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OPTIMIZATION OF METAL INJECTION MOULDING PROCESS PARAMETERS USING ANOVA METHOD

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ABSTRACT
Identification of significant process parameters during injection moulding of feedstock in Metal Injection Moulding (MIM) is essential because fine control is required for these parameters. The small change in these parameters can cause large variation in the impact energy absorbed of the parts produced by MIM. The controlled parameters used for optimization in this work include injection pressure, injection temperature, injection speed and cooling time. The parameters have been optimized using analysis of variance (ANOVA) for signal to noise ratios. The software used for this analysis is MINITAB 17. The ANOVA also provides the contribution of significant process parameters to impact toughness. Results show that the injection pressure, injection temperature are highly significant factors to the impact toughness, while the injection speed, cooling time, the interaction of injection pressure and injection temperature and interaction of injection speed and injection cooling time do not show significant effect at 95% confidence level.

INTRODUCTION
Metal injection moulding (MIM) is an emerging technology to process metal powders into parts of desired shapes. The MIM process combines the traditional shape-making capability of plastic injection moulding and materials flexibility of powder metallurgy. The process consists of four main steps: mixing, injection moulding, debinding and sintering. In the mixing step, the powder is mixed with a binder to form a homogeneous feedstock. The binder is key component, which provides the necessary flowability and formability for moulding. During injection moulding a green part with the desired shape is formed by the feedstock flow into a mold under pressure. After moulding, the binder holds the particles in place. The binder is then removed in the debinding step and the debound part is sintered to achieve the required mechanical properties. The quality of the green parts affects the sintered parts. Once the parts have been molded to the required shape, there is little that can be done to remedy defects caused during injection Moulding. The geometrical accuracy and mechanical properties of the final parts after sintering depend strongly on the process parameters in the different stages. Although the MIM process offers many advantages, it requires the proper moulding condition. The classical Design of Experiment (DOE) technique has been used by many authors for optimization of single process parameters at a time. In order to obtain high efficiency in the planning and analysis of experimental data, the Taguchi method is recognized as a systematic approach for design and analysis of experiments to improve product quality. The Taguchi method has been applied by many authors to investigate and optimize the process parameters. The majority of previous investigations in MIM have focused on the sintering parameters and the amount of metal powder in the mixture. The effects of the injection moulding parameters on impact toughness of the parts produced by MIM have not yet been thoroughly investigated. The objective of this paper is to optimize the moulding parameters that simultaneously satisfy the requirements for quality control of green part before it undergoes debinding and sintering processes to attain the desired impact toughness. In this paper, the experiment is conducted by following Taguchi L_{27} orthogonal array and data is analyzed by using analysis of variance (ANOVA) to find the significant factors and their contribution in impact toughness of final part.

MIM PROCESS PARAMETERS

Injection Moulding Procedure
Injection moulding process includes heating of the feedstock material to melting temperature, forcing the molten material into the mould cavities, holding at high pressure, then cooling and ejection of the molded parts out of the mould cavity. In the experimental work, a Damage injection moulding machine with microprocessor control was used. It was loaded with LCD display, function keys, pump control, heater control, manual function keys etc. Arrangements were provided for mould sensing and mould cooling, and pneumatic ejectors in the control panel. On the machine, the injection pressure, injection temperature, mould temperature, holding pressure,

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injection speed, holding time and cooling time were set at the desired values. Since, the powder loading is an external factor; it is not to be taken care by the machine control. Three types of feed stocks were developed before the start of the experiment with fine weight control and homogeneous mixing. The twenty seven runs were divided in three sets of nine runs each with the level of powder loading as constant. Each set of values was repeated five times to make samples at each processing conditions after the machine has come to smooth functioning. All the test parts were produced using only virgin feedstock. To achieve the maximum uniformity of the green parts the same moulding sampling plan was followed for five runs. Following the production of parts in each run the parts were visually inspected. In some cases there was processing error, such parts were discarded and replaced with new parts.

Debinding Procedure

The green parts produced were debinded according to the process parameter control decided for debinding. The solvent and thermal debinding techniques were used in this work to remove the binders effectively. In the first step, solvent extraction was used to extract out the PEG from the green parts. The green specimens were immersed in distilled water maintained at solvent debinding temperature 60°C for 6 hours with continuous stirring. The leached specimens were then dried in an oven at 50°C for 4 hours to completely remove the remains of water and then cooled. The second step, referred to as thermal debinding was used to remove the PMMA and stearic acid after solvent debinding. The leached specimens were put into an alumina tray in which the surrounding space was filled with alumina powder to avoid any distortion of the specimens. The thermal debinding temperature of 350°C was achieved in a vacuum furnace in three steps. First, heating upto 200°C at the rate of 2.5°C/min. Second, heating upto thermal debinding temperature of 350°C at the rate 1 °C/min. The temperature was held constant for 2 hours for the purpose to remove the polymers of the binder. The brown part was allowed for slow cooling to ambient temperature (27°C) at the rate of 1 °C/min to release the residual stress from the part.

Sintering Procedure

For sintering the brown parts were first presintered then sintered. The peak temperature for presintering after debinding was kept 900°C. The heating rate was 3°C/min and the holding time at peak temperature was 60 minutes. The cooling rate was 5°C/min. The presintered specimens were sintered afterwards in a batch furnace. The sintering was carried out in vacuum conditions at 1360°C. The heating cycle was completed in three steps. The specimen were heated upto 1360°C at the rate of 10°C/min, then held at isothermal sintering temperature for 90 minutes, and finally allowed to cool to ambient temperature (27°C) at the rate of 15°C/min.

Design of Experiment and Testing Procedure

The objective of this work was to find the significant factors and their contribution during the injection moulding of feedstock for best impact toughness. ANOVA was utilized to identify the significant level of each variable. The Taguchi approach was used for this purpose. The raw data was obtained using Taguchi Methodology. Taguchi technique utilises the signal to noise ratio (S/N) approach to measure the deviation of the quality characteristic from the desired value instead of average value. Here the term 'Signal' represents the desirable value (mean) and the 'Noise' represents the undesirable value. Thus S/N represents the amount of variation present in the performance characteristic. Therefore, the experimental results were converted into S/N values for optimization of parameters. The S/N ratio for higher the better was used. The ANOVA provided the confidence level and the variance of the data. The confidence level is measured from the variance of each parameter.

FORMULATION

Since, only Pi, Tm, and φ are the significant factors, the optimum value of impact toughness will depend mainly on these factors and could be estimated by Eq. (1) at the optimum levels.

$$\mu = T + [(Pi)-T] + [(Tm)-T] + [(\varphi)-T] \qquad - (1)$$

Where,
T is the overall mean of impact energy absorbed
(Pi) is the average value of impact energy absorbed
(Tm) is the average value of impact energy absorbed
(φ) is the average value of impact energy absorbed

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The 95% confidence interval (CI) for the expected yield from the confirmation experiment can be calculated using Eq. (2) as follows:

$$CI= (F\alpha(\upsilon 1,\upsilon 2)\ Ve[(1/\eta eff\ )+(1/r)])^{1/2} \qquad -(2)$$

Where, *neff* = (N/(1+ total degree of freedom of all factors used for estimating μ)
r = sample size for the confirmation experiment, r ≠ 0. is the variance ratio of and at level of significance α.

The confidence level is (1-α), is the degree of freedom of mean (equal to 1) and is the degree of freedom for the pooled error. Variance for pooled error is V*e*. The confidence interval indicates the maximum and minimum levels of the optimum performance.

EXPERIMENTAL ANALYSIS

The effect of variable controllable parameters on the mean values of impact toughness is measured by impact energy absorbed by the specimen during unnotched Charpy test. The calculated values for S/N ratio and mean at all process parameter levels are shown in Table 3 and Table 4. The analysis of variance made by using S/N ratio to find the significant factors is expressed in Table 5.

Table 1 : Variable Process Controllable Parameters in Injection moulding

Controllable Factors	Symbol	Level		
		Level1	Level2	Level3
Injection Pressure	Pi(MPa)	50	55	60
Injection Temperature	Ti(°c)	340	350	360
Injection Velocity	Vi(cm/s)	5	10	15
Cooling Time	tc(min)	5	8	15

Table 2: Experimental results

#	Pi (MPa)	Ti (°C)	Vi (cm/s)	Tc (min)	Energy abs(KJ/m²)
1	50	340	5	5	65.32
2	50	350	10	8	75.62
3	50	360	15	15	88.31
4	55	340	10	15	64.21
5	55	350	15	5	71.23
6	55	360	5	8	85.36
7	60	340	15	8	71.42
8	60	350	5	15	80.16
9	60	360	10	5	86.72

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For the given experimental data the analysis is done by ANOVA method for optimization of the controlled factors. The software MINITAB 17 is used for optimization analysis .The calculated values for S/N ratio for all process parameter levels are shown in Table given below.

Table 3: Response table for s/n ratio

Level	Pi	Ti	Vi	tc
1	37.60	36.51	37.67	37.37
2	37.28	37.57	37.50	37.76
3	37.97	38.77	37.68	37.72
Delta	0.70	2.26	0.19	0.39
Rank	2	1	4	3

Table 4: Response table for mean

Level	Pi	Ti	Vi	Tc
1	76.42	66.98	76.95	74.42
2	73.60	75.67	75.52	77.42
3	79.43	76.80	76.99	77.56
Delta	5.83	9.81	1.47	3.14
Rank	2	1	4	3

Total degree of freedom, fT
fT = N-1= 9-1=8
Where, N is the total number of results.
Degree of freedom for Factor A, fA: fA= KA-1= 3-1= 2

$$SSA = \frac{(\sum A1)^2}{KA} + \frac{(\sum \mathrm{A2})^2}{\mathrm{KB}} - \frac{(y1 + y2 + \cdots yn)^2}{n}$$

SST = ∑(SSA+SSB+…+SSE)
where stands for sum of the when Factor A is in the ith level.
Variance for Factor A, VA: $VA=\frac{SSA}{fA}$
Percentage contribution, C% for Factor A: $C\%=\frac{SSA}{SST} \times 100$
Percentage contribution (C%) shows which factors have a greater impact on impact energy absorbed

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Table 5: ANOVA Table using S/N Ratios for Impact Energy

Factors	DOF	Sums of square	(Vn)	(Fn)	(α)	Pure sum square	P (%)
Pi	2	2.2432	1.1216	7.43	0.05	1.9414	27.87
Ti	2	0.3002	0.1501	3.42	0.05	0.7319	10.51
Vi	2	0.5859	0.2930	2.23	0.05	0.3699	5.31
Tc	2	0.6904	0.0308	2.64	0.05	0.3042	5.12
Residual error	16	3.0176					38.57
Total	8	6.9662					100

From the graphs and residual plots the most optimistic values for highest impact energy absorption by s/n ratios are calculated on MINITAB 17 software by balanced ANOVA method.

Table 6: Optimum Factor Level for Highest Impact Energy Absorption

Process parameters	Symbol	Optimum value
Injection Pressure	Pi	57 MPa
Injection Temperature	Ti	352.3ºC
Injection velocity	Vi	12 cm/s
Cooling time	Tc	7 min

CONFORMATION TEST

Since, only Pi, Ti,Vi and tc are the significant factors, the optimum value of impact toughness will depend mainly on these factors and could be estimated by Eq. (1) at the optimum levels shown in Table 6.

$$\mu = Em + [(Pi)3 - Em] + [(Ti)3 - Em] + [(Vi)3 - Em] + [(tc)3 - Em] \qquad -(1)$$

Where,Em is the overall mean of impact energy absorbed =76.48KJ/m² (Pi)3 is the average value of impact energy absorbed at level 3 of factor Pi = 79.43J/m²

(Ti)3 is the average value of impact energy absorbed at level 3 of factor Tm = 76.80kJ/m²
(Vi)3 is the average value of impact energy absorbed at level 3 of factor Vi = 76.99KJ/m²
(tc)3 is the average value of impact energy absorbed at level 3 of factor tc =77.56KJ/m²

Hence, the expected impact energy absorbed at optimum condition is:
μ = 76.48+(79.43-76.48)+(76.80-76.48)+(76.99-6.48)+ (77.56-76.48)
μ = 81.43KJ/m²

Hence the optimum value of impact toughness will be 81.43KJ/m²
To confirm the prediction, another 3 samples were made at the recommended settings as shown in Table 6. The experimental observations if impact energy absorbed are given in Table 7.

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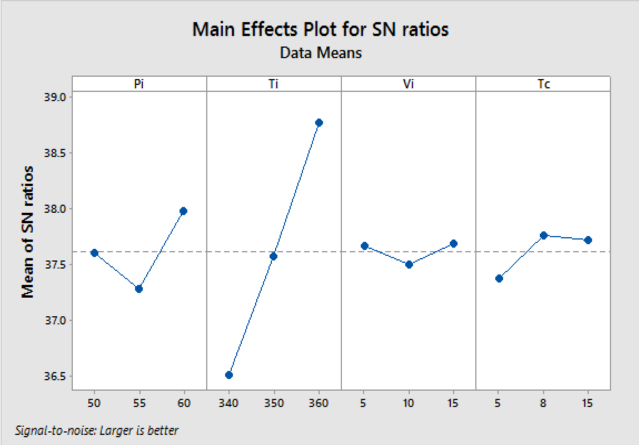

Fig.1 Graph showing main effect plot for SN ratios

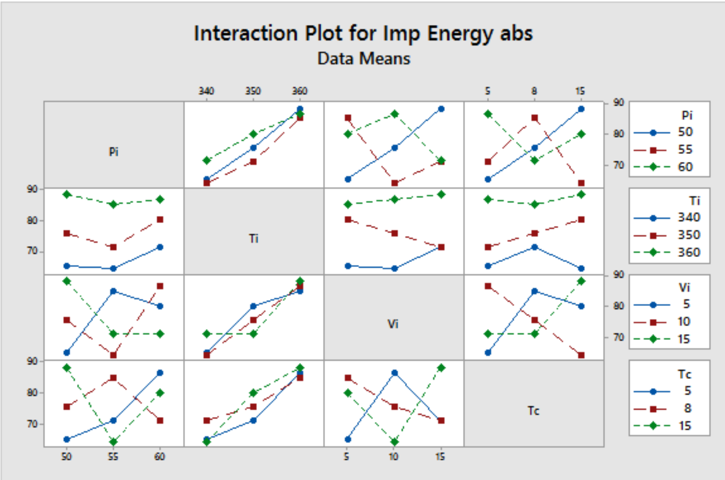

Fig.2: Graph for interaction plot for Impact Energy Absorbed

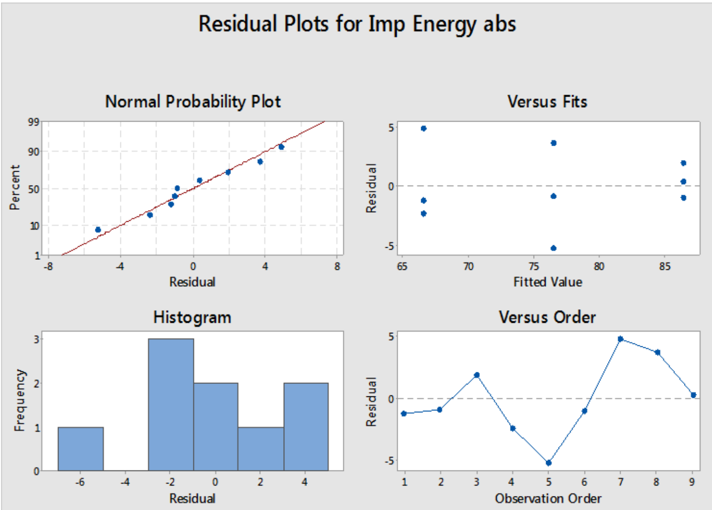

Fig.3: Residual plots for Impact Energy Absorbed

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Table 7: Results of conformation test

Parameter	Replication at optimum process parameters			Average	MINITAB predictade value
	E1	E2	E3		
Impact energy abs				79.26	81.43

It can be observed that the average impact energy absorbed obtained from the confirmation experiment. From Table 6, it can also be noted that the experimental results are close to the predicted result by Minitab 17 software. The difference between measured and predicted values is about 2.66%. It confirms the reliability of the control of process parameters

CONCLUSIONS

This paper presents a review of research work in the area of determination and optimization of the process parameters for MIM. A number of researcher works on the basis of various optimization techniques were including RSM, Taguchi method. A review of research work for various optimization techniques indicates successful industrial applications of Taguchi method, RSM. These are popular optimization techniques to make experimental design uncontrollable factors such as environmental parameters predict responses and optimize the MIM process for accuracy level. Research work has been carried out in order for better way for quality of the product.

REFERENCES

1. *Optimization of Injection Molding Process M. Stanek, D. Manas, M. Manas and O. Suba*
2. *Parameter Optimization of Injection Molding of Polypropylene by using Taguchi Methodology by M. V. Kavade, S. D. Kadam/ ISSN: 2278-1684 Volume 4, Issue 4 (Nov. - Dec. 2012), PP 49-58*
3. *Optimization of injection molding process parameters to improve the mechanical performance of polymer product against impact Yingjie Xu & QingWen Zhang & Weihong Zhang & Pan Zhang*
4. *Optimization of critical processing parameters for plastic injection moulding for enhance productivity and reduced time for development by N.Lahoti, Prof.M.D.Nadar, Swapnil S. Kulkarni /E-ISSN2249–8974*
5. *Application of Taguchi Method in the Optimization of Injection Moulding Parameters for manufacturing Products from Plastic Blend S. Kamaruddin, Zahid A. Khan and S. H. Foong / ISSN: 1793-8236/ Vol.2, No.6/ December 2010*
6. *Optimization of Injection Moulding Process Parameters in the Moulding of Low Density Polyethylene (LDPE) Sajjan Kumar Lal, Dr. Hari Vasudevane /ISSN: 2278-067X, p-ISSN: 2278-800X /www.ijerd.com Volume 7, Issue 5 (June 2013), PP.35-39*
7. *Sintering Parameter Optimization of Ti-6Al-4V Metal Injection Molding for Highest Strength Using Palm Stearin Binder by N.H. Mohamad Nora, N. Muhamadb, A.K.A Mohd Ihsanb, K.R. Jamaludinc / Procedia Engineering 68 (2013) 359 – 364*
8. *Application of Taguchi optimization technique in determining plastic injection molding process parameters for a thin-shell part by Hasan Oktem , Tuncay Erzurumlu , Ibrahim Uzman / Materials and Design 28 (2007) 1271–1278*
9. *Optimization of Injection Molding Process Parameters by Response surface Methods by Sokkalingam Rajalingam, Pandian Vasant, Cheng Seong Khe, Zulkifli Merican*
10. *Optimization of machining parameters of Al/SiC-MMC with ANOVA and ANN analysis by N. Muthukrishnana, J. Paulo Davimb*
11. *Optimization Of Process Parameters Of EDM Using ANOVA Method by Vishnu D Asal, Prof.R.I. Patel, Alok B Choudhary ISSN: 2248-9622 Vol. 3, Issue 2,*
12. *Tseng, W.J. Statistical Analysis of Process Parameters Influencing Dimensional Control in Ceramic Injection Moulding. Journal of Materials Processing Technology. 1998. 79; 242-250.*
13. *Jamaludin, K.R., Muhamad, N., Rahman, M.A., Amin, S.R.M., and Muntadhahadi, 2008: Analysis of Variance on the Metal Injection Moulding Parameters using a Bimodal Particle Size Distribution Feedstock. Proceedings of International Conference on Mechanical & Manufacturing Engineering.*

ISSN 2349-6193
Impact Factor: 2.805

IJESMR

International Journal OF Engineering Sciences & Management Research

14. *MPIF, 2002: Method for Determination of Charpy Impact Energy of Unnotched Metal Injection Molded Test Specimens. Standard 59, Standard Test Methods for Metal Powders and Powder Metallurgy Products.*
15. *Roy, R.K., 1990: A Primer on the Taguchi Method. Competitive Manufacturing Series, Van Nostrand Reinhold. 247*