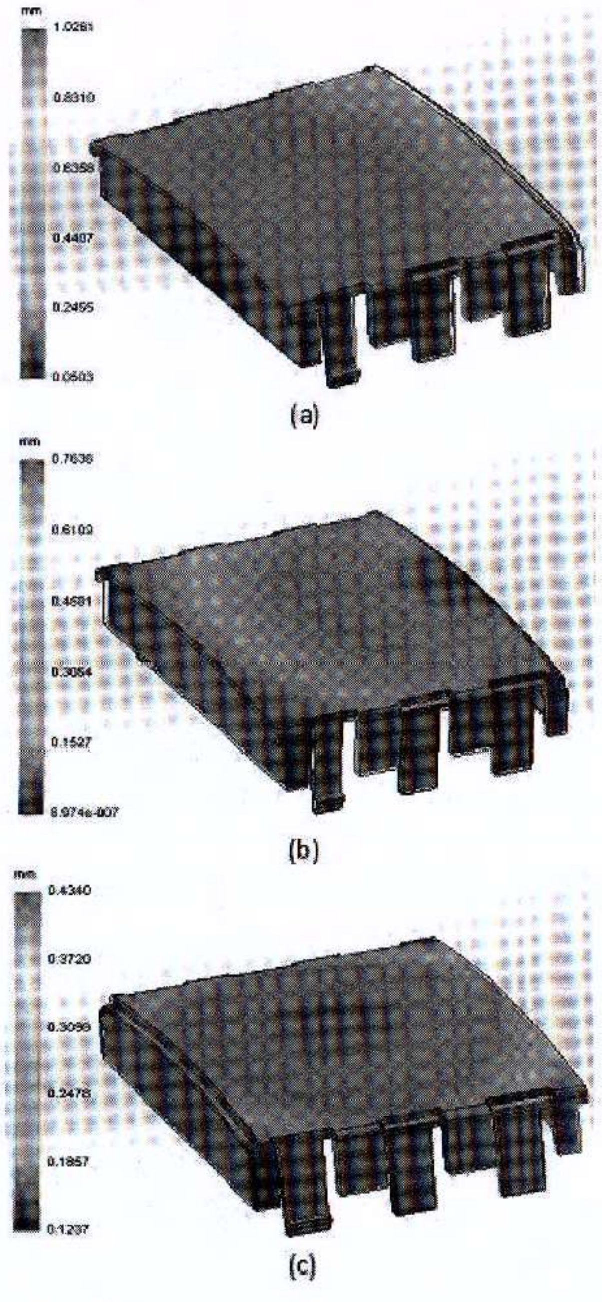


Fig. 5. Total warpage on component (a) Traditional straight line cooling channel (configuration 1), (b) Traditional straight line cooling channel (configuration 2), (c) Conformal cooling channel design.

The volumetric shrinkage is an essential factor in the thermoplastic injection moulding, science shrinkage is bounded to occur it may be influenced by improper mould filling, must be commenced during packing stage and is again highly influenced with a bad cooling strategy. The Fig. 6 (a) shows that the volumetric shrinkage is 11.93% when traditional cooling channels (configurations 1) is used. The maximum percentage of volumetric shrinkage is due to an early pressure removal and non-uniform cooling. On the other hand, the volumetric shrinkage is decreased up to 10.97% in traditional cooling channel (configurations 2), as shown in Fig. 6 (b). Results show that reduction in the shrinkage percentage is possible with the use of a more uniform and proper cooling configuration. With the conformal cooling channel design the volumetric shrinkage has been reduced up to 9.51 %, and also it reaches the lowest shrinkage value as compared to the other cooling configurations as shown in Fig. 6 (c). It shows that on the basis of these analyses with the conformal cooling channel configuration the shrinkage is more consistent and uniform and thermoplastic components can be produced with better quality as compared to traditional cooling channel configuration.

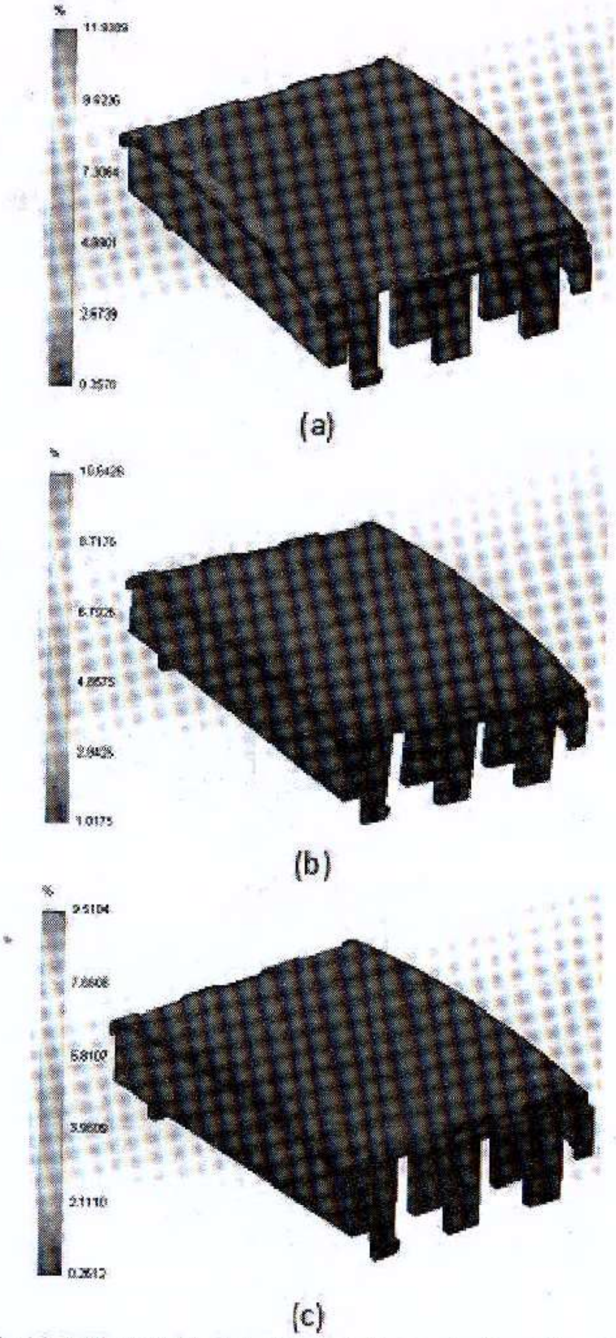


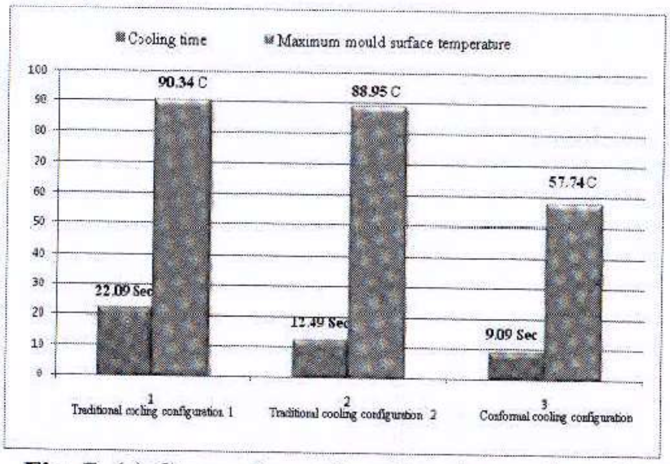
Fig. 6. Volumetric shrinkage at the end of packing (a) Traditional straight line cooling channel (configuration 1), (b) Traditional straight line cooling channel (configuration 2), (c) Conformal cooling channel design.

After the complete comparative analysis in Solidworks plastics (FEA analysis) for traditional cooling system and conformal cooling system all attained results are summarized. Comparison of cooling time with maximum mould surface temperature at the end of cooling is shown in Fig. 7 (a) and comparison between total warpage with volumetric shrinkage at the end of packing is shown in Fig 7 (b)

5. Conclusion

The investigation carried out intended to determine the best possible solution with comparative analysis of traditional cooling and conformal cooling systems in terms of proper material selection and by considering various process parameters (i.e. Coolant temp, mould temp, mould material). With an aim to determine which cooling configuration is appropriate for selected electrical component (VTPM cover), also by providing positive results such as uniform cooling, minimum cycle time, less warpage and shrinkage.

The analysis result shows that the use of conformal cooling system to manufacture thermoplastic injection moulding component is one of the most suitable method. With the use of conformal cooling system it is possible to have lower volumetric shrinkage, less warpage and improved cooling properties. It also offers lower cooling time and hence improved productivity



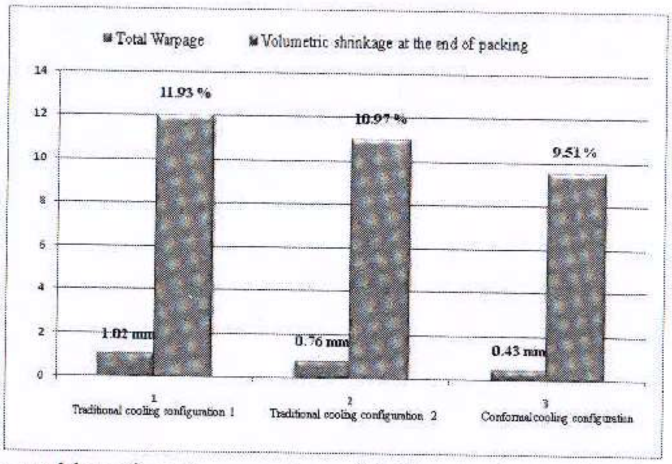


Fig. 7. (a) Comparison of cooling time and maximum mould surface temperature, (b) Comparison of total warpage and volumetric shrinkage.

an important asset to comply with in the thermoplastic injection moulding industry. However, results also show that conformal cooling system also decreases the total warpage (Total deformation) and volumetric shrinkage in the component as compared to the traditional cooling system and these two factors lead to part better quality.

The study is ongoing to examine the materials used in injection mould manufacturing with conformal cooling system, in order to establish the best solution to accomplish the industrialization terms.

Further work is required in conformal cooling system.

- Heat transfer analysis results can be optimized by changing the shape configuration of cooling channels and process parameters.
- Tool room industries should go for alternative material (i.e. Composites) as a replacement for steel to have additional enhanced results with conformal cooling system and should also envisage the use of non-traditional technological manufacturing processes such as rapid tooling and rapid prototyping.

6. Referances

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