MULTI-RESPONSE OPTIMIZATION OF PLASTIC INJECTION MOULDING PROCESS USING GREY RELATIONAL ANALYSIS BASED IN TAGUCHI METHOD

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ABSTRACT: This project investigates the multi-response optimization using grey relational analysis based in Taguchi method of plastic injection mould. Four input process parameters selected are mould temperature, melting temperature, injection time and cooling time. The responses investigated were part weight, shrinkage, warpage, ultimate tensile strength, tensile modulus and percentage of elongation. It is found that the optimum setting parameter generated from multi-response optimization is at run number 4 that are mould temperature at 56^{o}C, melting temperature at 250^{o}C, injection time at 0.7s and cooling time at 15.4s. Result of run number 4 for multi-response optimization for part weight, warpage, shrinkage, tensile ultimate strength, tensile modulus and percentage of elongation are 6.9807g, 0.087mm, 1.73%, 24.732MPa, 981.76MPa and 31.37%, respectively. Multi-response optimization results show that all response results are not higher or lower than experimental results. This is because multi-response optimization normalized all response value. Thus, by implemented multi-response optimization process, the materials characteristics value of plastic part can be predicted.

KEYWORDS: *Injection Moulding Process; Taguchi Method; Grey Relational Analysis; Processing Parameter; Multi-Response Optimization*

1.0 INTRODUCTION

Optimizations process parameters have been studied widely to improve the quality of the plastic part. One of them is using Taguchi method. In Taguchi optimization process, orthogonal array and S/N ratio was applied. The advantages of the Taguchi optimization, experimental runs for experimental process can be reduced and time and cost of the experiment can be save [1-2]. One of the outputs to be studied in this research is the weight of plastic parts. This is because the weight of the part is strongly related with its mechanical behavior. Nagahanumaiah and Ravi [3] have explored the effect of injection moulding process on product quality of part weight. The moulded plastic become stronger when the part weight was higher due to the product did not show any defect such as bubbles or void in the plastic part. Hassan [4] also studied the effect of process parameters such as packing pressure, packing time, injection pressure, injection time and injection temperature on the weight of the injection moulding products and found process parameters effect the part weight. Other researcher such as López et al. [5] investigated the effect of injection temperature on the weight of plastic part because part weight was interconnection with mechanical behavior of plastic part. They also reported that when the injection temperature increased, the weight of part also increased. This is because the material flows better due to its lower viscosity at high injection temperature.

Warpage was one of the important criteria in assessing the processing quality of injection moulded products and it was considered as one of the major defects plastic processing. Amran et al. [6] studied the effect of process parameters on warpage by using Taguchi method as optimization method. It was found that warpage of plastic part was minimized by using optimum combination of processing parameters from the Taguchi approach. The next response to be investigated in this study is shrinkage of plastic part. Shrinkage at gate and transverse direction was the most affected geometrical value in plastic assembly process. This phenomenon happens due to the un-optimized process condition [7]. Several researchers have investigated the effect of process conditions of injection moulded parts on part weight [8] and shrinkage [9]. For shrinkage direction, Zhang et al. [10] evaluated shrinkage in direction of melt flow meanwhile Annicchiarico et al. [11] studied the shrinkage of micro moulded part by considering the shrinkage in line to the gate direction.

In addition, the process parameters of injection moulding affect the quality and performance of the moulded product. The optimization process involved time of cooling and holding, temperature of melting and mould, holding pressure and injection speed are needed to produce plastic products that have a better performance in term of mechanical properties. There have been several studies to study the influence of process parameters on mechanical properties of plastic part. Mirvar et al. [12] found that the process parameters such as time of holding pressure is the most affected factor that affect the tensile strength followed by cooling time and holding pressure. Furthermore, Mehat et al. [13] studied the effect of process parameters such as melting temperature, holding pressure, time of cooling and packing on ultimate strength and elongation at break of plastic gear. They found that the changes in the process parameters have contributed the variation of result in the mechanical properties of the plastic part. One of the method to optimize the input parameters is using Taguchi method.

Even though Taguchi method is a powerful tool for optimization, it exhibits a number of limitations. The optimization design of injection moulding process parameters can be hard because more than one value characteristic was used in the evaluation. Problems occur when the optimal process parameters different between one another because of different characteristic of each response [14]. Therefore, some researchers have approached a multi-response method called Taguchi with Grey Relational Analysis (GRA) method to get the best combination of process parameters of multiple characteristic performances [15-17]. Hence, optimization of injection moulding parameters on weight, warpage, shrinkage and mechanical properties of plastic part using Taguchi method and GRA approach was conducted.

Various input process parameters of injection moulding affect the quality of plastic part. This project selects four input process parameters that are melting temperature, mould temperature, time of injection time and cooling. Further, in this study, experimental matrix design using Taguchi method and the multi-response optimization of GRA based on Taguchi method was used to investigate on the plastic part quality such as part weight, shrinkage, warpage, ultimate tensile strength, tensile modulus and percentage of elongation using GRA approach based in Taguchi method.

2.0 EXPERIMENTAL METHOD

CATIA software was used to design the dumbbell shape of plastic part. After that, the completed of dumbbell shape design was transferred to Autodesk Moldflow Simulation software for meshing the surface area. Then analysis moulding windows was done to obtain injection moulding process parameters based on mould temperature, melting temperature, time of injection and cooling. Then, the design of experiment implemented Taguchi method that generated total number of nine experimental runs. Injection moulding machine Arburg model 370H 600-170, 60 tonnages were used to conduct the experiment.

After dumbbell part was injected, analysis was performed to determine the warpage, geometrical shrinkage, part weight, ultimate tensile strength, tensile modulus and percentage of elongation of plastic parts. The studied responses were part weight measured by using digital electronic weighting machine, warpage using Mitutoyo horizontal optical comparator model PH 3500, shrinkage using Mitutoyo digital caliper and mechanical properties tested by using Universal Testing Machine (UTM) model Instron 5969. The multi-response optimization using GRA approach based on Taguchi method was implemented because there was more than one output to be optimized. Therefore, this method was used in order to find a set of optimum parameters of the multi-response.

2.1 Moulded Part

This project started by designing the dumbbell shaped part using CATIA V5 software and the completed design was transferred into Autodesk Moldflow Insight (AMI) for find the suggestion process parameters of mould temperature, melting temperature, time of injection and cooling. The plastic part performed was using polypropylene material with density of 0.9g/cm^3 and melt flow index (MFI) of material is 4g/10 min. Figure 1 shows the ejected plastic part with its feed system that consists of sprue, runner and gate.

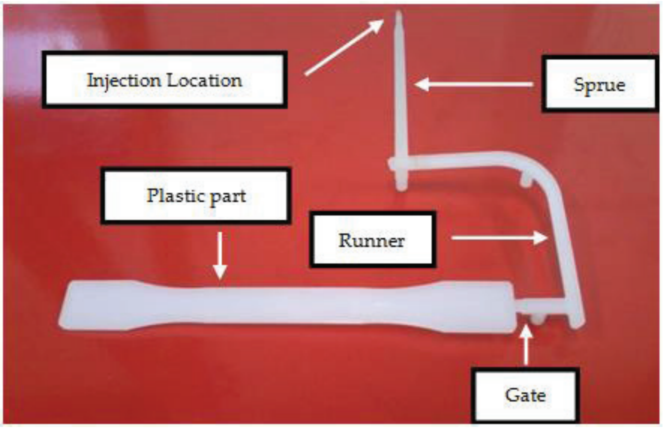

Figure 1: Ejected plastic part with feed system

2.2 Experimental Process

Moldflow software using molding window application was performed to find the process parameters. It is found that experimental processing suggested by AMI software were mould temperature (MoT) 56°C, melting temperature (MeT) 280°C, injection time (IT) 0.7s and cooling time (CT) 14s. Three level designs on each factor were performed according to orthogonal array concept of Taguchi method where "0" symbol in the figure means medium, "-1" means low and "+1" means high. This project has implemented 10% of minus and plus from medium value [18]. Table 1 shows the process parameters setting having three levels with four factors.

Table1: Experimental parameters setting for injection moulding process

Input Factors	-1	0	+1
MoT (°C)	50	56	62
MeT (°C)	250	280	310
IT (s)	0.63	0.70	0.77
CT (s)	12.6	14.0	15.4

3.0 RESULT AND DISCUSSION

3.1 Experimental Work Result

Table 2 shows the result of experimental work for all responses that are part weight, warpage, shrinkage, ultimate tensile strength, tensile modulus and percentage of elongation. It is found that the highest and the lowest of part weight found at 6.9888g for run number 3 and 6.9773g for run number 7, respectively. Meanwhile, the highest and the lowest of warpage found at 0.378mm for run number 5 and 0.087mm for run number 4, respectively. For shrinkage, the highest and the lowest found at 1.86% at run number 9 and 1.72% at run number 3 respectively. Further, the highest and the lowest of ultimate tensile strength found at 24.785MPa for run number 8 and 23.458MPa for run number 2 respectively. Tensile modulus, the highest and the lowest found at 1014.72MPa at run number 8 and 939.37MPa at run number 3 respectively. Finally, for percentage elongation, the highest and the lowest found at 35.26% at run number 2 and 29.27% at run number 1, respectively.

Table2: Summarization of experimental work result from all responses

Run	MoT (°C)	MeT (°C)	IT (s)	CT (s)	Part Weight (g)	Warpage (mm)	Shrinkage (%)	Ultimate Strength (MPa)	Tensile Modulus (MPa)	Percentage Elongation (%)
1	50	250	0.63	12.6	6.9842	0.313	1.73	23.608	947.55	29.27
2	50	280	0.70	14.0	6.9822	0.299	1.76	23.458	953.39	35.26
3	50	310	0.77	15.4	6.9888	0.229	1.72	23.539	939.37	34.33
4	56	250	0.70	15.4	6.9807	0.087	1.73	24.732	981.76	31.37
5	56	280	0.77	12.6	6.9798	0.378	1.77	24.380	970.59	33.07
6	56	310	0.63	14.0	6.9853	0.190	1.82	24.405	949.58	32.65
7	62	250	0.77	14.0	6.9773	0.286	1.80	24.577	966.82	31.79
8	62	280	0.63	15.4	6.9784	0.339	1.84	24.785	1014.72	32.23
9	62	310	0.7	12.6	6.9800	0.274	1.86	24.430	958.28	31.91

3.2 Multi-response Optimization

Data from the experimental work are compiled for multi-response optimization prediction. The Gray Relation Analysis (GRA) is used to get the best quality features by optimization of conditions of multiple input parameters. The data should be processed into normalize the raw data for another analysis from quantitative index. In comparison between 0 and 1, the converting process from the unique into decimal arrangement needs to be made by cracking the raw data. The GRA normalized arrangement after data processing. The higher-the-better is performed on the experimental results such as ultimate tensile strength (UTS), tensile modulus, percentage of elongation and part weight, then the original sequence can be normalized using Equation (1). If the expected data sequence is of the form smaller-the-better especially for warpage and shrinkage, then the original sequence can be normalized as Equation (2).

$$x_i^* = \frac{x_i^0(k) - \min[x_i^0(k)]}{\max[x_i^0(k)] - \min[x_i^0(k)]} \tag{1}$$

$$x_i^* = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{2}$$

Where $x_i^0(k)$ is the original sequence, $x_i^*(k)$ the sequence after the data preprocessing, max $x_i^0(k)$ the largest value of $x_i^0(k)$ and min $x_i^0(k)$ imply the smallest value of $x_i^0(k)$. After data normalization Grey relational coefficient (GRC) was formularized to show the connection between the ideal and actual normalized data results. The GRC can be stated as in Equation (3).

$$\xi_i(k) = \frac{\Delta_{min} + \zeta \bullet \Delta_{max}}{\Delta_{0i}(k) + \zeta \bullet \Delta_{max}} \quad (3)$$

Where $\Delta_{0i}(k)$ was the deviation sequence of the reference sequence, ζ was credentials coefficient: $\zeta\varepsilon[0,1]$, $\zeta = 0.5$ was generally used. Next, after the GRC, normally the average of the GRC was engaged as the grey relational grade (GRG) and expressed in Equation (4). Table 3 shows the GRC and GRG for the all responses.

$$\gamma_i = \frac{1}{n}\sum_{k-1}^{n}\xi_i(k) \quad (4)$$

Table 3: Order result of multi-response for all responses

Run	GRC						GRG	Order
	UTS	Tensile Modulus	Percentage Elongation	Warpage	Shrinkage	Weight		
1	0.3607	0.3593	0.3333	0.3917	0.8750	0.5556	0.4793	8
2	0.3333	0.3805	1.0000	0.4070	0.6364	0.4656	0.5371	4
3	0.3474	0.3333	0.7631	0.5061	1.0000	1.0000	0.6583	2
4	0.9296	0.5334	0.4350	1.0000	0.8750	0.4152	0.6980	1
5	0.6226	0.4605	0.5776	0.3333	0.5833	0.3898	0.4946	6
6	0.6408	0.3664	0.5343	0.5855	0.4118	0.6216	0.5267	5
7	0.7674	0.4403	0.4633	0.4224	0.4667	0.3333	0.4822	7
8	1.0000	1.0000	0.4971	0.3660	0.3684	0.3560	0.5979	3
9	0.6535	0.4003	0.4720	0.4376	0.3333	0.3952	0.4487	9

It is found that from Table 3, run number 4 is the most suitable combination of multi-response optimization. Result of run number 4 for multi-response optimization for part weight, warpage, shrinkage, tensile strength, tensile modulus and percentage of elongation are 6.9807g, 0.087mm, 1.73%, 24.732MPa, 981.76MPa and 31.37% respectively. As compared with experimental work results, the value of all responses by multi-response optimization are not higher and lower than experimental work result except for warpage which input parameters for warpage similar with run number 4 in experimental work and multi-response optimization as shown in Table 4. This is because multi-response takes all responses, which normalized the output value. This was setting the characteristics during normalization process by taken the higher the better for part weight and mechanical properties meanwhile the lower the better for warpage and shrinkage.

Table 4: Comparison result of multi-response optimization with experimental work result for all responses

	Part Weight (g)	Warpage (mm)	Shrinkage (%)	Ultimate Strength (MPa)	Tensile Modulus (MPa)	Percentage Elongation (%)
Run no.	3	5	9	8	8	2
Maximum	6.9888	0.378	1.86%	24.785	1014.72	35.26
Run no. 4	6.9807	0.087	1.73	24.732	981.76	31.37
Minimum	6.9773	0.087	1.72%	23.458	939.37	29.27
Run no.	7	4	3	2	3	1

4.0 CONCLUSION

The multi-response optimization of dumbbell plastic part in an injection moulding process using Taguchi method based in grey rational analysis is investigated. The optimization run of multi-response optimization of all responses are found on run number 4 which mould temperature 56^{o}C, melting temperature 250^{o}C, injection time 0.73s and cooling time 15.4s. In addition, it is found that multi-response optimization results of all responses such as part weight, warpage, shrinkage and mechanical properties show in the range of result found by experimental work. It shows that by implemented multi-response optimization, the result of material characteristics is not higher or lower than experimental work result for all responses. This is because, multi-response optimization taking all considerations based on objective in initial setup and normalized all output responses.

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REFERENCES

[1] M.H. Osman, N.F. Tamin, M.N. Ahmad, M.H. AB. Rahman, M.K. Wahid, N.A. Maidin, M.H. Abu Bakar, A.A. Azahar, "Effect of cutting parameters on surface roughness in dry drilling of AISI D2 tool steel by using Taguchi method", *Journal of Advanced Manufacturing Technology,* vol. 12, no. 1(2), pp. 535-545, 2018.

[2] X.S. Sánchez, A.E. Zuñiga and M.H. Avila, "Processing of ultra-high molecular weight polyethylene/graphite composites by ultrasonic injection moulding: Taguchi optimization", *Ultrasonics Sonochemistry*, vol. 44, pp. 350-358, 2018.

[3] Nagahanumaiah and B. Ravi, "Effects of injection molding parameters on shrinkage and weight of plastic part produced by DMLS mold", *Rapid Prototyping Journal*, vol. 15, no. 3, pp. 179–186, 2009.

[4] H. Hassan, "An experimental work on the effect of injection molding parameters on the cavity pressure and product weight", *International Journal of Advanced Manufacturing Technology*, vol. 67, no. 1, pp. 675-686, 2013.

[5] A. López, J. Aisa, A. Martinez and D. Mercado, "Injection moulding parameters influence on weight quality of complex parts by means of DOE application: case study", *Measurement*, vol. 90, pp. 349-356, 2016.

[6] M. Amran, S. Salmah, M. Zaki, R. Izamshah, M. Hadzley, Sivaraos, M. Shahir and M. Amri, "The effect of pressure on warpage of dumbbell plastic part in injection moulding machine", *Advanced Materials Research*, vol. 903, pp. 61-66, 2014.

[7] E. Hakimian and A.B. Sulong, "Analysis of warpage and shrinkage properties of injection-molded micro gears polymer composites using numerical simulations assisted by the Taguchi method", *Materials and Design*, vol. 42, pp. 62-71, 2012.

[8] M.A.M Amran, N. Idayu, K.M. Faizal, M. Sanusi, R. Izamshah and M. Shahir, "Part weight verification between simulation and experiment of plastic part in injection moulding process", *IOP Conference Series: Materials Science and Engineering*, vol. 160, no. 1, pp. 1-7, 2016.

[9] B. Kc, O. Faruk, J.M. Agnelli, L. Leao, J. Tjong and M. Sain, "Sisal-glass fiber hybrid biocomposite: optimization of injection molding parameters using Taguchi method for reducing shrinkage", *Composite Part A: Applied Science Manufacturing*, vol. 83, pp. 152-159, 2016.

[10] K. Zhang, L. Jiang, P. Luo, J. Jiang and G. Wu, "Effect of melt flow on morphology and linear thermal expansion of injection-molded ethylene–propylene–diene terpolymer/isotactic polypropylene blends", *Polymer International*, vol. 64, no. 9, pp. 1225-1234, 2015.

[11] D. Annicchiarico, U.M. Attia and J.R. Alcock, "Part mass and shrinkage in micro injection moulding: statistical based optimisation using multiple quality criteria", *Polymer Testing*, vol. 32, no. 6, pp. 1079-1087, 2013.

[12] S.E. Mirvar, R.M. Kaleybar and A. Afsari, "Optimization of injection molding process parameters to increase the tensile strength in polyamide-specimen using the taguchi method", *Advanced Materials Research*, vol. 341, pp. 395-399, 2011.

[13] N.M. Mehat, S. Kamaruddin, and A.R. Othman, "Investigating the effects of injection moulding process parameters on multiple tensile characteristics of plastic spur gear via experimental approach", *Advanced Materials Research*, vol. 748, pp. 544-548, 2013.

[14] N.M. Mehat, S. Kamaruddin, A.R. Othman, N.M. Mehat, S. Kamaruddin and A.R. Othman, "Hybrid integration of taguchi parametric design, grey relational analysis, and principal component analysis optimization for plastic gear production", *Chinese Journal of Engineering*, vol. 2014, pp. 1-11, 2014.

[15] S. Gobinath, D. Elangovan, E. Sivakumar and S.R. Devadasan, "Viability study of use of reprocessed high density polyethylene for manufacturing products and multi response optimization of injection moulding parameters using grey relational analysis", *Polymer & Polymer Composite*, vol. 24, no. 7, pp. 547-555, 2016.

[16] H. Pervez, M.S. Mozumder and A.-H. Mourad, "Optimization of injection molding parameters for HDPE/TIO2 nanocomposites fabrication with multiple performance characteristics using the Taguchi method and grey relational analysis", *Materials*, vol. 9, no. 8, pp. 710-721, 2016.

[17] P. Jayaraman and L.M. Kumar, "Multi-response optimization of machining parameters of turning AA6063 T6 aluminium alloy using grey relational analysis in taguchi method", *Procedia Engineering*, vol. 97, pp. 197-202, 2014.

[18] M.A.M. Ali, A. Abdullah, S. Dahaman, A. Amin and S. Mansor, "Review the mechanical properties of reinforcing agents in polypropylene matrix of car bumper", *ARPN Journal of Engineering and Applied Sciences*, vol. 12, no. 14, pp. 4209-4213, 2017.