SIMULATION AND ANALYSIS OF STEP LIGHT MID PART USING MOLD FLOW ANALYSIS

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Abstract - Mold flow simulation helps designers to see how their designs will be resulted after injection molding process. The use of simulation programs saves time and reduces the costs of the Molding system design. Injection molding design simulation holds an important role in analyzing the outcome of the design. Today, many manufactures have proven mold flow analysis (MFA) to be the medium between a flawless design and production. Taguchi method is used for optimizing the molding process parameters. This thesis presents use of taguchi method for Design of Experiment in plastic injection Molding. The study applies Taguchi's L9 orthogonal array design technique to study the effect of process settings of plastic injection molding on part quality. Experimental trial data is used to compare the results with moldflow simulation. The optimum levels for mold surface temperature, melt temperature, injection time and v/p switch over are determined.

Key Words:* *Molding window, design of experiment (DOE), mold flow analysis, taguchi method..

1. INTRODUCTION

Mold flow simulation helps designers to see how their designs will be resulted after injection molding process without needing to do the Injection Molding process. The use of simulation programs saves time and reduces the costs of the Molding system design. Injection molding design simulation holds an important role in analyzing the outcome of the design. Creating a high performing mold is a vital part of the injection molding process, but can be challenging. While one might think liquid plastic simply takes on the shape of the mold it's injected into. Today, many manufactures have proven mold flow analysis (MFA) to be the medium between a flawless design and production. CIPET Aurangabad provides the scope for research in plastic engineering.

The Autodesk Simulation Moldflow results help to identify the main problem areas before the part is manufactured that are particularly difficult to predict with traditional methods. Analysis is essential for designing and mould making through simulation step-up and result interpretation to show how changes to wall thickness, gate location, material and geometry affects manufacturability and also experiments with "what-if" scenarios before finalizing a design. Injection Moulding simulation software into the mould design process in order to analyze the product, foresee the possible defects, and optimize the design to achieve the maximum outcome of the products with minimum cycle time in each production cycle.[18]

On the study of injection moulding process the most important point that lies under is the mould. The mould, which is the most important component part, that gives the product the shape required and designing the part product associated with the mould, hence worth study.

Back in time before the involvement of product, mould designing and appearance of mould designers, artisans and die makers were taking part. After the second world war when plastic technologies was beginning this artisans were engaged on mould designing but as time pass by and there emerged a demand for increased verities of plastic products designing with different moulding parameters and high specialization seeks enabling the level of mould makers, mould and product designing on a specific profession.[19]

1.1 LITERATURE REVIEW

J. Rao, at al [1] had focused on the analysis of plastic flow in two plate injection mold. Mold flow analysis software is used to perform the analysis of filling, wrap and best gate location. The analysis begins with the origin of the flow channels such as Barrel, nozzle, sprue, runners, and gates until the cavity is completely filled. The main objectives their research were to design plastic part, to design feeding system like sprue, runner and gate in two plate injection mold, to set optimum process parameter like injection pressure, speed, temperature and other, analysis plastic flow in two plate injection Mold.

J. Liu [2] had analyzed warp analysis. In practical process, it is always controlled by technicians through practical experience accumulation, which will lead to high waste. Through Mold flow powerful analysis ability, a practical warp analysis is conducted, and then several plans are compared and adjusted, finally the best design is chosen. It simplifies the design process, improves design efficiency and decreases molding waste greatly, with strong practical application.

P. P. Shinde, at al [3] had analysed analytically and experimentally injection mold for Auto component. Injection molding process is much widely spread; it can produce very complex shaped parts with minimal time compared to other process. Even parts with metal inserts can also be produced on injection molding machine. Injection molding dies are expensive to produce but each die can be used to manufacture thousands of components with rapid rate, so that per-part cost is very low. Dealing analytically, the tonnage (clamping force for both halves) required for Plastic Injection Molding is derived from the projected surface area of the component. Then 3D model of component and its mold design was created by using CAD software such as CATIA. On the other hand experimentation carried out using physical tests to find out the defects such as porosity, air traps and blow holes.

J. Ganeshkar, at al [4] This paper presents the design of plastic injection mold an Automotive Component "air Vent Bezel" through mold flow analysis for design Enhancement, Before proceeding, the part was analyzed by mold flow software to remove defects such as air trap, weld line, Shrinkage of part, Dimension not exact and incorrect Clamping Force, Cooling Channels not Properlyto Remove Heat such Problems are and try to Eliminate or Minimized, also Flow of plastic is observed. Dimensional accuracy is measured and checked with the specified dimensions. Visual and actual inspection did while attempting to identify the defects. Further, for fitment in the subassembly the component is checked.

S.M. Nasir, at al [15] In this paper the authors have identified the best setting for single and double gate, which affect the warpage for thick component using Taguchi and ANOVA methods. Mold Temperature, Melt Temperature, Packing Pressure and Packing Time are the selected parameter that used in this study. These experiments were performed by Autodesk Moldflow Insight (AMI) software based on L9 orthogonal array designed by Taguchi. Effects of single and double gates to the warpage formation also were compared. The results show that Taguchi method is capable to minimize the warpage deflection. Moreover, double gate design was better than single gate in minimizing the warpage deflection.

A.M. Gwebu, at al [16] The authors have used Taguchi method to determine the optimum values of the injection moulding process parameters for high density polyethylene (HDPE.) plastic parts. A moulding processing window in which the process achieved maximum quality, with major focus being on mould filling is developed.

P. Sanap, at al [17] In this paper the authors have focused on optimization, this paper deals with the optimization of plastic moulding by reducing warpage with the application of Taguchi optimization technique & part design modifications. Taguchi optimization technique is used for determining the optimum plastic injection moulding process parameters. In part design modifications, ribs are added to the wash lid component to provide additional strength to the washing machine. Analysis of the process parameters are initially carried out by utilizing the combination of process parameters based on three-level of L27 Taguchi orthogonal design. Further, signal-to-noise (S/N) ratio is applied to find the optimum process parameters for warpage defect in the wash lid component. The design modifications and analysis for warpage using optimum parameters obtained from S/N ratio using Pro-E design software and Solid Edge Plastic analysis software. The results obtained reveals that improvement in total warpage is 22.0% & in X-direction it is 37% and stress distribution is by 28% which proves that the strength of the wash lid has increased.

1.2 Objectives

1. 3D modeling of the plastic product using suitable software and meshing using dual domain mesh with proper aspect ratio.
2. To study the component design and identify the critical parameters in the molding window analysis.
3. To set optimum process parameters like injection pressure, speed, and temperature.
4. To simulate the flow and finding the fill time, injections molding defects and deciding the best gate location.
5. Validation through trials and testing by comparing the results of trials and DOE.

2. METHODOLOGY

Methodology presented here is accepted after reviewing several studies done to do similar moldflow analysis. This will lead to better understanding of the objectives and analyzed characteristics to make a one to one comparison between the process parameters.

2.1 Research Issues

1. After studying various papers in this context the major findings are the defects arising in injection molding viz; unequal filling, over filling, warpages and sink marks, silver linings, etc. For enhancing the product quality these defects are needed to be minimised. For this, setting of the process parameters must be optimum which will give the molten plastic a proper way for manufacturing.
2. As injection molding is a trial and error basis process of manufacturing, a optimum way to manufacture the step light mid part needed to be find by design of experiment.

2.2. Problem Definition

"Simulation and Analysis of Step Light Mid Part using Mold flow Analysis".

1. 3D modeling of the plastic product (Plastic part selection, meshing using dual domain mesh with proper aspect ratio)
2. Identify the critical parameters in the molding window analysis. (Material Selection, Experimental setup for injection molding machine, determining the molding conditions.)
3. To set optimum process parameters setting. (Design of Experiments using minitab and Trials on Injection molding machine)
4. To simulate the flow and finding fill time, injection time and molding defects, best gate location analysis using moldflow software
5. Validation of results by comparing the moldflow results and trials.

2.3. 3D model of step light mid part

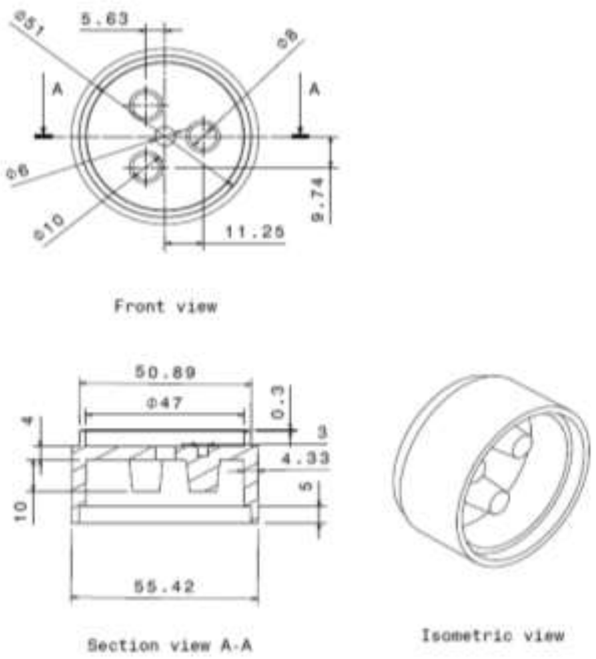

Figure 1.1. CAD Model Step light Mid Part

2.4. Mesh Procedure

1. Import the part .stp file in Autodesk Mold flow Insight
2. Mesh Now, using dual domain type mesh.
3. After the meshing command is executed and processing finished the following mesh part result of the Step Light Mid Part is obtained for dual domain mesh.

Figure 1.2 Meshing result of the Step Light Mid Part

The implication is that the software disintegrate the part design in to triangular or /and tetrahedral elements and joined by nodes, at the node connection points been a transferring point of load and force for the analysis. From the above mesh analysis it is done perfectly to result the mesh version of the product design and revels that the part design in Creo is completely compatible and matches for melt simulation and analysis. Hence, there are no overlapping nodes so that the simulation carried out and generates the result that would have been not so if the mesh is not proper.[22]

2.4. Material:

Polycarbonate (PC) Grade: Romawhite, Macrolon, 2407

3. TAGUCHI EXPERIMENTAL DESIGN

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

After the general procedures carried on, meaning importing the file in Autodesk Moldflow Insight and meshing it according to the method described above. Then after the right mesh statics achieved the melt flow procedures proceeds as follow:

Table.3.1. Critical parameters

S/N	Process	Details
1	Importing	.Stp file in Autodesk Moldflow Insight
2	Meshing	Dual Domain
3	Fill	Material customizes: Polycarbonate (PC) Romawhite, Macrolon, 2407
4	Set Injection Point	
5	Processing Setting:	
6	Filling control	Flow rate: 56520 mm ^{3}/s = 56.52 CM>3/s
7	Injection Pressure	51.4 MPa
8	Mould Temperature	100 °C
9	Melt Temperature	300 °C
10	Injection Moulding Machine	JIT80T
11	Maximum Machine Injection pressure	60 Mpa
12	Hydraulic pressure Intensification Rate	10
13	Machine Clamp Force	80 tonne

Four super plastic forming parameters are considered as controlling factors. They are Mold surface temperature, melt temperature, Injection time and V/P Switch over. Each parameter has three levels – namely low, medium and high, denoted by 1, 2 and 3 respectively. According to the Taguchi method, if four parameters and 3 levels for each parameter are consider, L9 orthogonal array should be employed for the experimentation. Table shows the parameters and their levels considered for the experimentation.

Table.3.2. Critical parameters

Process parameters	Levels		
	Level 1	Level 2	Level 3
Mold S/F Temperature (°C)	80	100	110
Melt Temperature (°C)	285	300	310
Injection Time (sec)	4	5	5
V/P Switch Over (%)	97	98	98

For four parameters and three levels L9 orthogonal array was selected from the array selector. The trials were taken on JIT80T injection molding Machine in accordance with Table and inspection of the formed component was done. Experimental data hence measured is as a shown in table. Taguchi method of optimization involves finding out Signal-to-Noise ratio (S/N) in order to minimize quality characteristic variation due to uncontrollable parameter. Cooling time belongs to "larger the better" quality characteristics.

Table.3.3. DOE by L9 OA

Experiment No.	Levels			
	Mold Surface Temperature (°C)	Melt Temperature (°C)	Injection Time (Sec)	V/P Switch Over %
1	80	285	4	97
2	80	300	5	98
3	80	310	5	98
4	100	285	5	98
5	100	300	5	97
6	100	310	4	98
7	110	285	5	98
8	110	300	4	98
9	110	310	5	97

Total 9 experiments were conducted and the runs for the experiment are as shown in the table 3.3

4. RESULTS & DISCUSSIONS

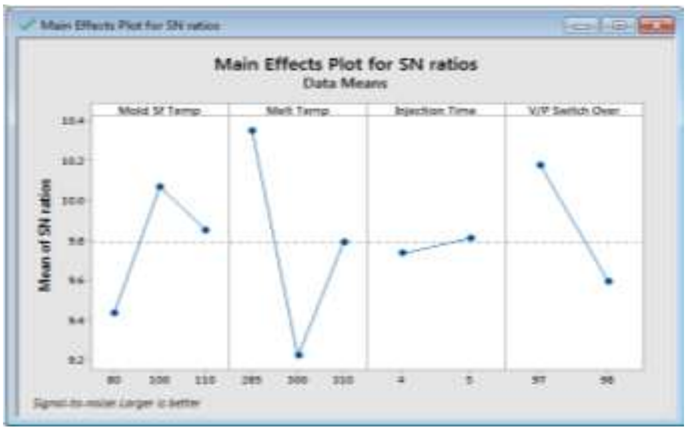

Figure 4.1 Graph For S-N Ratio – Larger is better.

The Fig. 4.1. shows the graph of S/N ratio of the input variables used for design of experiment.

Table.4.1. Optimized parameters and output results

Sr. No	Levels	Parameters					
		Mold S/f Temperature (°C)	Melt Temperature (°C)	Injection Time (sec)	V/P Switch over (%)	Cooling Time (sec)	Fill Time (sec)
1	Optimum values for Step light mid part	100	300	5	98	25	2.21

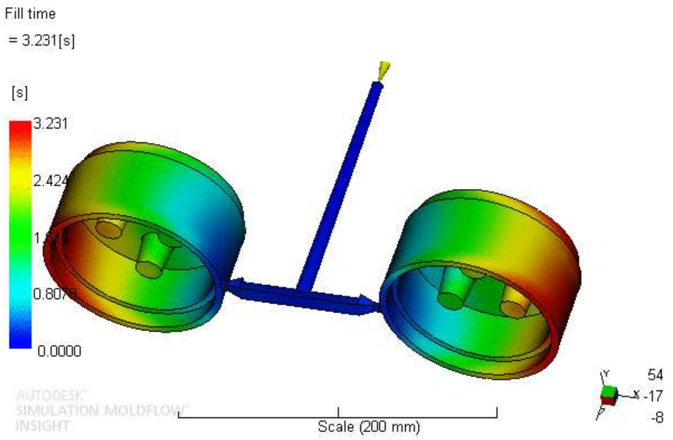

Figure 4.2 Fill time analysis result

Filling time starts with the blue region where the optimum injection point set for the maximum filling and propagates to peripherals of the cavity as it passes the blue, green and finally maximum filling time of red region which takes for all full filling of the cavity to be a duration of 3.231 s.

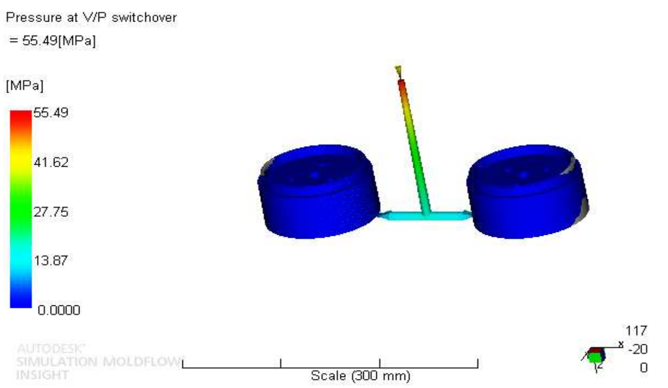

Figure 4.3 V/P switch over

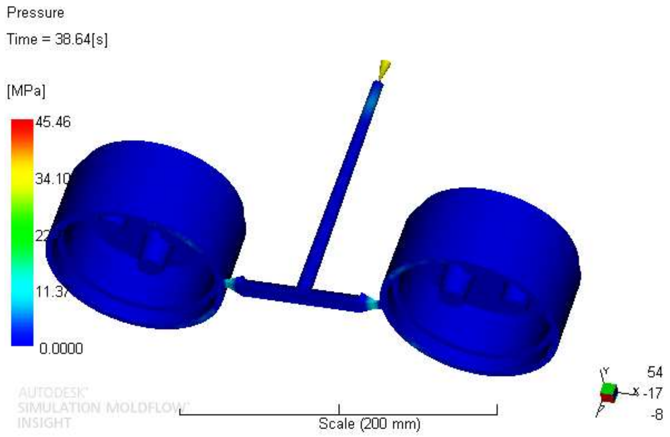

Figure 4.4 Pressure analysis result

The result obtained from the simulation of the analysis shows that though a maximum pressure in the red zone is allowed as high as 45.46 MPa the melt can completely fill the cavity with the yellow region of maximum optimum operating pressure of 34.10 MPa that would be enough for complete filling, and hence this pressure is enough for the operating pressure of the mould

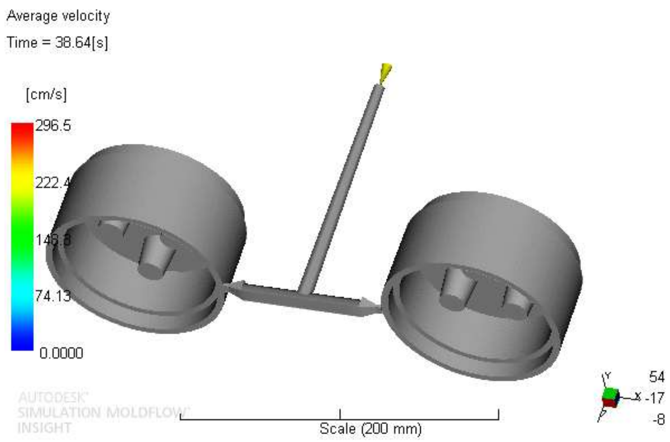

Figure 4.5 Average velocity result

The analysis shows allowable range of maximum average velocity possibility of 74.13 cm/s it is quite enough for the product to be in the range of the blue zone and finally, it is also resulted average melt flow of the melt duration to be 38.64 sec.

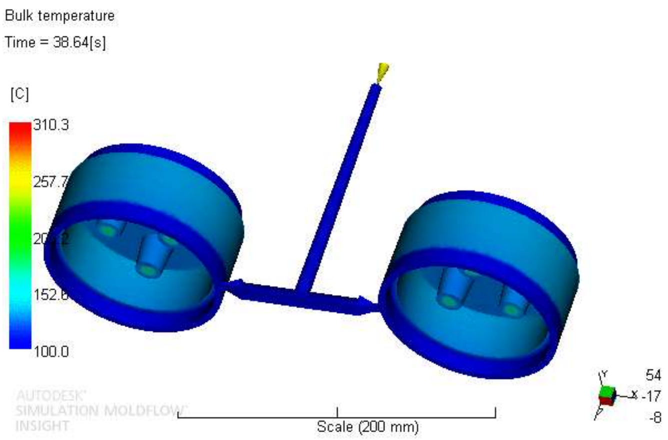

Figure 4.6 Temperature analysis result

Based on this the simulation analysis resulted as shown in the figure below of about a maximum of 310.3 degree Celsius on the red zone of the melt part on the cavity which then drops after filling with a time interval of 38.64 s to a blue part on the region to a temperature range of 100 degree Celsius where then on wards thermal stabilization achieved and the mould temperature stays in equilibrium.

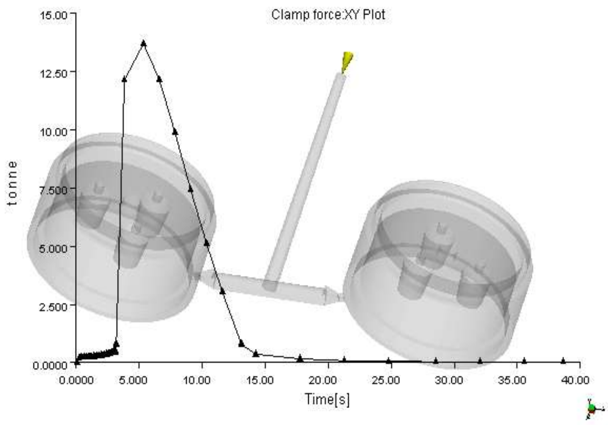

Figure 4.7 Clamp force analysis Result

From the analysis result a clamp force of 13 tonne is required for the maximum filling of the cavity as an optimum result. On the analysis setting for the machine the clamp force is assigned as 1.04 tonne after several trials and it is near the simulation analysis results and feasible being optimum for the result. Moreover the analysis tells there need this 13 tonne amount of clamp force for the part product manufacturing which is on average feasible range of JIT 80T machine operation practically. The plot of the clamp force versus time is shown.

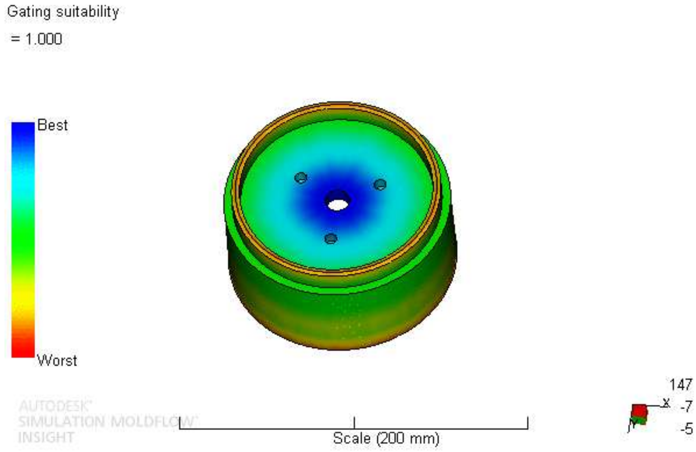

Figure 4.8 Gating Suitability

The best gate location is near node number =2351.

Table 4.2 Observations from moldflow simulation.

Moldflow Simulation							
Sr. No.		Input Parameters				Output Parameters	
1		Mold S/f Temperature (°C)	Melt Temperature (°C)	Injection Time (sec)	V/P Switch over (%)	Cooling Time (sec)	Fill Time (sec)
2	Trial 1	88.98	309.5	2.9	98	20	2.56
3	Trial 2	100	300	4.6	98	26	2.33
4	Trial 3	115	315	5	98	30	3.2

As shown in table 4.2. the moldflow simulation is run on Autodesk moldflow insight. The input parameters such as mold s/f temperature, melt temperature, injection time and v/p switch over are analyzed and output parameters like 1)Cooling time and 2)Fill time observations are recorded. The Trial 2 readings (highlighted) for Input parameters and output parameters are compared with DOE and actual trial readings.

Table 4.3 Optimized Process Parameters.

Sr. No	Levels	Input Parameters				Output Parameters	
		Mold S/f Temperature (°C)	Melt Temperature (°C)	Injection Time (sec)	V/P Switch over (%)	Cooling Time (sec)	Fill Time (sec)
1	Optimum values	100	300	5	98	25	2.21

The Design of experiment by Taguchi method is performed by using L9 orthogonal array, and the optimum levels of the process parameters are highlighted as shown in table 4.3.

Table 4.4 Observations from trials

Sr. No.	Parameters	Trial 1	Trial 2	Trial 3	Trial 4
1	Mold Surface Temperature	65ºc	75ºc	85ºc	95ºc
2	Melt Temperature	285ºc-310ºc	290ºc-[illegible]	290-305ºc	300ºc
3	Injection Time	4 Sec	5 Sec	5 Sec	5 Sec
4	V/P Switch Over (Transfer Position)	2 mm	1 mm	1 mm	98%
6	Cooling Time	35 Sec	25 Sec	28 Sec	28 Sec

The mold trials are done at CIPET, Aurangabad under the stated molding conditions and the observations for the different trials are recorded. The trial 4 readings are compared with mold flow simulation results and design of experiment optimum readings and it is found that there is similarity between all the results.

4.1 Manufacturing of step light mid part during trial

Figure 4.9 Step Light Mid Part

Figure 4.10 Trials at CIPET, Aurangabad

As shown in the figure 4.9. the step light mid part is manufactured by using the stated molding conditions and visual inspection is done for identifying the defects if any. The part is acceptable.

6. CONCLUSIONS

The mid part, keeping its complexity in mined was tried designing several times until the desired functional part geometry is achieved. Design of Experiments was done by Taguchi's technique. For four parameters and three levels L9 orthogonal array was selected. Through pilot study experiments the levels of parameters were selected. These experiments were conducted between 80ºC to 120 º C mold surface temperatures and 285ºC to 310ºC melt temperature. From the pilot study the selected levels of mold surface temperature were 80ºC, 100ºC, 110ºC. The melt temperature was 285ºC, 300ºC, 310ºC. Cooling Time and Fill time were two response variables. Total nine experiments were conducted and S/N ratios for cooling time and fill time were plotted. Confirmation tests were conducted using the higher the better values for cooling time and fill time.

After making the prototype simulation with mold flow, it can be concluded that it makes the ground for the manufacturing of Step light mid part practically in industries for injection molding.

6.1. Scope

Analysis of the product using Autodesk Mold flow (Simulation tool) software helps us validate and optimize plastic parts, injection molds, and the injection molding process. This software is essential for designing and mold making through simulation setup and results interpretation to show how changes to wall thickness, gate location, material, and geometry affect manufacturability. and also experiments with "what-if" scenarios before finalizing a design.

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