The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.10158877

ENHANCEMENT OF WELD LINE IN ABS AUTOMOTIVE COMPONENTS VIA GAS - ASSISTED MOLD TEMPERATURE CONTROL

K. SURUTHI [1], C. MANIMARAN [2], IYYANAR L [3], JAYAPRADAP E [4] and BARANITHARAN.K [5]

[1] M.E(Cad/Cam) Assistant Professor, Department of Mechanical Engineering, IFET College of Engineering, Villupuram, Tamil Nadu, India.
[2] M.Tech (Energy Tech) Associate Professor, Department of Mechanical Engineering, IFET College of Engineering, Villupuram, Tamil Nadu, India.
[3, 4, 5] B.E (Mechanical Final Year), Department of Mechanical Engineering, IFET College of Engineering, Villupuram, Tamil Nadu, India.

Abstract

This research paper focuses on reducing the weldline defectives in an ABS molded part through an innovative technique involving the introduction of gas into the cavity. The aims of the experiment to assess the impact on weld line visibility in comparison to the conventional method of using water for cooling within the cavity. The aim is to reduce rejection of molded ABS parts, which are produced using LG MP 220 Grade materials, intended for automotive applications with subsequent plating. To conduct this study, specimen samples were produced using an injection molding machine. Three different sizes of gas vents were employed, allowing gas to flow through the tool's cavity. The research is to then collect data on the resulting weld lines which are measured for comparison and employed to comprehensively analyse and interpret the effects of gas cooling across varying vent sizes in contrast to traditional water cooling. This statistical analysis facilitates the determination of the optimal vent size based on experimental findings and to compare the same with the traditional water-cooled products.

Keywords: Fatigue Strength, Weld Lines, Gas-Assisted Mold Temperature Control, ABS Automotive Parts, Injection Molding, Durability.

1. INTRODUCTION

This study is meant to predict the weld line defects and its effects in injection moulded thermoplastics components. The study has been done to eliminate the weldline which is most critical defects in the moulding process. Experiments were conducted with water at a temperature of and speed which influences and controls the injection molding process. Flow simulation to predict the flow of plastics material in the mold was done using mold flow analysis. The mold flow analysis can help us in identifying the weldline defect area and its intensity. The material used is ABS (Acrylic Butadiene Styrene) and its characteristic is shown in Table 1, this study, is done systematically and carried out to identify the effects of water versus the gas for improvement of weld line in the molding defect. Sreedharan et al [1] studied the effect of molding parameters on weldline defects and experiments have been performed by using L27 Orthogonal array and these have been normalized by Grey relational analysis (GRA). By conducting the experiment, they have got optimized parameters which has reduced the weld-line width to 56.4%.

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.10158877

This paper deals with effects of weldline on a plastic molded component and understand and the behaviour of mold cooling through water and gas passed through the cavity of the tool to improve and reduce the rejection of the molded part. Hong, J. et al [2] observes when the cavity temperature is low, the cooling process occurs more rapidly. However, it becomes challenging to efficiently fill the mold cavity with the hot molten material because a frozen layer tends to form. Li jiquan et al [3] investigated the influence of the weldline on the tensile strength of RHCM and conventional injection molded (CIM) components. The test specimens with weldline were scanned with electron microscopy (SEM) shows improvement in weldline on the thinned-out parts. Several methods are available to achieve the desired cavity temperature of the molds like application of hot water or hot oil, steam heating, resistance heating using cartridge heaters, and coating of graphene heaters. Mostly the concept of passing hot water or oil has been employed to achieve the mold temperature Jeng, M et al [4].

The most common defect encountered in injection-molded parts is the formation of weld lines. Weldline occur when multiple molten material fronts, traveling from different directions, converge and merge during the filling of the mold cavity. The weldline reduces the mechanical properties of the molded part. There has been number of trials being taken to reduce the vulnerability of weld lines and to improve the weldline strength. The studies have revealed that molding parameters plays an important role like melt temperature, mold temperature, injection speed, and packing pressure are the most significant influence on weld line strength [5–7].

J.Sreedharan et al [8] has done studies on weldline behaviour after molding and plating which shows that the weldline if visible in the molded part is more prominent after plating which also reduces the strength and aesthetics of the part. The experiments showed an average improvement in cumulative process outputs as 40.56% by grey relational analysis and 38.50% by desirability analysis. Kitayama, S et.al [9] has done experiments on rapid heat cycle molding (RHCM) which controls the mold temperature is a plastic injection molding (PIM) technology. The molten plastic flows easily into the cavity if the high mold temperature is high and weldline is reduced. Po-Wei Huang et al [10] gives us an overview of the multigate design of the injection-mold can result in weldline formation during the filling process and the experimental results shows that the overflow of the mold-cavity overflow-well area improves the surface and in turn weldline reduces the weldline.

Hong Liu, et.al [11] has given an input on mold heating parameters of mold temperature controller are important for mold temperature, and researchers have shown us the calculation how to improve the flow of the water inside the mold cavity and how to overcome they have created an algorithm for calculation of heating the mold by water. Chun-Sheng Chen, et.al [12] this study examines the impact of processing parameters on the weldline strength of thin-wall Acrylonitrile Butadiene Styrene Copolymer (ABS) parts. The parameters which are taken are melt temperature, mold temperature, injection speed and packing pressure. Higher the melt and mold temperatures the residual stress shows lower and allows the weldline interface to be better.

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.10158877

Table 1: Properties of ABS LG MP 220

Sl. No	Properties	Test Method	Unit	Typical values
1	Specific Gravity	ASTMD792		1.05
2	Molding shrinkage (Flow), 3.2mm	ASTMD955		
3	Melt Flow Rate	ASTMD1238	g/10min	18
4	Tensile Strength,3.2mm@yield	ASTMD638	Kg/cm^2	450
5	Tensile Elongation,3.2mm@Yield	ASTMD638	%	
6	Tensile Elongation,3.2mm@Break	ASTMD638	% 40	
7	Flexural Strength, 3.2mm, 15mm/Min	ASTMD790	Kg/ cm^2	760
8	Flexural Modulus,3.2mm,15mm/Min	ASTMD790	Kg/ cm^2	25000

Kitayama et.al [13] in this paper, the authors have successfully minimized the clamping force, and cycle time to get high product quality and productivity using the RHCM. Thanh Trung Do et.al [14] this research paper gives advantages of Dynamic mold surface temperature control (DMTC) for thin-wall product. In this paper, DMTC is applied on thin-wall product part and observed the weldline appearance and the weldline strength. DMTC uses hot air flow directly to the weldline surface and that the heating rate could be reached to faster to avoid the weldline.

Park, K et.al [14] has studied High-frequency induction to heat the mold surface by non-contact electromagnetic induction. The experiment performed with induction heating on the molded surface and it almost eliminated the weldline.

2. EXPERIMENTAL AND SIMULATION METHODS

In this we have considered the design characteristic of a specimen mold which was developed to understand the weldline behaviour. Mold flow analysis was done on the specimen part which was taken for the study. This study employed External Gas-Assisted Mold Temperature Control (Ex-GMTC) in the injection molding process to manage mold temperature within a gas temperature range of 200–420 °C.

The process involved six key steps,

Step 1 initiated immediately after the completion of the molding cycle and product ejection. In this step, the hot gas source was moved to the heating area, where the cavity temperature remained low.

Step 2 involved directing hot gas into the heating area. Heat convection facilitated the transfer of thermal energy to the cavity area, gradually raising it to the desired temperature. Once the target temperature was reached, the heating process ceased, leaving the cavity at a high temperature.

Step 3 saw the removal of the gas drier from the molding area, and the two half Molds closed as a new molding cycle prepared to commence.

In Step 4, melt filling into the cavity marked the beginning of the new cycle. The elevated cavity temperature allowed for smooth flow of the hot melt into the thin-walled area. As the entire cavity filled in this step,

ISSN 1533-9211
DOI: 10.5281/zenodo.10158877

Step 5 initiated the cooling process, transferring heat from the hot melt to the mold plate. The process continued until the part temperature reached the ejection temperature.

Finally, in Step 6, the two half molds opened to eject the part, and the subsequent molding cycle commenced.

Figure 1, showcases the assembly of the heating system, which included a cooling system, a high-powered hot gas source with 12 kW capacity, and an Ex-GMTC controller. The controller effectively managed the movement of the hot gas generator via a robot arm.

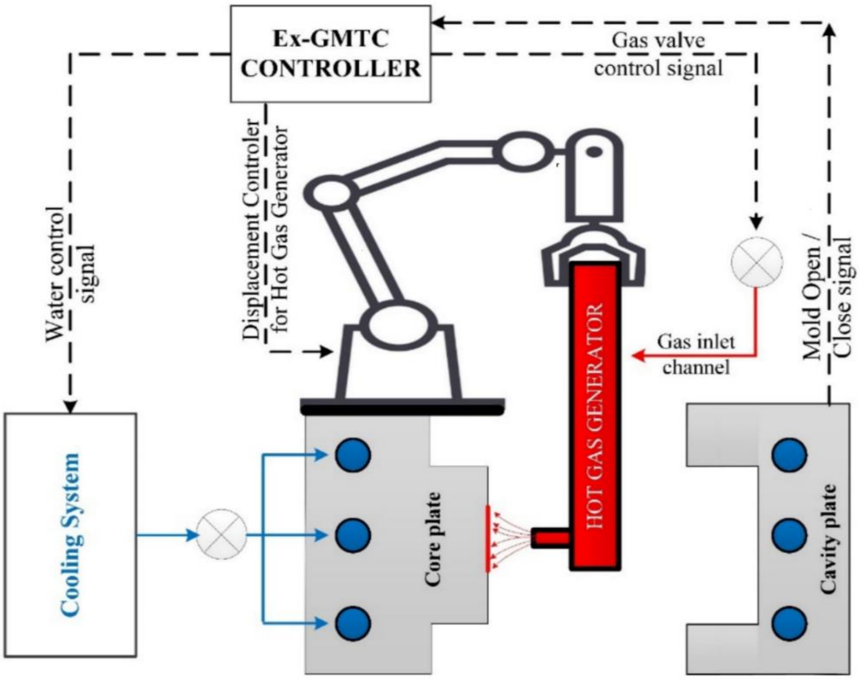

Figure 1: Representation of the Ex-GMTC system

To generate the required hot air, an air drier with external dimensions of 230 mm × 90 mm × 50 mm was employed. Ambient air was introduced into the air drier at a pressure of 0.7 MPa. It then flowed through the gas channel, absorbing thermal energy from the hot air channel's heated wall. Subsequently, the hot air exited through the gas gate with a 10 mm diameter. This high-powered hot gas generator system effectively supplied hot air at required temperatures of up to 420 °C.

The study focused on assessing improvements in weld line appearance and strength. A thin-walled product with dimensions of 70 mm × 25 mm and a thickness of 0.4 mm was examined, featuring a central hole. This hole was a primary factor contributing to weld line formation during injection molding.

ISSN 1533-9211
DOI: 10.5281/zenodo.10158877

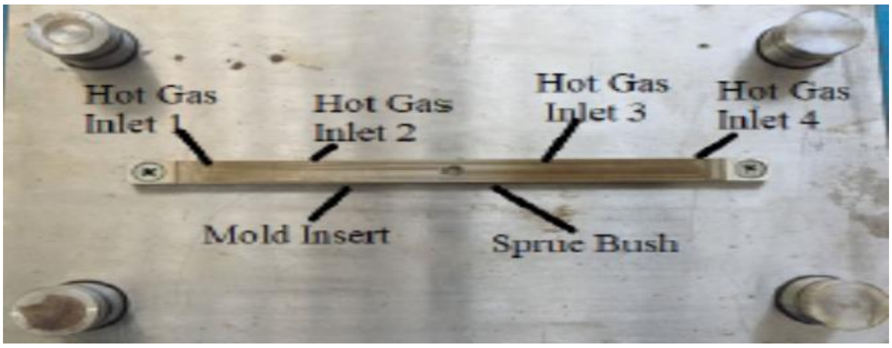

Figure 2: Mold design used in the experiment

The injection mold design structure, illustrated in Figure 2, comprised two cavities within the mold plate. One cavity followed a conventional design, while the other incorporated with an NI-CO insert to enhance heating efficiency and provide better control over the heated area, as shown in Figure 3.

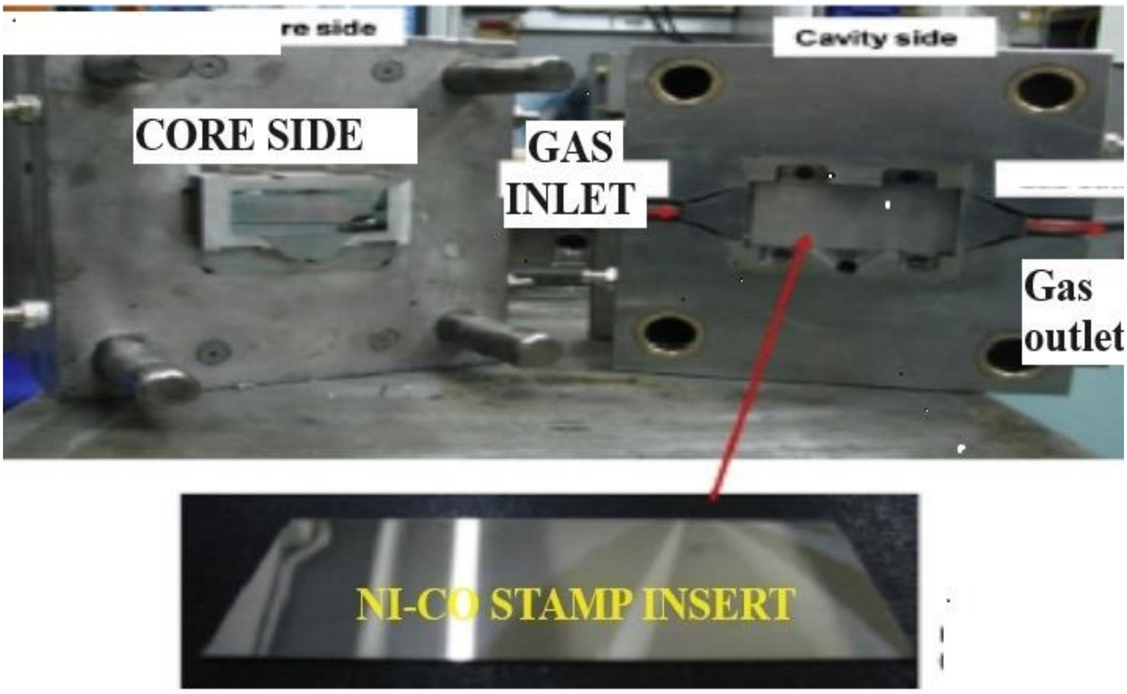

Figure 3: Mold insert used in the experiment

Following investigations into weld line appearance, tensile strength measurements were conducted using a model with a mesh structure in the weld line area. Figure 6 provides detailed insights into this design, featuring two gates at the side to allow the weld line to manifest in the mesh area. The thickness (t) of the mesh area was set to 0.5, 0.7, or 0.8 mm. Ex-GMTC was applied to elevate the temperature of the meshing area before melt filling, aiming to improve tensile strength.

ISSN 1533-9211

DOI: 10.5281/zenodo.10158877

The experimental setup featured a mold with two cavities, with both cavities filled by the two gates at the side. Only one cavity was heated by Ex-GMTC, enabling a comparison of tensile strength with and without Ex-GMTC.

Moreover, an insert structure and stamp were applied to the mesh area. The insert stamp measured 15 mm × 40 mm and had a thickness of 5 mm. Hot gas was directly applied to the insert stamp to enhance its temperature and enhance weld line quality during the molding process.

Figure 4: Machine used and sample part used in the experiment

These experiments, addressing both weld line appearance and strength, were conducted using An Engel 220T machine was used and the sample part is seen in Figure 4.Figure 5 and 5a provides an overview of the gas vent size, showcasing the positions of the hot gas generator, hot gas gate, and heating area The distinctive traits characterizing injection-molded items have evolved to include miniaturization, wherein both aesthetic and engineering considerations converge as central themes within contemporary manufacturing. High output levels are achieved at a cost lower than traditional methods, further supported by the incorporation of advanced features like the hot runner system and gate valves in mold design. These innovations facilitate swifter cycle times and enhanced process adaptability.

Figure 5: Gas vents used with different Dimensions

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.10158877

Figure 5a: Gas vents used with different Dimensions

In this experiment, all the parameters were kept constant apart from changing the vent for 4 different sizes in order to find the effect of weld line in the molded parts. The logic is, when the temperature is maintained, the flow is easier and the injection pressure required will also be less to conduct this experiment, the injection speed and the pressure has been kept constant and less. If the flow is uniform and with mold temperature maintained throughout the mold with minimal increase in the vent sizes can play a big role in reducing the weldline in the molded part. The vent sizes are varied by trial-and-error method in order to get an acceptable molded part with minimum weldline.

Table 2: Experimental Design for the process

			Weldline with Gas		Water Temp in °C	Weldline with Water	
Batches	**Vent Size**	**Batch Quantity**	**Accepted**	**Rejected**		**Accepted**	**Rejected**
VS 1	2MM	25	16	9	50	7	18
VS 2	2.5MM	25	18	7	55	1	24
VS 3	3MM	25	22	3	60	9	16
VS 4	3.5MM	25	10	15	65	9	16

The fatigue strength of weld lines in injection molded automotive components, particularly those made from Acrylonitrile Butadiene Styrene (ABS), plays a crucial role in ensuring the long-term structural integrity of these parts. Weld lines, resulting from the convergence of melt fronts during injection molding, often exhibit reduced mechanical properties that can compromise the overall durability of the components. To address this concern, this study investigates the potential of utilizing gas-assisted mold temperature control as a means to enhance the fatigue strength of weld lines in ABS automotive parts.

The Methodology used here is to reduce the less weld line on the moulded part by using Rapid heating cycle molding (RHCM) which controls the mold temperature during molding. molding process parameters: melt temperature, injection time and packing pressure. Several methods are available to achieve the desired cavity temperature of the molds like application of hot water or hot oil, steam heating, resistance heating using cartridge heaters,and coating of graphene heaters. The characteristic of the hot air is shown in Table 3.

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.10158877

Table 3: Characteristic of the HOT AIR GAS

Parameters	Units	Value
Hot Air Temperature	°C	420
Density of Hot Air	kg/m3	0.524
Heat Capacity of Hot Air	J/kg·K	1068
Thermal Coefficient Expansion of Hot Air	×10−3/K	1.52
Density of Steel P20 ASTM A681)	kg/m3	7861
Heat capacity of steel P20 (ASTM A681)	kJ/kg·K	1926
Thermal conductivity of steel P20 (ASTM A681)	W/m·K	41.5
Simulation type		Transient

The proposed approach leverages controlled gas flow channels integrated within the mold to regulate and optimize local cooling rates at the weld line. By mitigating differential shrinkage and minimizing stress concentration, the gas-assisted mold temperature control aims to improve the overall fatigue performance of weld lines. The molding parameters on the machine constant and only the vent sizes are varied along with the temperature for the experiment which is carried out with water mold temperature controller which are kept constant and shown in Table 4.

Table 4: Molding Parameters for the Experiment

Molding Parameter for ABS MP 220 LG Petrochem	
Melt temperature	230°C
Injection Pressure	100 bar
Injection time	1Sec
Packing Pressure	60bar
Packing Time	3Sec
Temperature at the weldline area	30°C,45°C,60°C or 90°C
Part Thickness	0.4mm

The study employs a combined computational and experimental approach. In this experiment it is proved if the temperature of the mold surface is maintained by varying the vent size can bring down the rejection of molded part because of the weldline on molded parts after molding. One can observe from the Table 2 when the vent size VS 1 denotes 2mm the weldline is more due to high injection pressure to fill the part which can create gas or bubble due to flow restrictions and due to no uniformity in heating of the mold surface which can weldline but much better the water-cooling method.

As shown in Table 2 and Fig. 5 vent size of 2.5mm denoted with VS2 has shown improvement in the results but still the material flow is not smooth as expected which causes the weldline formation after molding. Since there is an improvement in the weldline we have tried to increase it to 3mm vent size which is denoted has VS3was made and is shown in Fig. 5a. The results are shown in Table 2 and the results are far superior and acceptable. Further vent size was increased to 3.5mm which is shown in Table 4 and Fig. 2 to cross check the results are optimal on 3.5mm vent size denoted with VS4 but the results are negative and observed overheating of the cavity surface which can cause other molding defects such as parting line flashes, silver streaks and warpage which will affect the molding acceptance and quality. Hence

The Seybold REPORT
ISSN 1533-9211
DOI: 10.5281/zenodo.10158877

the trials were stopped at 4mm vent size where the results were good and consistent. We have observed that the acceptance of the part with vent size of 3mm is optimal and the rejection is less.

Similarly experiments with varying the water temperature on the MTC from 50°C varying by 5°C for 4 steps shows there is not much improvement in the weldline and the acceptance varies and the it's not consistent. The molding parameters are kept constant and only the vent size is increased to check the effect of the Hot air gas which is sent into the cavity of the mold and it is shown in the Table 4.We have also measured the temperature at the weldline area which is indicated by the mold flow shown in figure 6 and it indicates the possibility of the weld line area which is measured after and during the process to get the actual temperature to get the optimal heating of the weldline area which can reduce the weldline defect.

The findings of this research indicate a promising enhancement in weld lines achieved through the gas-assisted mold temperature control technique. By promoting uniform cooling and minimizing stress concentration, this innovative approach has the potential to significantly improve the durability and reliability of ABS automotive parts.This study contributes to the ongoing efforts in optimizing the manufacturing processes of injection-molded automotive components to meet the demanding requirements of safety and performance in the automotive industry.Flow of molten material is restricted due to sprue, runner, gate and part design which can overheating while injecting the molten material into the cavity. Back pressure on the screw improves the mixing of the material in the barrel which will release the gas from the material which will help in the flow of the material. It is seen the vent size has to be optimal and it should be in checked for parting line flash as well. If the vent size are bigger the parting line flash and burn mark on the molded part can cause other molding defects

3. CONCLUSIONS

In this study, Evaluation of the weldline by the innovative process against the traditional method is to reduce the weld line appearance and the tensile strength of injection molding products. It is generalized as follows:

Weld line can be avoided by uniform heating of the mold surface which will improve the flow of the material inside the cavity without much resistance and the last filling area is identified by the mold flow based on that we can measure the heat of the weldline area and based on the findings we can always increase the size of the vent to pass hot air gas into the cavity. Care must be taken not to overdo the vent sizes which will impact the material properties as well as the product quality.

Here we can clearly infer that passing hot air gas into the cavity will help the weldline to reduce and quality of the parts can be improved. Comparatively the mold temperature controller with water shows no major improvement in the acceptance level of the molded part for weldline and the process remains inconsistent. The study reveals the innovative approach by using Hot air gas for reducing weldline in the molded parts.

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.10158877

References

1) J. Sreedharan, A.K. Jeevanantham, Optimization of Injection Molding Process to Minimize Weld-line and Sink-mark Defects Using Taguchi based Grey Relational Analysis, Materials Today: Proceedings, Volume 5, Issue 5, Part 2,2018, Pages 12615-12622, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2018.02.244.

2) Hong, J.; Kim, S.K.; Cho, Y.H. Flow and solidification of semi-crystalline polymer during micro-injection molding. Int. J. Heat Mass Transf. 2020, 153, 1–18.

3) Li, Jiquan, Yang, Shaoguang, Turng, Lih-Shen Xie, ZuojianComparative Study of Weldline Strength in Conventional Injection Molding and Rapid Heat Cycle Molding September 2016, Materiale Plastice 53(3):448-453.

4) Jeng, M.-C.; Chen, S.-C.; Minh, P.S.; Chang, J.-A.; Chung, C. Rapid mold temperature control in injection molding by using steam heating. Int. Commun. Heat Mass Transf. 2010, 37, 1295–1304.

5) Wu, C.H.; Liang, W.J. Effects of geometry and injection-molding parameters on weld-line strength. Polym. Eng. Sci. **2005**, 45, 1021–1030.

6) Chen, S.C.; Chang, Y.; Chang, Y.P.; Chen, Y.C.; Tseng, C.Y. Effect of cavity surface coating on mold temperature variation and the quality of injection molded parts. Int. Commun. Heat Mass **2009**, 36, 1030–1035.

7) Chen, C.S.; Chen, T.J.; Chien, R.D.; Chen, S.C. Investigation on the weld line strength of thin-wall injection molded ABS parts. Int. Commun. Heat Mass **2007**, 34, 448–455.

8) Sreedharan J, Jeevanantham A, Rajeshkannan A. Multi-objective optimization for multi-stage sequential plastic injection molding with plating process using RSM and PCA-based weighted-GRA. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*. 2020;234(5):1014-1030. doi:10.1177/0954406219887993.

9) Kitayama, S., Tsurita, S., Takano, M. *et al.* Multi-objective process parameter optimization for minimizing weldline and cycle time using heater-assisted rapid heat cycle molding. *Int J Adv Manuf Technol* (2023). https://doi.org/10.1007/s00170-023-12245-9

10) Mold-Face Heating Mechanism, Overflow-Well Design, and Their Effect on Surface Weldline and Tensile Strength of Long-Glass-Fiber-Reinforced Polypropylene Injection Molding, Po-Wei Huang 1, Hsin-Shu Peng 2 and Wei-Huang Choong.

11) Hong Liu, Danqi Pan* and Zheqi Jian, Algorithm for calculating parameters of mold temperature controller, https://doi.org/10.1051/e3sconf/202236001062

12) Chun-Sheng Chen, Tsyr-Jang Chen, Rean-Der Chien, Shia-Chung Chen,Investigation on the weldline strength of thin-wall injection molded ABS parts,International Communications in Heat and Mass Transfer,Volume 34, Issue 4,2007,Pages 448-455,ISSN 0735-1933,https://doi.org/10.1016/j.icheatmasstransfer.2007.01.005.

13) Kitayama, S., Tsurita, S., Takano, M. *et al.* Multi-objective process parameters optimization in rapid heat cycle molding incorporating variable packing pressure profile for improving weldline, clamping force, and cycle time. *Int J Adv Manuf Technol* **120**, 3669–3681 (2022). https://doi.org/10.1007/s00170-022-08994-8.

14) Study On The External Gas-Assisted Mold Temperature Control For Thin Wall Injection Molding, ThanhTrung Do, Tran Minh TheUyen*, Pham Son Minh, DOI: 10.9790/9622-0703021519

15) Park, K., Sohn, DH. & Cho, KH. Eliminating weldlines of an injection-molded part with the aid of high-frequency induction heating. *J Mech Sci Technol* **24**, 149–152 (2010). https://doi.org/10.1007/s12206-009-1127-4.