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Optimization of Extrusion Process Parameter to Reduce Uneven Wall Thickness in HDPE Pipes By Using Taguchi Method

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ABSTRACT: HDPE pipes are manufactured by extrusion techniques all over the world. HDPE pipe is strong, durable, flexible and lightweight. Plastic extrusion is a high-volume manufacturing process in which plastic raw material is melted with application of heat and form into continuous profile. The study quality characteristic will be focused on variation of thickness of pipe. Thickness variation is major concern in pipe extrusion process. One method of reducing HDPE pipes thickness variation problem is by applying Taguchi method. Nominal the better approach is selected for S/N ratio. Here Taguchi approach is used to establish optimum parameter combinations that reduce variation on performance of pipe due to asymmetric pipe production. An optimal set of process parameters obtained from a response graph for the main. Moreover, a signal to noise ratio computation analysis of variance will be conducted to evaluate the results of experiments. There is run of confirmation experiment to verify the result of experiments

KEYWORDS: Extrusion, Taguchi method, signal to noise ratio, Asymmetric.

I. INTRODUCTION

HDPE pipes are manufactured by extrusion techniques all over the world. HDPE pipe is strong, durable, flexible and lightweight. When fused together, HDPE offers zero leak rate due to the seamless nature of the pipe system. HDPE pipe meet all your requirements such as corrosion and chemical resistant, long life span, nontoxic and is suitable for trenchless installation methods. Plastic extrusion is a high-volume manufacturing process in which plastic raw material is melted with application of heat and formed into a continuous profile. Thickness variation is a major concern in the pipe extrusion process. One method of reducing HDPE pipes thickness variation problem is by applying Taguchi method. Nominal is best approach selected for S/N ratio. ANOVA is done to find the significance of factor affecting the quality characteristics. From the response table for signal to noise ratio it can be noted that Extruder Temperature T4 is having largest effect and die temperature T6 has smallest effect on variation of thickness of HDPE pipe. Therefore, from response tables of S/N ratio we can decide the possible parameter settings for reducing variation in thickness are Extruder Temperature T1 150°C, Extruder Temperature T2 200°C, Extruder Temperature T3 187°C, Extruder Temperature T4 180°C, Adapter Temperature T5 175°C, Die Temperature T6 175°C, Die Temperature T7 160°C, Die Temperature T8 175°C. A mathematical model find from regression analysis to predict thickness of pipe. Mean Average thickness from regression equation 1.50146 mm. Later, Confirmation experiment has been conducted by running another four trails at the optimum settings of process parameters analysis as mentioned above. Mean of average thickness of these four trials are 1.502 mm. This mean of average thickness having more than 90 percent confirmation with the predicted result from regression equation.

II. LITERATURE REVIEW

Mr. Sandip S. Gadekar et al [1] studied the defects in the plastic pipe, to optimize the plastic pipe manufacturing process. It is very essential to learn the process parameter and the defect in the plastic pipe manufacturing process to optimize it. For the optimization Taguchi techniques is used in this paper. For the research work Shivraj HY-Tech Drip Irrigation pipe manufacturing, Company was selected. This paper is specifically design for the optimization in the current process. The experiment was analyzed using commercial Minitab16 software, interpretation has made, and optimized factor settings were chosen. After prediction of result the quality loss is

calculated and it is compared with before implementation of DOE. The research works has improves the Production, quality and optimizes the process.

Narasimha and Rejikumar [2] presented a systematic approach to find the root causes for the occurrence of defects and wastes in plastic extrusion process. The cause-and effect diagram was implemented to identify the root causes of these defects. The extrusion process parameters such as vacuum pressure, temperature, take-off speed, screw speed of the extrusion process and raw material properties were identified as the major root causes of the defects from the cause-and-effect diagram. The quality loss for the current performance variation was calculated using Taguchi's principle of loss function and requirement for improvement was verified. In this paper design of experiment (DOE) was applied to optimize the process parameters for the extrusion of high-density polyethylene (HDPE) pipe \varnothing 50mm and plain pipe \varnothing 25mm. Four independent process parameters viz. vacuum pressure, take-off speed, screw speed and temperature were investigated using Taguchi method. Minitab 15 software was used to analyze the result of the experiment. Based on the result of the analysis, optimum process parameters were selected.

Dharmendra Kumar and Sunil Kumar [3] used the taguchi method to optimize the process parameters and improve the quality of components that manufactured. The objective of this study was to illustrate the procedure adopted in using taguchi method to a extrusion blown film machinery. The orthogonal array, signal-to-noise ratio employed to study the performance characteristics on tensile strength; a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimum level of the process parameters was the level with the greatest S/N ratio. In this analysis; four factors namely melting temperature, extrusion speed, extrusion pressure and winding speed were considered. Accordingly, a suitable orthogonal array was selected and experiments were conducted. After conducting the experiments, the tensile strength was measured and Signal to Noise ratio was calculated. With the help of graph and table, optimum parameter values were obtained.

Mukesh kumar verma and Mukesh dubey [4] study present a systematic approach to find the root causes for the occurrence of defects and wastage in plastic extrusion process in the pipe manufacturing industries. It is very essential to learn the process parameter and the defect in the plastic pipe manufacturing process to optimize it. For the optimization Taguchi technique is used in this paper. Taguchi Method is a statistical approach to optimize the process and improve the quality of components that are manufactured. The experiment was analyzed using Minitab 17 software, interpretation has made, and optimized factor settings were chosen. In this analysis three factors namely take-off speed, melting temperature, extruder speed, were considered. Accordingly, a suitable orthogonal array was selected and experiments were conducted. After conducting the experiments the diameters were measured and Signal to Noise ratio was calculated. With the help of graph and table, optimum parameter values were obtained.

G.V.S.S.Sharma et.al. [5] explains HDPE pipes find versatile applicability for transportation of water, sewage and slurry from one place to another due to which HDPE pipes undergo tremendous pressure by the fluid carried. They optimize withstanding pressure of HDPE pipes using taguchi technique. They conducted design of experiments wherein different control parameter combinations are analyzed by considering multiple settings levels of each control parameter. They applied concept of S/N ratio and obtained optimum levels of process control parameter such as pushing zone temperature 1660C, Dimmer speed at 08 rpm and Die head temperature to be 1920C. Also conducted confirmation experimental run to verify the analysis and research result and values prove to be in synchronization with the main experimental findings and the withstanding pressure showed a significant improvement from 0.6 to 1.004 MPa.

Vikash agarwal et.al. [6] studied and investigated the optimization parameters of extrusion blow molding process for making plastic container of high-density polyethylene grade B6401(HDPE) produced by mitsui CX processed at HALDIA PETROCHEMICAL LTD.A plastic container made by the using L9 orthogonal array. The process parameters are used screw temperature, blowing time, exhaust/cooling time and the responses were the compressive strength and volume accuracy were selected as quality target. An optimal parameter combination of the Extrusion blow molding process was obtained by grey relational analysis. By analyzing the Grey relational grade , the degree of influence foe each controllable process factor onto individual quality targets can be found. Additionally, the analysis of variance has been also applied to identify the most significant factor.

III. METHODOLOGY

3.1 Selection of the quality characteristic

There are three types of quality characteristics in the Taguchi methodology such as the-smaller-the-better, the-larger the -better, and the-nominal-the-best. Signal to Noise analysis is designed to measure quality characteristic. It is

given by

$$S/N = -10 \log_{10}(MSD)$$

Where MSD= Mean Squared Deviation

For the smaller the better characteristic,

$$MSD=(Y_1^2+Y_2^2+Y_3^2+\dots\dots\dots)/n$$

larger the better characteristic,

$$MSD=(1/Y_1^2+1/Y_2^2+1/Y_3^2+\dots\dots\dots)/n$$

nominal the best characteristic,

$$MSD = [(Y_1 - m)^2 + (Y_2 - m)^2 + (Y_3 - m)^2 + \dots\dots\dots]/n$$

Where Y_1, Y_2, Y_3 are the responses and n is the number of tests in a trial and m is the target value of the result.

HDPE pipes were produced on extrusion machine as per the parameters set given to the machine. After manufacturing of pipe, samples are taken and its thickness was measured with the help on Digital Micrometer. The difference between thickness value as per design and actual thickness value shows the amount of variation that took place in the pipe. Variations in the thickness value were measured and recorded and it is considered as response variable for the study. To measure the thickness variations we divide the periphery of pipe in 8 equal parts at 45° each as shown in figure.

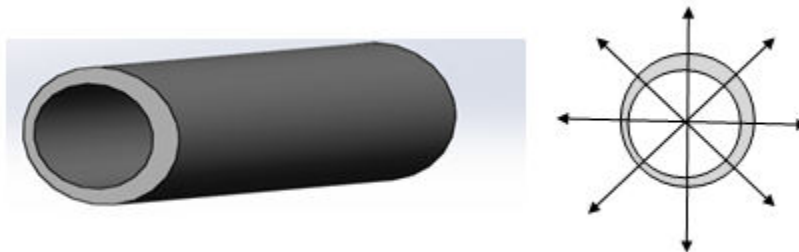


Fig 3.1 Position for Thickness Measurement

To locate the measurement position we used circular cut out having diameter equal to outer diameter of pipe and divided it into eight equal parts. In this case as we require nominal variation in the thickness so we selected Nominal is best as quality characteristic.

3.2 Selection of Component for Study

We have carried out our study at HDPE pipe extrusion machine at Jain Irrigation Systems Ltd. Jalgaon selected component having dimensions as follows.

- 1) Designed Diameter 20mm
- 2) Wall thickness 1.3 to 1.8mm
- 3) Material Grade PE 63

PE pipe as per ISO 4427:96

3.3 Selection of Parameters and Their Levels

In today’s market, quality of extruded pipe is most important factor for pipe manufacturing industry. From the past literature review it is found that several factors influence the quality of pipe in the extrusion process. The thickness of pipe generally dependent on the feed drum temperature, Adapter Temperature, Mold temperature, Core Temperature, take off speed, vacuum pressure, Screw speed, Extruder speed. Due to uneven melt delivery from die extruder surging,



uneven take off speed, improper alignment of die and haul off units, Die and pin not centered evenly, excessive sag of polymer due to which uneven wall thickness occurs in HDPE pipes. In study of effect of parameter in investigation it is not possible consider all parameter at same time. So in this work feed drum temperature at various sections, Adapter Temperature, Mold temperature various sections taken as a extrusion process parameter.

Table 3.1 Control Factors And Level

NOTATION	FACTOR DESCRIPTION	Level 1	Level 2	Level 3
A	Extruder Temp Section 1 (T ₁) (°C)	150	155	160
B	Extruder Temp Section 2 (T ₂) (°C)	190	195	200
C	Extruder Temp Section 3 (T ₃) (°C)	187	192	197
D	Extruder Temp Section 4 (T ₄) (°C)	180	185	190
E	Adaptor Temperature (T ₅) (°C)	170	175	180
F	Die Temperature 1(T ₆) (°C)	165	175	185
G	Die Temperature 2(T ₇) (°C)	160	170	180
H	Die Temperature 3(T ₈) (°C)	175	185	195

3.4 Design of Experiments by Taguchi Method

3.4.1 Selection of Orthogonal Array

There are eight parameters and each parameter with three levels is considered. So, as per the standard table of the orthogonal array the preferable orthogonal array selected is L₂₇. Hence we are given process parameter value to minitab software as per below table

Table 3.2 Orthogonal Array L27

	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2
3	1	1	1	1	3	3	3	3
4	1	2	2	2	1	1	1	2
5	1	2	2	2	2	2	2	3
6	1	2	2	2	3	3	3	1
7	1	3	3	3	1	1	1	3
8	1	3	3	3	2	2	2	1
9	1	3	3	3	3	3	3	2
10	2	1	2	3	1	2	3	1
11	2	1	2	3	2	3	1	2
12	2	1	2	3	3	1	2	3
13	2	2	3	1	1	2	3	2
14	2	2	3	1	2	3	1	3
15	2	2	3	1	3	1	2	1
16	2	3	1	2	1	2	3	3
17	2	3	1	2	2	3	1	1
18	2	3	1	2	3	1	2	2
19	3	1	3	2	1	3	2	1
20	3	1	3	2	2	1	3	2
21	3	1	3	2	3	2	1	3
22	3	2	1	3	1	3	2	2
23	3	2	1	3	2	1	3	3
24	3	2	1	3	3	2	1	1
25	3	3	2	1	1	3	2	3



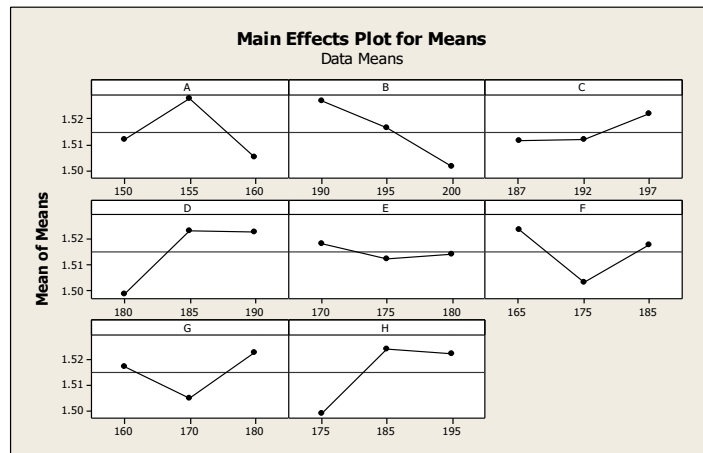
	A	B	C	D	E	F	G	H
26	3	3	2	1	2	1	3	1
27	3	3	2	1	3	2	1	2

IV. EXPERIMENTAL RESULTS

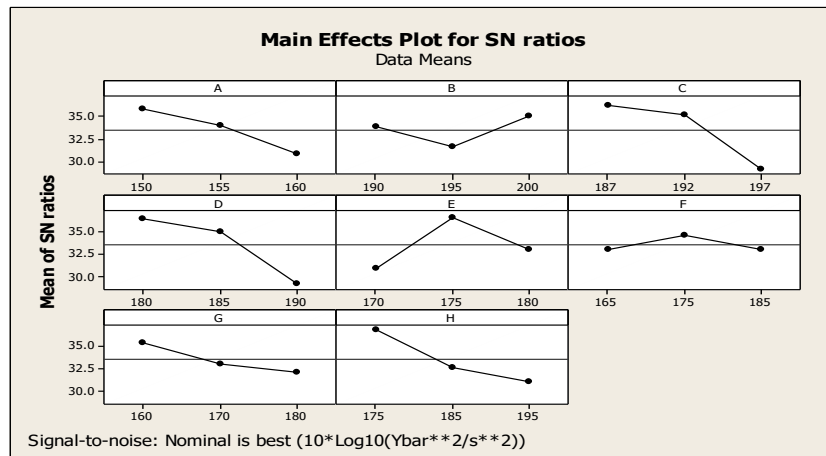
4.1 Based on Above Orthogonal Layout Experiments Are Conducted. Two Trials are conducted for set of Factors of each experiment

Table 4.1 Summary Report for Different trials conducted during Experiments

Trial No.	Average Thickness in mm			
	Sample 1	Sample 2	Mean	S/N Ratio
1	1.480	1.501	1.4905	40.0326
2	1.506	1.500	1.5035	52.5730
3	1.544	1.494	1.5190	32.6621
4	1.576	1.525	1.5505	32.6683
5	1.453	1.475	1.4640	39.4727
6	1.555	1.530	1.5425	38.8160
7	1.569	1.508	1.5385	31.0457
8	1.551	1.443	1.4970	25.8463
9	1.544	1.464	1.5040	28.4935
10	1.545	1.504	1.5245	34.4172
11	1.558	1.510	1.5340	33.1020
12	1.623	1.525	1.5740	27.1259
13	1.584	1.471	1.5275	25.6284
14	1.569	1.508	1.5385	31.0457
15	1.511	1.475	1.4930	35.3654
16	1.554	1.505	1.5295	32.8974
17	1.520	1.514	1.5170	51.0670
18	1.529	1.491	1.5100	34.9942
19	1.541	1.443	1.4920	26.6612
20	1.623	1.525	1.5740	27.1259
21	1.560	1.501	1.5305	31.2899
22	1.598	1.468	1.5330	24.4423
23	1.596	1.455	1.5255	23.6942
24	1.496	1.453	1.4745	33.7138
25	1.510	1.448	1.4790	30.5618
26	1.453	1.464	1.4585	45.4606
27	1.500	1.463	1.4815	35.0603



Graph 4.1: Main Effect Plot for Average Thickness



Graph 4.2: Main Effect Plot for Average S/N Ratio

Table 4.2 Response table for Signal to Noise Ratio

Level	A	B	C	D	E	F	G	H
1	35.73	33.89	36.23	36.49	30.93	33.06	35.45	36.82
2	33.96	31.65	35.19	35.00	36.60	34.54	33.00	32.68
3	30.89	35.05	29.17	29.10	33.06	32.98	32.13	31.09
Delta	4.84	3.40	7.06	7.39	5.67	1.56	3.31	5.73
Rank	5	6	2	1	4	8	7	3

Table 4.3: Analysis of Variance for Signal to Noise Ratio

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
A. Extruder Temp. T1	2	108.13	108.13	54.065	1.59	0.251
B. Extruder Temp. T2	2	53.70	53.70	26.848	0.79	0.480
C. Extruder Temp. T3	2	261.69	261.69	130.847	3.85	0.057
D. Extruder Temp. T4	2	274.96	274.96	137.478	4.05	0.051
E. Adaptor Temp. T5	2	147.67	147.67	73.835	2.17	0.164
F. Die Temp. T6	2	13.96	13.96	6.981	0.21	0.817
G. Die Temp. T7	2	53.14	53.14	26.568	0.78	0.483



H. Die Temp. T8	2	157.63	157.63	78.814	2.32	0.149
Residual Error	10	339.49	339.49	33.949		
Total	26	1410.37				

S = 5.827%

R-sq = 75.9%

R-sq(Adj.) = 37.4%

Analysis of Variance is done to find the significance of factors affecting on the quality characteristic. It can be noted that Extruder Temperature T4 is having largest effect of variation of thickness of HDPE pipe. Die Temperature T₆ has smallest effect on variation of thickness. Response table and main effect plots shows the effect of parameter combination settings on quality characteristic which is in this case is Nominal is the Best. The possible parameter settings with higher S/N ratio is said to be optimal parameter settings. Therefore, from response tables of S/N ratio we can decide the possible parameter settings for reducing the variation in thickness are given in the Table 3.7

Table:4.4 Optimum settings for HDPE pipe extrusion machine

Sr. No.	Factor	Level	Level Description
A	Extruder Temp. T1	1	150
B	Extruder Temp. T2	3	200
C	Extruder Temp. T3	1	187
D	Extruder Temp. T4	1	180
E	Adaptor Temp. T5	2	175
F	Die Temp. T6	2	175
G	Die Temp. T7	1	160
H	Die Temp. T8	1	175

4.2 Prediction Model

Table 4.5 Summary of Regression Analysis

Predictors	Coefficients	SE Coefficients	T	P
Constant	1.28	0.5315	2.40	0.027
Extruder Temp. T ₁	0.000276	0.0002382	-1.16	0.262
Extruder Temp. T ₂	0.00252	0.001312	-1.92	0.071
Extruder Temp. T ₃	0.00103	0.001312	0.79	0.441
Extruder Temp. T ₄	0.00238	0.001312	1.82	0.086
Adaptor Temp. T ₅	0.00040	0.001312	-0.30	0.764
Die Temp. T ₆	0.000308	0.0006559	-0.47	0.644
Die Temp. T ₇	0.000275	0.0006559	0.42	0.680
Die Temp. T ₈	0.00129	0.0006559	1.77	0.094

Sum of Sq. = 0.0278296

R-Sq = 41.1%

R-Sq(Adj.) = 14.9%

Regression analysis is used to find the mathematical model to predict thickness variation for the present work. In the model, average thickness is assumed as function of Extruder Temperature T1, Extruder Temperature T2, Extruder Temperature T3, Extruder Temperature T4, Adaptor Temp. T5, Die Temp. T6, Die Temp. T7, Die Temp. T8 The relationship between average thickness and other input variables is modeled as follows. For regression analysis Minitab 15 software is used.

$$\begin{aligned}
 \text{Mean Thickness} &= 1.28 - 0.000276 * T_1 - 0.00252 * T_2 + 0.00103 * T_3 + 0.00238 * T_4 - 0.00040 * T_5 - \\
 &\quad 0.000308 * T_6 + 0.000275 * T_7 + 0.00129 * T_8 \\
 &= 1.28 - 0.000276 * 150 - 0.00252 * 200 + 0.00103 * 187 + 0.00238 * 180 - 0.00040 * 175 - \\
 &\quad 0.000308 * 175 + 0.000275 * 160 + 0.00129 * 175 \\
 &= 1.50146 \text{ mm}
 \end{aligned}$$

4.3 Confirmation Experiment

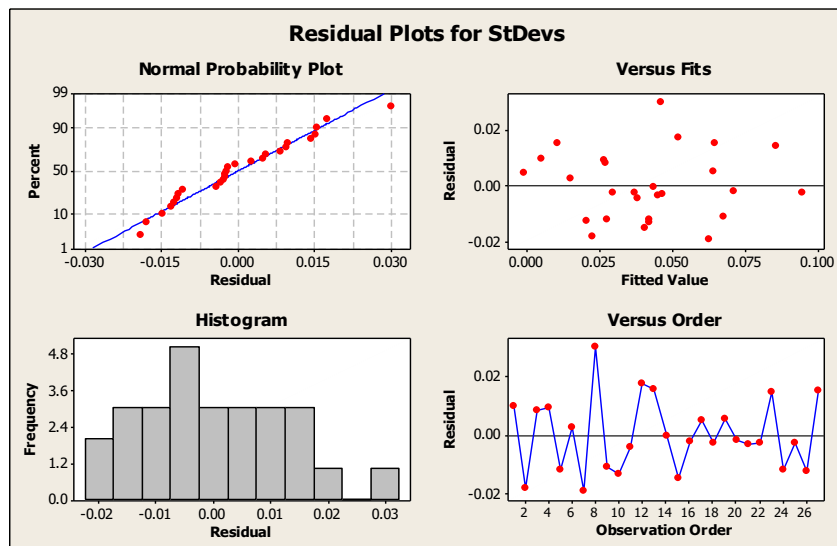
In order to test predicted results, confirmation experiment has been conducted by running another four trials at the optimal settings of process parameters determined from analysis i.e. Extruder Temperature T1 = 150°C, Extruder



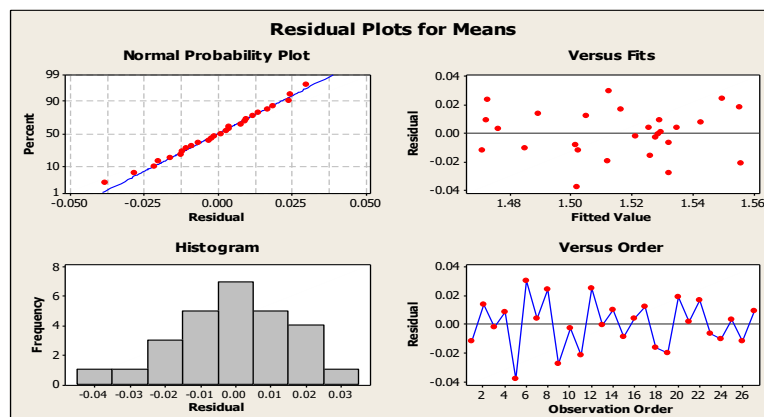
Temperature T2 = 200⁰C, Extruder Temperature T3 = 187⁰C, Extruder Temperature T4 = 180⁰C, Adaptor Temperature T5 = 175⁰C, Die Temperature T6 = 175⁰C, Die Temperature T7 = 160⁰C, Die Temperature T8 =175⁰C.

Observation	Trial 1	Trial 2	Trial 3	Trial 4	Mean of Avg. Thickness in mm
1	1.501	1.499	1.500	1.508	1.502

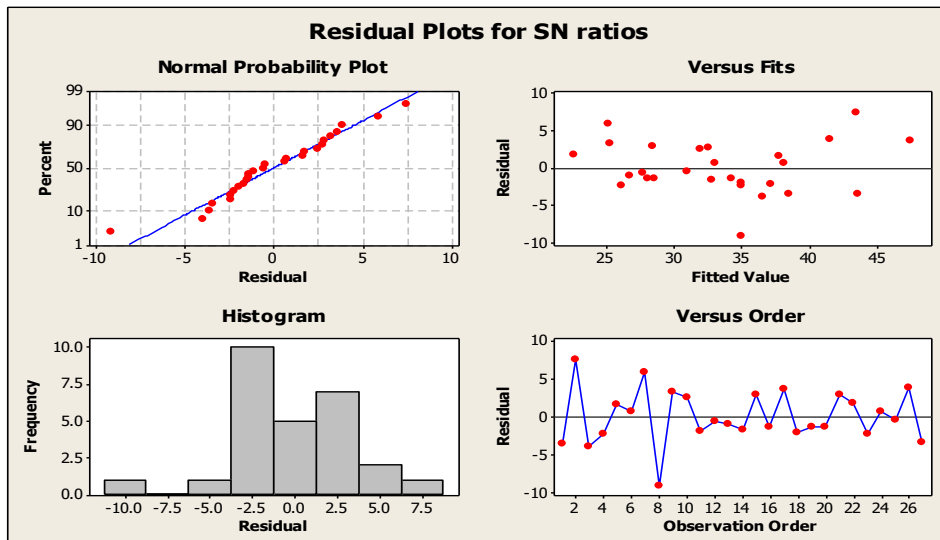
The results shown in above table and it is observed that the mean of average thickness i.e. 1.502 having more than 90% confirmation with the predicted results from regression equation i.e. mean average thickness = 1.50146mm



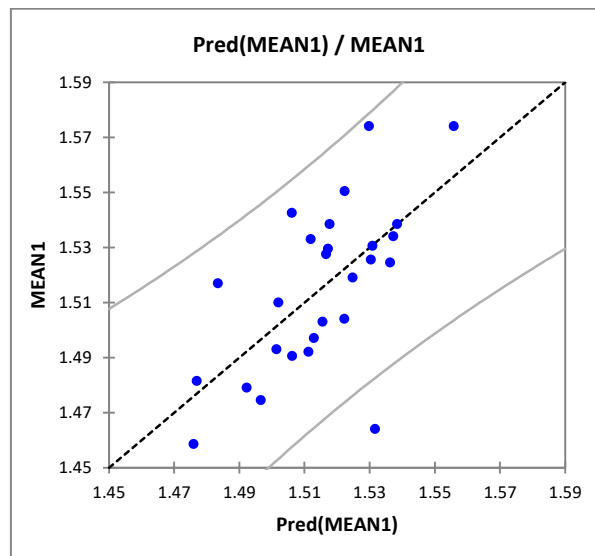
Graph 4.3: Residual Plot for Standard Deviation



Graph 4.4: Residual Plots for Means



Graph 4.5: Residual Plot for SN Ratios



Graph 4.6 Plot for Actual mean to Prediction mean

V. CONCLUSION

Following are the conclusions are drawn:

- i. Among the eight process parameters Extruder Temperature T4, Extruder Temperature T3, Die Temperature T8, Adaptor Temperature T5 is having more significant effect on Quality Characteristic.
- ii. The Optimal level of process parameter were found to be Extruder Temperature T1 = 150⁰C, Extruder Temperature T2 = 200⁰C, Extruder Temperature T3 = 187⁰C, Extruder Temperature T4 = 180⁰C, Adaptor Temperature T5 = 175⁰C, Die Temperature T6 = 175⁰C, Die Temperature T7 = 160⁰C, Die Temperature T8 =175⁰C
- iii. The predictions made by Taguchi parameter design technique are in good agreement with confirmation results.
- iv. The result of present investigation are valid within specified range of process parameters
- v. Graph 3.3 to 3.6 gives the relationship between actual and predicted values of average thickness. The developed model gives the predicted values against the actual thickness values. The residuals tend to be close to diagonal line indicating that the developed model is adequate, confirmation tests are conducted by using new conditions at optimal levels as obtained by using Minitab Statistical Software.
- vi. Also the prediction made by Regression Analysis is in good agreement with confirmation results.

- vii. From Graph 3.3 to 3.6 it is confirm that by optimizing the process parameters and setting the average thickness closer to nominal value (targeted value i.e 1.5mm) will minimize thickness variations

The Optimal level of process parameter were found to be Extruder Temperature T1 = 150⁰C, Extruder Temperature T2 = 200⁰C, Extruder Temperature T3 = 187⁰C, Extruder Temperature T4 = 180⁰C, Adaptor Temperature T5 = 175⁰C, Die Temperature T6 = 175⁰C, Die Temperature T7 = 160⁰C, Die Temperature T8 =175⁰C and also the process parameters which affecting thickness variations are focused and controlled..

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