Processing parameters Optimization of Injection Moulding in DN20 Vent of Water Meter Manufacturing

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Abstract. The conventional optimization process in Injection Moulding includes actual shop floor trials in which melt temperature, mould temperature, injection time, injection pressure, pattern, feeder size, shape and location cores, mould layout, gating etc. are changed in each iteration which involves high machining cost, tooling cost, modification cost, melting cost, and transportation cost as well as, materials, energy, time are wasted in each trial until and unless the required results are obtained. Water meter component (DN20 Vent) is designed in CREO 5.0, and then components are 3D printed to cross check the dimensions and also to confirm whether all the other components can be accommodated or not. Then the mould flow analysis will be performed on a water meter components using different materials and changing the processing parameters. The input processing parameters considered are melt temperature, mould temperature and injection time, whereas the responses are warpage, volumetric shrinkage, cycle time and quality prediction. Grey relational analysis is carried out to determine the optimum injection moulding processing parameters.. The effort has been made to minimize the warpage, volumetric shrinkage, cycle time and maximize the quality prediction mould cavity and core for the components are designed in CREO 5.0 and manufactured using P20 tool steel. Then the water meter components are manufactured by inputting the optimal processing parameters in injection moulding machine to achieve high productivity and quality.

1 Introduction

Products of highest quality can be obtained with enhance mould design by using Mould Flow Analysis (MFA) software which replicates flow of the plastic inside the mould cavity. Potential areas of concern can be highlighted by this analysis as it offers results of how the selected material fills the mould cavities. An analysis of the mould flow indicates potential problems associated with moulding and can be corrected before cutting steel to make the mould so that expensive and laborious tooling rework can be prevented.

In beginning, mould is designed and evaluate to ensure uniform parts production from cavity using MFA. Flow of Resin in mould cavity is forecasted by model developed and resin characteristics. Mould processing parameters like melt temperature, pressure profile, or filling time, injection pressure are optimized before the mould is manufactured. Optimum processing parameters, shorter cycle times, shorter filling times and fewer defects will be analysed. This optimum parameters are used in the manufacture of the DN20 vent.

Vishwas Lomate, Salunke M, K. Rushikesh, S.Gajanan 2015, [1] have performed modelling of mould flow on the plastic part with deviations such as shrinkage, weld lines, air traps and immersion marks in manufacture of toy. Sanusi Md, Aziz, Ali Amran, Idayu N, Hadzley Md, and S Sivarao 2016 [2] has carried out simulation and found optimized injection mould melt temperature. S.Rajalingam, Awang Bono and Jumat bin Sulaiman 2013, [3] optimized processing parameters such as (screw rotation speed, injection pressure and mould temperature in manufacture of mobile phone case and investigated the affect the shrinkage defect of the plastic case.

MD Helen, Huszar M, Belblidia F, Arnold C, David Bould, Johann Sienz 2018, [4] investigated and suggested common defect i.e warpage in injection moulding process. Gurjeet, Pradhan M K, Ajay Verma 2018 [5] proposed an approach for multifactor optimization of parameters of the injection moulding process such as packing time, injection pressure, cycle time and melting temperature. Satyanarayana Kosaraju, Vijay Kumar M, Sateesh N. 2016, [6] employed multi-objective optimization based on Taguchi-based Grey relational method, to find the optimal levels of cutting

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parameters for the objective of lower cutting force and better surface finish under dry cutting conditions for Inconel 625. Tosun 2006, [7] determined of optimum parameters for multi-performance characteristics in drilling by using grey relational analysis. A.Noorul Haq, P.Marimuthu, R.Jeyapaul, 2008, [8] presented a new approach for the optimization of drilling parameters on drilling Al/SiC metal matrix composite with multiple responses based on orthogonal array with grey relational analysis. Experiments are conducted on LM25-based aluminium alloy reinforced with green bonded silicon carbide of size 25 µm (10% volume fraction). Drilling tests are carried out using TiN coated HSS twist drills of 10 mm diameter under dry condition. V.Balaji, N.Sateesh, M. Manzoor Hussain, 2015, [9] manufactured of Aluminium Metal Matrix Composite (Al7075-SiC) by Stir Casting Technique. N.Sateesh, P.Sampath Rao, D.V.Ravishanker, K.Satyanarayana, 2015, [10] conducted to investigate the environmental impacts of fiber composites. The main objective of this work is to investigate the degradation of GFRP composite which is exposed to different environmental conditions and its influence on the tensile strength. Ratna Deepika Manikonda, Satyanarayana kosaraju, K. Arul Raj, N.Sateesh 2018, [11] investigated Wear Behavior Analysis of Silica Carbide Based Aluminum Metal Matrix Composites using pin on disc.

2. Experimentation

2.1 DN20 Vent Component Modelling

DN20 vent component is designed in CREO 5.0 as shown in fig.2.1. Processing parameters levels considered in mould flow analysis is shown in table 2.1.

Table.2.1. Processing parameters levels for DN20 vent

PARAMETER	LEVELS		
	1	2	3
Melt Temperature(^{0}C)	280	300	320
Mould Temperature(^{0}C)	70	80	90
Injection Time(Sec)	0.4	0.7	1.0

2.2 Mould flow Analysis (MFA) of DN20 vent

MFA of DN20 vent is performed using mould flow adviser 2016 software. The material is used is Nylon 6 and its properties are considered for analysis. Three levels of each processing parameters are considered as melt temperature (280ºC, 300ºC, and 320ºC), mould temperature (70ºC, 80ºC, 90ºC) and injection time (0.4s, 0.7s, 1.0s).

When solidification begin, cooling state to ejection state part volume is reduced which is known as volumetric shrinkage. The sum of mould opening time, cooling time fill and pack time is known as cycle time. Like that MFA is done for nine different inputs of processing parameters as shown in table 2.2 and the corresponding results of MFA shown in same table 2.2. The results like deflection, volumetric shrinkage and deflection (warpage) shown in the table 2.2.

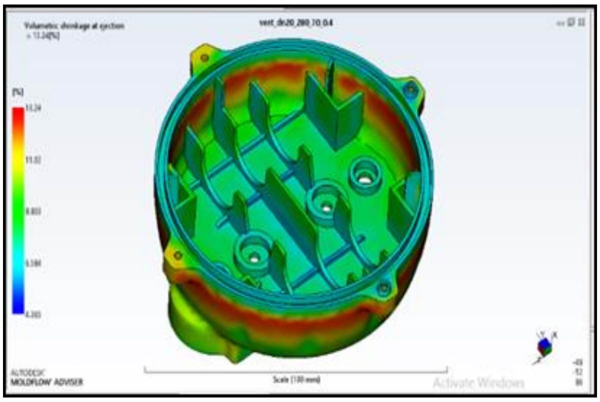

Fig.2.1. Result of analysis of DN20 vent at melting temperature =280ºC, mould temperature = 70ºC, injection time = 0.4 s.

Table.2.2. MFA Results of DN20 vent

S. No	Melt Temperature (^{0}C)	Mould Temperature (^{0}C)	Injection Time (Sec)	Deflection (mm)	Volumetric Shrinkage at Ejection (%)	Cycle Time (Sec)	Quality Prediction (%)
1	280	70	0.4	1.425	13.24	17.65	46.1
2	280	80	0.7	1.426	13.35	18.20	16.6
3	280	90	1.0	1.438	13.47	18.76	7.55
4	300	70	0.7	1.357	13.12	15.72	95.7
5	300	80	1.0	1.416	13.33	16.03	95.4
6	300	90	0.4	1.390	13.14	15.41	95.4
7	320	70	1.0	1.463	14.72	20.26	78.6
8	320	80	0.4	1.464	14.83	20.9	78.1
9	320	90	0.7	1.469	14.88	21.71	78.2

2.3 Mould Design and manufacturing of DN20 Vent

Core and cavity of DN20 vent is modelled using CREO software shown in fig.2.1, 2.2 2.3, 2.4 and 2.5.

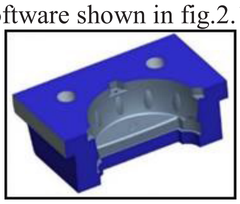

Fig.2.2. Core

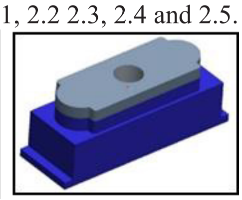

Fig.2.3. Cavity sub insert

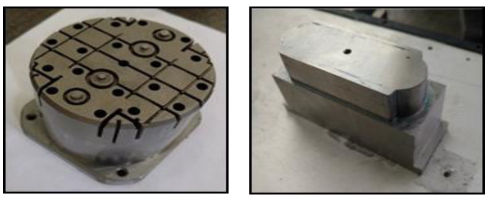

Fig.2.4. Core and cavity sub insert of DN20 vent

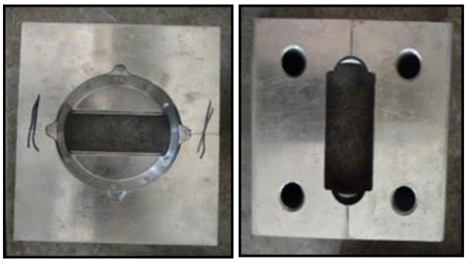

Fig.2.5. DN20 Vent core

3. Grey Relational-Analysis

3.1 Dn20 Vent manufacturing results:

Considering table 2.2 results and using the grey relational analysis method, the normalized values of cycle time, volumetric shrinkage, quality prediction and deflection can be found. The same is shown in table 3.1.

The qualitative characteristic "smaller the better". Hence it is used to minimize the cycle time, volumetric shrinkage, and deflection. "larger is better" is used to maximize the quality prediction. The equations are used for finding normalized values are taken from grey relational analysis method. Table 3.1 presented the results and table 3.2 shows deviation sequences.

Table. 3.1. DN20 vent- cycle time, volumetric shrinkage, quality prediction and deflection

S. No	Deflection (mm)	Volumetric Shrinkage (at Ejection) (%)	Cycle Time (Sec)	Quality Prediction (%)
1	0.3928	0.9318	0.6444	0.4373
2	0.3839	0.8693	0.5571	0.1026
3	0.2767	0.8011	0.4682	0
4	1	1	0.9508	1
5	0.4732	0.8806	0.9016	0.9965
6	0.7053	0.9886	1	0.9965
7	0.0535	0.0909	0.2302	0.8060
8	0.0446	0.0284	0.1285	0.8003
9	0	0	0	0.8015

Table 3.2 DN20 vent - Deviation sequences

S. No.	Δ0i (1)	Δ0i (2)	Δ0i (3)	Δ0i (4)
1	0.6072	0.0682	0.3556	0.5627
2	0.6161	0.1307	0.4429	0.8974
3	0.7233	0.1989	0.5318	1
4	0	0	0.0492	0
5	0.5268	0.1194	0.0984	0.0035
6	0.2947	0.0114	0	0.0035
7	0.9465	0.9091	0.7698	0.194
8	0.9554	0.9716	0.8715	0.1997
9	1	1	1	0.1985

Since all links are given the same choice, it is considered ξ as 0.25. Coefficient of gray relativity for each experiment is found and shown in table 3.3. Based on highest grey relational grade (i.e Rank 1) experiment no 4 has the best multiple performance characteristics among all nine experiments. In present study optimum processing parameters of injection moulding can be found from grey relational grade.

Table 3.3 Grey relational-grade values and order

S. No	Grey Relational Coefficient				Grey relational grade (γi)	Rank
	Deflection (mm)	Volumetric Shrinkage at Ejection (%)	Cycle Time (s)	Quality Prediction (%)		
1	0.2916	0.7856	0.4128	0.3076	0.4494	4
2	0.2886	0.6566	0.3608	0.2178	0.3809	5
3	0.2568	0.5569	0.3197	0.2	0.3335	6
4	1	1	0.8355	1	0.9588	1
5	0.3218	0.6768	0.7175	0.9862	0.6755	3
6	0.4589	0.9564	1	0.9862	0.8504	2
7	0.2089	0.2157	0.2451	0.5631	0.3802	7
8	0.2074	0.2046	0.229	0.5559	0.2992	8
9	0.2	0.2	0.2	0.5574	0.2893	9

It can be distinguished the influence of each processing parameter on the gray relational bias at different levels since experimental design is orthogonal. By averaging the relative gray estimate for experiments 1, 2, and 3, 4, 5 and 6, 7, 8 and 9, respectively, average value of the relative gray estimate for the melt temperature at levels 1, 2, and 3 will be found. The same is shown in Table 3.4. Response graph (Signal-to-noise ratio) of gray relational estimate shown in Figure 3.1. The optimal level of processing parameters is the level with the highest degree of relativity of gray.

The average value of the relative degree of greyness for each level of processing parameters and total average gray value for nine experiments are presented in table 3.4. Optimized processing parameters (less volume shrinkage, cycle time, deflection, and high-quality prediction) correspond to [A2B1C2], is shown in table 3.4.

Table 3.4 Grey relational grade -Response table

Symbol	Processing parameters	Grey Relational Grade			Main Effect (max – min)	Rank
		LEVEL 1	LEVEL 2	LEVEL 3		
A	Melt Temperature	0.3879	0.8282*	0.2989	0.5293	1
B	Mould Temperature	0.5721*	0.4518	0.4911	0.1203	2
C	Injection Time	0.533	0.543*	0.4391	0.1034	3
Total average grey relational grade values (γm = 0.513) * grey relational grade-optimum values						

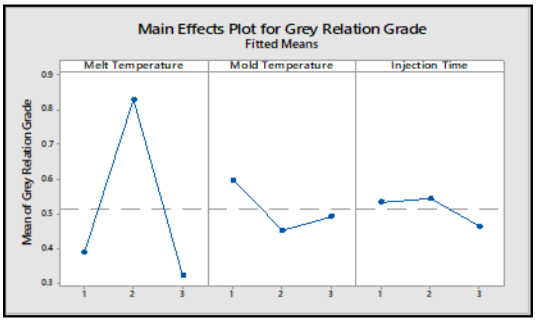

Fig. 3.1. S/N ratios response graph of Grey Relational Grade

3.2 Analysis of Variance (ANOVA)

ANOVA is being carried out to investigate which factor is most influence on performance. It is achieved by isolating the relational estimates of gray total variability. This is calculated by the sum of the squares of the deviations from the total average value of the relational estimates of gray for each process parameter and error. The contribution % of each factor to sum of square of deviations can be used to assess the processing parameters performance. The F value shown in Table 3.5 will also be used to find the factor which has a more influence on performance. A change in a certain factor has more influence on the performance profile, when the F value is large.

Table 3.5 Processing parameters - contribution percentage

Source	DF	Adj SS	Adj MS	F-Value	Percentage contribution (%)
Melt Temperature	2	0.453455	0.226728	57.67	89.6
Mould Temperature	2	0.033389	0.016694	4.25	6.60
Injection Time	2	0.011380	0.005690	1.45	2.25
Error	2	0.007863	0.003931		1.55
Total	8	0.506086			100

It is obvious that melt temperature is substantial parameter and is given in table 3.5. Table 3.3 shows that 0.09588 was the highest score of grey scale from experiment run 4.

Average grey relational grade from Mould flow analysis results shown in table 2.2. it can be observed that the highest grey relational grade value i.e mould temperature, melt temperature, and injection time are 70ºC, 300ºC, and 0.7s, respectively.

In order to achieve best quality, lower volumetric shrinkage, less deviation, and lesser cycle time these are few levels of controlled technological factors that are recommended. This analysis shows that most influence processing parameter is melting temperature, next by injection time, and mould temperature which affect the injection moulding of DN20 Vent.

3.3 DN20 Vent- Injection Moulding

Fig.3.2. Dn20 vent mould core and cavity manufacturing process.

Fig.3.3. DN20 vent manufacturing
(melting temperature is 300ºC, mould temperature is 70ºC, injection time is 0.7s.)

DN20 vent mould cavity, and core are manufactured by injection moulding process shown in fig. 3.2. DN20 vent is manufactured at optimized processing parameters where mould temperature is 70ºC, melting temperature is 300ºC, and injection time is 0.7 s as presented in fig. 3.3.

4. Conclusion

Water meter components of DN20 Vent were developed in CREO software. The components are printed in 3D to evaluate the dimensions and to cross check whether all components can be placed in mould or not. MFA is carried out on the components of the water meter using nylon 6, 6 taking into account 3 levels of each processing parameter, i.e., the melting point (280°C, 300°C, 320°C), mould temperature (700°C, 800°C, 900°C) and injection time (0.4s, 0.7s, 1.0s) using Mould Flow Adviser sofware. From the results of MFA, it was found that the responses are cycle time, deflection, shrinkage volume, and quality prediction. According to the grey relational analysis results, the highest degree of gray for DN20 Vent, processing parameters are mould temperature 70°C, melting temperature 300°C, and injection time 0.7s. The mould cavity and core components are developed in CREO and made of P20 tool steel. DN20 Vent components are manufactured with optimized processing parameters by injection moulding machine.

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