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OPTIMIZATION OF INJECTION MOULDING PROCESS PARAMETERS TO CONTROL SHRINKAGE OF HDPE AND NYLON COMPONENTS

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ABSTRACT
Injection moulding is one of the most popular polymer processing methods due to its high production rate as well as its ability to produce very intricate geometries at very cheaper cost and within few seconds. There are several flaws which occur while producing plastics parts by injection moulding like warpage, shrinkage, flash, sink marks etc. Shrinkage is one of the most critical problems which cause dimensional changes in the parts during the moulding process. Shrinkage can be minimized by optimal process parameters on injection moulding machine. In this study, optimal injection moulding conditions for minimum shrinkage during moulding are found by DOE Technique of TAGUCHI and ASTM D955. This experiment will help us to study the shrinkage behavior of above plastic materials and both these materials can be processed in a single mould to get the moulding with close tolerance by adding average shrinkage allowance 2% in the cavity in order to know the dimensional difference of both NYLON -66& HDPE product. Taguchi method is used to investigate the effects of melting temperature, injection pressure, holding pressure and cooling time on shrinkage of HDPE & NYLON-66 products.

Keywords: Injection pressure, melting temperature, holding pressure, cooling time, shrinkage, S/N ratio, Taguchi method.

I. INRTODUCTION
Injection moulding is a manufacturing process for producing parts by injecting material into a mould. Injection moulding can be performed with a host of materials, including metals, glasses, elastomers, confections, and most commonly thermoplastics and thermosetting polymers. Material for the part is fed into a heated barrel, mixed, and forced into a mould cavity where it cools and hardens to the configurations of the cavity. Injection moulding is widely used for manufacturing a variety of part, from the smallest components[4].

The material used for the part, the desired shape & features of the part, the material of the mould and the properties of the moulding machine must all be taken into account. The versatility of injection moulding is facilitated by the breadth of design considerations and possibilities. Shrinkage is one of the most important reasons that cause dimensional changes in the part and it can be minimized by setting optimum process parameters on injection moulding machine.

M.C. Huang and C. C. Tai [1] studied the effects of five input parameters on surface quality of thin moulded parts. The input parameters were mould temperature, melting temperature, packing pressure, packing time and injection time. AItan [2] utilized Taguchi method to optimize shrinkage of plastic, PP and PS, injection moulding part. He also applied neural network to model the process and was able to achieve 0.937% and 1.224% shrinkage in PP and PS, respectively.

II. TAGUCHI TECHNIQUE
Taguchi method[3] has two main instruments, which are signal-to-noise (S/N) ratio and orthogonal arrays. It is used to optimize the performance characteristics within the combination of design parameters. In the product/process design of Taguchi, there are basically three steps involved:-

i) System Design: selection of a system for a give objective function.

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ii) Parameter Design:- to find the optimum combination of the process conditions for improving performance characteristics.

iii) Tolerance Design:- determine of tolerance around each parameter level.

Taguchi method uses signal-to-noise (S/N) ratio which reflects both the average and the variation of the quality characteristics[11]. It is a measure of performance aimed at developing products and processes insensitive to noise factors.

Types of S/N ratio:

Larger- the- better:

$S/N = -10 \log_{10} (1/n \Sigma 1/yi^2)$

Where, i=1 to n, n = no. of replications applied to the problems where maximization of quality characteristics of interest is needed.

Smaller- the- better:

$S/N = -10 \log_{10} (1/n \Sigma yi^2)$ It is used where minimization of the characteristics is intended

Nominal-the-best:

$S/N = -10 \log_{10} [\mu^2/\sigma^2]$

Where μ = mean, σ = standard deviation

It is used where one tries to minimize the mean squared error around a specific target value. Adjusting the mean to the target by any method renders the problem to a constrained optimization problem. S/N ratios were used for determining the optimum combinations of the process conditions for shrinkage [12].

III. EXPERIMENTAL STUDY

3.1. Materials

HDPE and NYLON-66 were used for this study. Properties of HDPE and NYLON-66 are mentioned in given table. The grade [IOCL 180 M50] of HDPE and NYLON-66 are injection moulding grade material. Both materials have high melt flow index makes it ideal for moulding of very thin, intricate and large items having adequate mechanical properties. Nylon-66 is a hygroscopic material so it requires dry before processing and HDPE is not a hydroscopic material so it does not require drying before production[7]. The input parameters selected are melting temperature, injection pressure, holding pressure and cooling time. Shrinkage is selected as output.

Properties	Unit	HDPE	NYLON-66
Density	g/cm3	0.941-0.967	1.14
Melt Flow Index	g/10 min	2-20	30-40
Tensile Strength	MPa	18.6-30.3	90.0
Elongation at Break	%	100-1000	20.0
Water Absorption	%	<0.01	2.8
Mould Shrinkage	%	2.0-5.0	1.0-2.5
Melt Temperature	°C	170-180	280-300
Mould Temperature	°C	27	30

3.2. Injection Moulding Process

Specimens (Fig.1) were injection moulded using a 180 ton all electric injection moulding machine (Fig.2), make JSW (Japan Steel Works) with microprocessor control system[5]. Single cavity injection mould (Fig.3) was used to mould the specimens as per ASTM D955, by setting the experimental process parameters. Due to hygroscopic nature of Nylon-66, it is dried for 4 hrs at 90°C prior to injection moulding and hopper dryer is used to protect the material from any moisture attack after the material is put in hopper[6].

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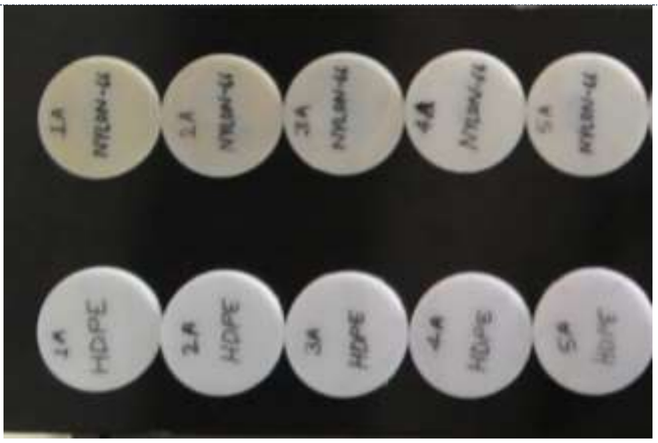

Fig.1: Specimens

Fig.2:Injection Moulding Machine

Fig, 3: Single cavity specimen Mould

3.3. Shrinkage Measurement

Shrinkage is the different between the size of mould cavity and size of finished part divided by size of the mould cavity. It is expressed in percentage[10]. Four points were marked on the circular disk specimen; dimension is

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measured using digital Vernier having accuracy of 0.01 mm and mean dimension is considered for shrinkage calculation.

S = [(Dm-Dp) / Dm] *100

Where,

Dm= mould cavity dimension,
Dp= part dimension and
S= shrinkage

3.4. Experimental Design

In order to control the optimal process conditions and the effect of processing parameters on shrinkage of HDPE and NYLON6,6 product, the Taguchi L9 orthogonal array was selected[11]. The controllable factors selected were the melt temperature, injection pressure. holding pressure and cooling time. Four control factors with three levels were studied, as shown in Table 3.1 & Table 3.2.The signal to noise ratio for each experiment were determined by using smaller the better characteristic.

Table -3.1: Control factors and level for HDPE

Factors	Level 1	Level 2	Level 3
Melting Temperature (°C)	165	170	175
Injection Pressure (MPa)	62	67	72
Holding Pressure (MPa)	44	47	50
Cooling Time (Sec.)	30	35	40

Table -3.2: Control factors and level for NYLON-66

Factors	Levels 1	Level 2	Level 3
Melting Temperature (°C)	280	290	300
Injection Pressure (MPa)	94	102	110
Holding Pressure (MPa)	55	56	57
Cooling Time (Sec.)	3	4	5

IV. RESULTS AND DISCUSSION

Experimental result for HDPE and NYLON-66 is given in table 4.1 & Table 4.2. In this study lower value of shrinkage behavior is expected to be obtained. Thus, for S/N ratio characteristic the Smaller-the-better is applied in analysis of experiment result.

Table-4.1: Shrinkage Values for HDPE

Temp. (°C)	Injection Pressure (MPa)	Holding Pressure (MPa)	Cool. Time (S)	Shrinkage (%)	
				Trial-1	Trial-2
165	62	44	30	1.93	1.91
165	67	47	35	1.91	1.90
165	72	50	40	1.85	1.79
170	62	47	40	1.81	1.91
170	67	50	30	1.95	1.91
170	72	44	35	1.84	1.87
175	62	50	35	1.85	1.97
175	67	44	40	1.83	1.87
175	72	47	30	1.86	1.91

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Table-4.2: Shrinkage Values for NYLON-66

Temp. (°C)	Injection Pressure (MPa)	Holding Pressure (MPa)	Cool. Time (S)	Shrinkage (%)	
				Trial-1	Trial-2
280	94	55	3	2.72	2.85
280	102	56	4	2.92	2.92
280	110	57	5	2.99	3.16
290	94	56	5	3.10	2.95
290	102	57	3	2.98	3.13
290	110	55	4	2.88	2.84
300	94	57	4	2.86	3.01
300	102	55	5	3.03	3.02
300	110	56	3	2.79	2.73

Table-4.3: The response Table of S/N ratios for HDPE

Levels	Melting Temp. (°C), (A)	Injection Pressure (MPa), (B)	Holding Pressure (MPa), (C)	Cooling Time (S), (D)
1	-5.4832	-5.5588	-5.4564	-5.6256
2	-5.4906	-5.5495	-5.4977	-5.5283
3	-5.4919	-5.3573	-5.5115	-5.3118
Delta	0.0087	0.2014	0.0550	0.3138
Rank	4	2	3	1

Table-4.4: The response Table of S/N ratios for NYLON-66

Levels	Melting Temp. (°C), (A)	Injection Pressure (MPa), (B)	Holding Pressure (MPa), (C)	Cooling Time (S), (D)
1	-9.3222	-9.1823	-9.2135	-9.1400
2	-9.3745	-9.5416	-9.1398	-9.2633
3	-9.2626	-9.2354	-9.6059	-9.5559
Delta	0.1118	0.3593	0.4661	0.4158
Rank	4	3	1	2

The best set of combination parameter can be determined by selecting the level with highest value for each factor. The optimal process parameter combination for HDPE is A1, B3, C1 & D3 and for NYLON-66 is A3, B1, C2 & D1.

The Delta value denotes as to which factor is the most significant for shrinkage of HDPE components in Table-4.3 and NYLON-66 components in Table-4.4. Cooling time was found to be most effective factor for HDPE followed by Injection pressure. Melting temperature was found to be the least effective factor. And holding pressure was found to be most effective factor for NYLON-66 followed by cooling time. Melting temperature was found to be the least effective factor.

By analysing the data in Table-4.3 for HDPE, the highest S/N ratio for each factor gave the optimal process condition which corresponds to melting temperature of 165°C, injection pressure of 72MPa, holding pressure of 44 MPa and cooling time of 40 sec.

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By analysing the data in Table-4.4 for NYLON-66, the highest S/N ratio for each factor gave the optimal process condition which corresponds to melting temperature of 300°C, injection pressure of 94MPa, holding pressure of 56 MPa and cooling time of 3 sec..From the above data, the S/N ratio response diagram was drawn for HDPE and NYLON66 products; it is shown in Chart4.1 and Chart4.2.

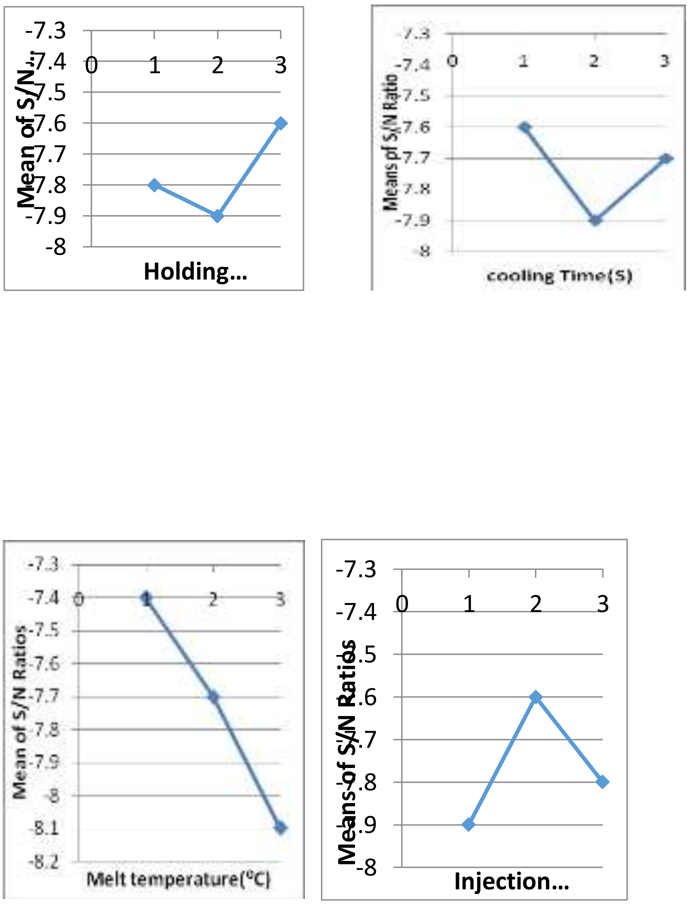

Chart -4.1: The S.N Ratio response diagram for HDPE

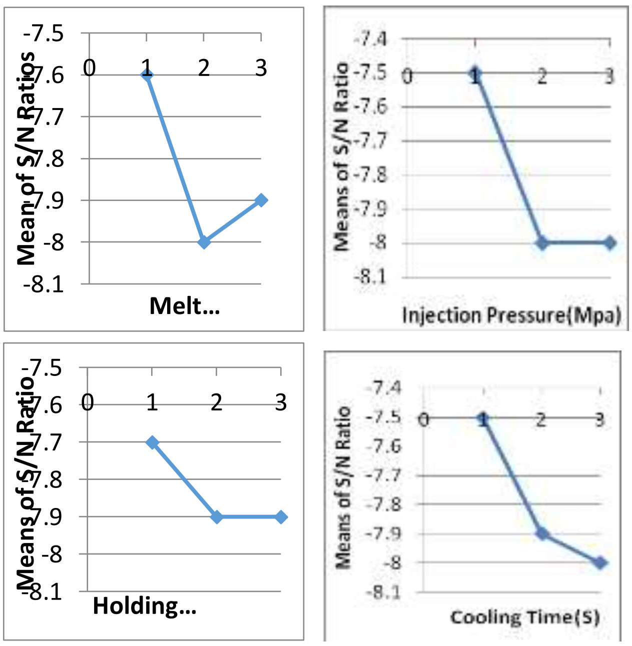

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Chart -4.2: The S.N Ratio response diagram for nylon66

V. CONCLUSIONS

Taguchi method is used to investigate the effect of melting temperature, injection pressure, holding pressure and cooling time on the shrinkage of HDPE and NYLON-66. S/N ratios were used for determining the optimum combinations of the process conditions for shrinkage. The result showed that melting temperature of 165°C and 300°C ,injection pressure of 72MPa and 94MPa, holding pressure of 44 MPa and 56 MPa and cooling time of 4sec. and 3sec. gave minimum shrinkage for HDPE and NYLON, respectively.

This experiment will help us to study the shrinkage behavior of above plastic materials and both these materials can be processed in a single mould to get the moulding with close tolerance by adding average shrinkage allowance 2% in the cavity in order to know the dimensional difference of both NYLON-66 &HDPE product. Taguchi method is a powerful tool for evaluating the defect of shrinkage in the plastic injection moulding.

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