Volume 6 Issue 4 (2018) 335-339 ISSN 2347-3258
International Journal of Advance Research and Innovation

A Taguchi Approach on Optimal Process Control Parameters for PVC Pipe Extrusion Process

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Article Info:
Article history
Received 18 August 2018
Received in revised form:
28 August 2018
Accepted 2 September 2018
Available online 15 December 2018

Keywords: Extrusion process, Optimization, Taguchi Method, Orthogonal array, Signal to noise ratio

Abstract
In this study, the Taguchi method is used to find the optimal process parameters for process of producing PVC pipes by the technological extrusion process. An orthogonal array (OA), main effect, signal-to-noise (S/N) ratio, and analysis of variance (ANOVA) were to investigate the pipe ring flexibility. The process parameters, namely speed traction lines, nozzle temperature, doser expander, screws speed extruder, screws speed co-extruder, barrel temperature, dozer mixture of extruder, and doser mixture of coextrudes are optimized with considerations of the performance characteristics flexible pipe ring. Through this study, not only can the optimal process parameters for extrusion process be obtained, but also the main process parameters that affect the bending performance of the pipe ring flexibility. Experimental results are provided to confirm the effectiveness of this approach.

1. Introduction

Extrusion of polymeric materials to produce finished products for industrial or consumer applications is an integrated process, with the extruder comprising one component of the entire line. One of the main goals of extrusion is the improvement of quality of extruded parts. Determining optimal process parameter settings critically influences productivity, quality, and cost of production in the plastic related industries. Figure 1 shows PVC pipe extrusion.

The complexity and parameter manipulation may cause serious quality problems and high manufacturing costs. Quality characteristics in extrusion process are mechanical properties, dimensions or measurable characteristics, and attributes. Factors that affect the quality of an extruded part can be classified into four categories: part design, die design, machine performance and processing conditions [9]. The pipe ring flexibility is mainly a result of control process parameters such as: speed traction lines, nozzle temperature, doser expander, screws speed extruder, screws speed coextruder,barrel temperature, doser mixture of extruder, and doser mixture of coextruder. Figure 2 shows the Factor characteristic relatice diagram for exstrusion process.

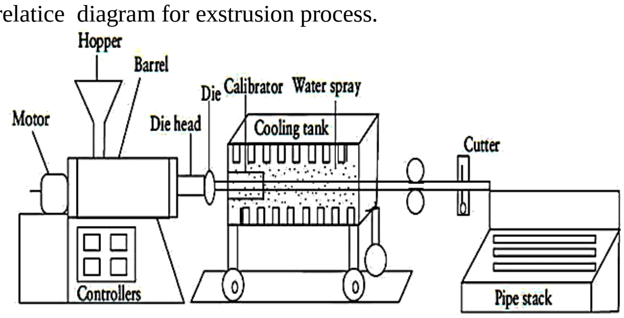

Fig.1 PVC pipe extrusion [1]

Production of three-layer from UPVC (Unplasticized Polyvinyl Chloride) pipes with a diameter of 110 mm includes the technological procedure of extrusion and co-extrusion. The pipes are manufactured according to the requirements of EN 13476. They are intended for the infrastructure system of plastic piping for discharging sewage and waste waters from the immediate human environment and their removal to the purification device or direct discharge into the appropriate receiver.

Drainage systems are engineering objects whose stability, functionality, operational capacity and durability are defined by standards. Therefore, in accordance with the specified requirements for the design and execution of the drainage system, it is necessary that the PVC pipes have consistent physical and mechanical quality characteristics that ensure a stable and reliable system. Higher pipe ring flexibility is supposed to result in a better condition of the pipe. Therefore, flexibility the withstanding should be set the higher the better. Figure 3 and 4 shows extruders for the production of PVC pipe and the extruded PVC pipes.

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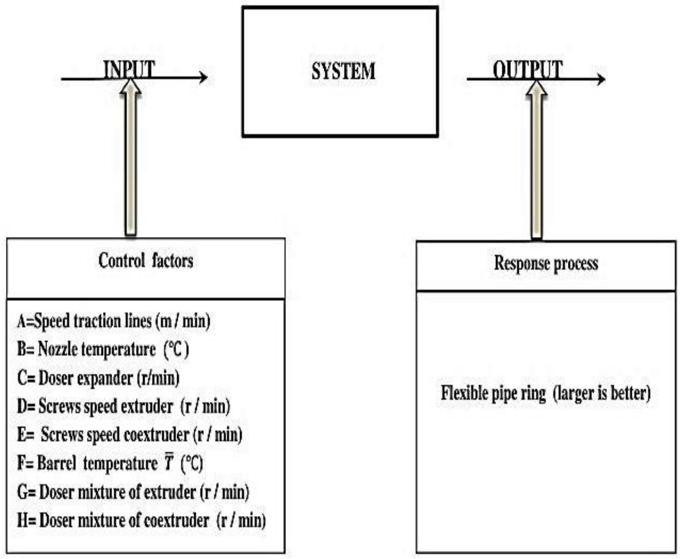

Fig. 2 Factor characteristic relative diagram for extrusion process

The pipe ring flexibility test carried out 24 hours after the production process. The procedure of testing the flexible pipe ring - whether the pipe fulfills the requirement to bear a deformation greater than 30% in relation to the outer diameter of the pipe it was performed as follows:

Step 1: By measuring the outer diameter, the thickness of the walls, the length and the mass of the samples 300 ± 10 mm in length, the first sample is marked at the site where the minimum thickness of the wall, and the next two at 120° or, respectively, 240 ° cells of that point. It is then necessary to measure the inner diameter of the pipe at each point drawn.

Step 2: The prepared sample is placed in the apparatus between two parallel plates. The pattern due to the action of the vertical compression force is deformed or fired, the reference values are read out on the monitor. Testing parameters: ambient temperature of 23 ± 2 °C, the compression type of test, the speed of 5 mm/min, method of testing – single. Figure 5 shows Dynamometer for testing the flexibility of the ring pipe method .

To date, Taguchi method as a robust experimental design is commonly used by the researchers to obtain the best combination set of factors/levels with lowest cost solution to achieve the product quality requirements. It consists of several functional elements that can provide the necessary contribution needed to enhance the optimization implementation especially the Taguchi's orthogonal array.

Essentially, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [11].

Fig. 3 Extruders for the production of PVC pipe

Fig. 4 The extruded PVC pipes

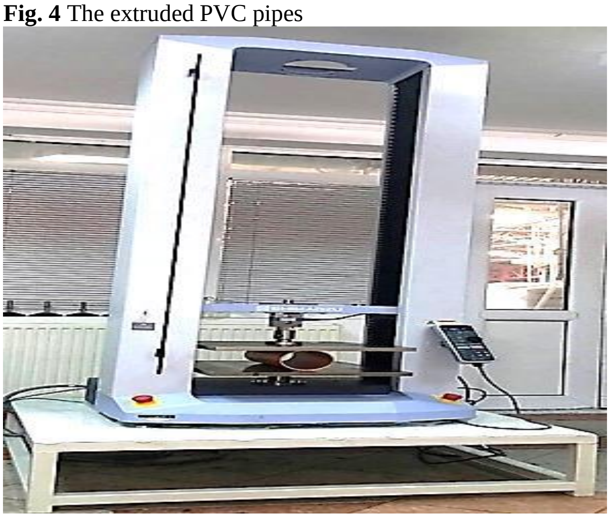

Fig. 5 Dynamometer for testing the flexibility of the ring pipe method

From the review reference [2] of optimize the production process using A Taguchi approach on optimal process control parameters for HDPE pipe extrusion process. The concept of signal-to-noise ratio (S/N ratio) is applied and ultimately optimum values of process control parameters are obtained as: pushing zone temperature of 166 °C, Dimmer speed at 08 rpm, and Die head temperature to be 192 °C. Confirmation experimental run is also conducted to verify the analysis and research result and values proved to be in synchronization with the main experimental findings and the withstanding pressure showed a significant improvement from 0.60 to 1.004 Mpa. Narasimha and Rejikumar [3] presented a systematic approach to find the root causes for the occurrence of defects and wastes in plastic extrusion process. Applied the Taguchi approach and determined the optimal value to optimize the process parameters for the extrusion of high-density polyethylene (HDPE) pipe Ø 50mm and plain pipe Ø 25mm. Four independent process parameters viz. vacuum pressure, take-off speed,screwspeed and temperature were investigated using Taguchi method.

Aggarwal et al. [4] optimized the machining parameters of CNC turned parts using Principal Component Analysis with Taguchi method and inferred that more than two principal components with eigen value more than one are necessary to explain the variability in the experimental data. Yu et al.[5] determined the optimal die gap programming of extrusion blow molding processes that establish a back propagation network using a Taguchi's experimental array to predict the relationship between design variables and responses. Kamaruddin et al. [6] evaluated the performance of plastic (75% polypropylene and 25% low-density polyethylene LPDE) trays in terms of its shrinkage behavior.

Taguchi's robust design method is a powerful tool for the design of a high-quality system.

In addition to the S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on extrusion process. The steps applied for Taguchi optimization in this study are as follows.

- Select noise and control factors
- Select Taguchi orthogonal array
- Conduct Experiments
- Metal Removal Rate measurement
- Analyze results; (Signal-to-noise ratio)
- Predict optimum performance
- Confirmation experiment

By selecting and controlling the control factors, it is necessary to identify the dominant factors, the effect of the effect of factors on each of the considered characteristics of the process performance, design the technological process parameters that optimize the process and contribute to the robust quality of the product and the reliability of the process in order to improve the efficiency of the production process by the technological extrusion process.

Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups. ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations [6].

2. Experiment Set Up

The experimental work was carried out at the company for the production of polymers Pestan, Serbia. Extruders for the production process are shown in Figure 3. A dry powder formulation for the production process of a three-layer pipe made of unplasticized PVC outside diameter of 110 mm was used. The test samples were manufactured according to standard EN 13476.

2.1 Process parameters of the extrusion technological process

In this study, the initial technological process parameters were: speed traction lines 8.8 m/min, nozzle temperature 201°C,doser expander 21.2 r/min, screw speed extruder 17.5 r/min, screw speed coextruder 40.6 r/min, barrel temperature 176 $\overline{T}$ °C, doser mixture of extruder 26.1 r/min and doser mixture of coextruder 36.4. Experimental settings for determining optimal technological process parameters: speed traction lines 8.8 m/min or 9.1m/min, nozzle temperature 201°C or 206°C or 211°C, doser expander 19.2 r/min or 21.2 r/min or 23.2 r/min, screw speed extruder 16.5 r/min or 17.5 r/min or 18.5 r/min, screw speed co extruder 39.6 r/min or 40.6 r/min or 41.6 r/min, barrel temperature 174 $\overline{T}$ °C or 176 $\overline{T}$ °C or 178 $\overline{T}$ °C, doser mixture of extruder 24.1 r/min or 26.1r/min or 28.1 r/min, doser mixture of coextruder 34.4 or r/min, 36.4 r/min or 38.4 r/min. The process parameters selected for the present work are shown in Table 1.

Experiments were conducted based on the Taguchi standard orthogonal array L_{18} (2^1 x 3^7) was used with eight columns and eighteen rows array, and then followed by optimization of the results using. Speed traction lines factor A is defined on two levels to minimize the risk of the occurrence of process damage on the production line. Risk of changing the speed traction lines: interruption of the production process on the production line due to the decrease in the value of the vacuum pressure in the calibration bath, ie, the formation of the tube in the final cross-section. The range of defined vacuum values ranges from 0.2 - 0.3 bar. By increasing the speed traction lines, stretching of the pipe occurs, and consequently the determination of the atmospheric pressure and the pressure in the calibration tank is performed. Under these conditions there is no possibility of forming the tube in the final cross-section.

Analysis of Variance (ANOVA) to find maximum the pipe ring flexibility.An experimental disintegration for the manufacturing process by the extrusion technique is presented in Table 2.

Table: 1. Process parameterss and their levels

Cod e	Technological process parameters	Leve l 1	Leve l 2	Leve l 3
A	Speed traction lines (m/min)	8.8	9.1	-
B	Nozzle temperature (°C)	201	206	211
C	Doser expander (r/min)	19.2	21.2	23.2
D	Screw speed extruder (r/min)	16.5	17.5	18.5
E	Screw speed coextruder (r/min)	39.6	40.6	41.6
F	Barrel temperature $\overline{T}$ (°C)	174	176	178
G	Doser mixture of extruder (r/min)	24.1	26.1	28.1
H	Doser mixture of coextruder (r/min)	34.4	36.4	38.4

Table: 2. Experimental layout using an L_{18} orthogonal array

	Technological process parameters and their levels							
Ex. No	Speed traction lines (m/min)	Nozzle temperature (°C)	Doser expander (r/min)	Screw speed extruder (r/min)	Screw speed coextruder (r/min)	Barrel temperature $\overline{T}$ (°C)	Doser mix.of extruder (r/min)	Doser mix.of coextruder (r /min)
1	8.8	201	19.2	16.5	39.6	174	24.1	34.4
2	8.8	201	21.2	17.5	40.6	176	26.1	36.4
3	8.8	201	23.2	18.5	41.6	178	28.1	38.4
4	8.8	206	19.2	16.5	40.6	176	28.1	38.4
5	8.8	206	21.2	17.5	41.6	178	24.1	34.4
6	8.8	206	23.2	18.5	39.6	174	26.1	36.4
7	8.8	211	19.2	17.5	39.6	178	26.1	38.4
8	8.8	211	21.2	18.5	40.6	174	28.1	34.4
9	8.8	211	23.2	16.5	41.6	176	24.1	36.4
10	9.1	201	19.2	18.5	41.6	176	26.1	34.4
11	9.1	201	21.2	16.5	39.6	178	28.1	36.4
12	9.1	201	23.2	17.5	40.6	174	24.1	38.4
13	9.1	206	19.2	17.5	41.6	174	28.1	36.4
14	9.1	206	21.2	18.5	39.6	176	24.1	38.4
15	9.1	206	23.2	16.5	40.6	178	26.1	34.4
16	9.1	211	19.2	18.5	40.6	178	24.1	36.4
17	9.1	211	21.2	16.5	41.6	174	26.1	38.4
18	9.1	211	23.2	17.5	39.1	176	28.1	34.4

$$S/N = -10\log_{10}\left(\frac{\sum_{i=1}^{N} 1/y_i^2}{N}\right) \quad (1)$$

wherey1; y2; ...; yn are the responses of strength and flexibility of the ring for a trial condition repeated n times. The S/N ratios were computed using Eq. (1) for each of the eighteen experiments.

The higher value of the pipe ring flexibility the defined requirements of the production process of three-layer PVC pipes. Accordingly, for the above mentioned reactions the process is applied to a higher-the-better methodology S / N ratio.

Table 3 shows the experimental results of the flexibility PVC pipe and the signal and noise ratio based on the experimental schedule Table 2. To test the flexibility of the ring, the dynamometer of the manufacturer Shimadzu, AGS-X 20 kN, Japan, was shown in Figure 5. In addition to adequate stiffness, it is necessary that the pipe has flexibility and resistance to dynamic and static loads. To test the flexibility of the ring applied the standard SRPS EN ISO 13968: 2009.

Table: 3. Experimental results for output variables and their S/N ratio

Experiment Number	Flexible pipe ring	
	N	**S/N**
1	969.70	59.733
2	969.70	59.733
3	1153.90	61.243
4	1258.40	61.994
5	1224.50	61.759
6	1172.80	61.384
7	1005.60	60.048
8	1166.80	61.340
9	1142.90	61.160
10	862.50	58.715
11	982.80	59.849
12	1028.60	60.250
13	1032.50	60.278
14	1061.40	60.518
15	1142.00	61.153
16	975.80	59.787
17	1136.00	61.108
18	1240.50	61.872

2.2 Determination of factor effects and optimal settings

MINTAB software was used for Taguchi's method and for analysis of variance (ANOVA). The obtained results are analyzed using Minitab software and all the values are shown in the Tabe 4 and 5.

Table: 4. S/N Ratio for higher the better

Level	A	B	C	D	E	F	G	H
1	60.93	59.92	60.09	60.83	60.57	60.68	60.53	60.76
2	60.39	61.18	60.72	60.66	60.71	60.67	60.36	60.37
3	0.00	60.89	61.18	60.50	60.71	60.64	61.10	60.86
Delta	0.54	1.26	1.08	0.34	0.14	0.04	0.74	0.49
Rang	4	1	2	6	7	8	3	5

The S / N ratio and ANOVA for tube flexibility response is calculated and shown in the Table 5 and Figure 8. The above response requires maximization, based on the above, we conclude that the best relationship between technological process parameters A_1, B_2, C_3, D_1, E_2, F_1, G_3 and H_3, respectively. As a result, the recommended combination of factors and their levels for the most responsive to this parameter is A_1, B_2, C_3, D_1, E_2, F_1, G_3 and H_3. ANOVA analysis shows that the greatest contribution to the pipe ring flexibility response is a factor B (37.02%), then factor C (25.14%). From the above, it can be concluded that for the the pipe ring flexibility the most important factor is B .The main effect plot for pipe ring flexibility shown in following figures .They show the variation of individual response with eight. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal the pipe ring flexibility. According to this main effect plot, the optimal conditions for maximum the pipe ring flexibility speed traction lines at level 1 (8.8 m/min), nozzle temperature at level 2

(206°C), doser expander at level 3 (23.2 r/min), screw speed extruder at level 1 (16.5 r/min), screw speed co extruder at level 2 (40.6 r/min), barrel temperature at level (174 $\overline{T}$ °C), doser mixture of extruder at level 3 (28.1 r/min) and doser mixture of coextruder at level 3 (38.4 r/min). The main effect plot for S/N ratios of the pipe ring flexibility for data means is shown in Figure 6 and 7.

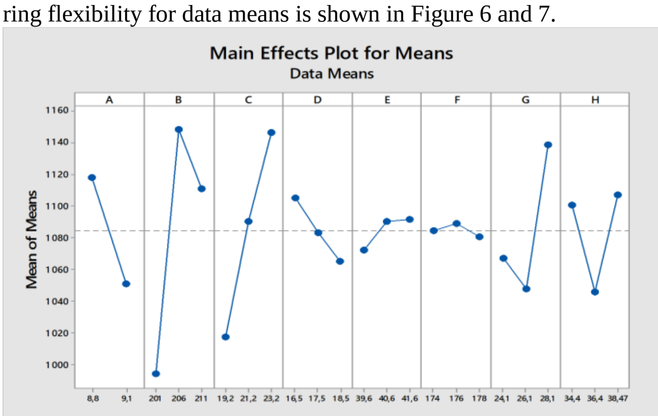

Fig. 6 Main Effects for Means: pipe ring flexibility

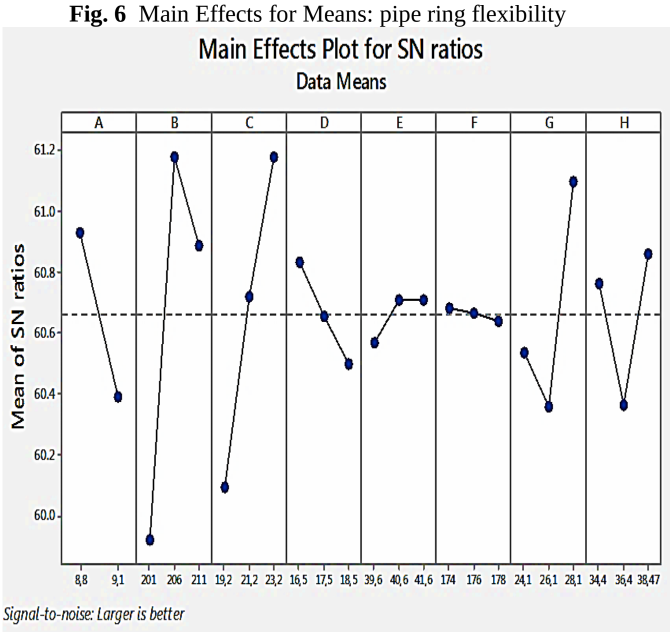

Fig. 7 Main Effects for S/N Ratios pipe ring flexibility

Table: 5. ANOVA S/N Ratio for pipe ring flexibility

Code	Level			DF	Contribution (%)	Adj SS	Adj MS	F
	1	2	3					
A	60.93	60.39	0.00	1	9.34%	1.319	1.319	0.244
B	59.92	61.18	60.89	2	37.02%	5.226	2.612	5.29
C	60.09	60.72	61.18	2	25.14%	3.549	1.774	3.59
D	60.83	60.66	60.50	2	2.39%	0.337	0.169	0.34
E	60.57	60.71	60.71	2	0.57%	0.008	0.040	0.008
F	60.68	60.67	60.64	2	0.004%	0.005	0.002	0.01
G	60.53	60.36	61.10	2	12.68%	1.790	0.895	1.81
H	60.76	60.37	60.86	2	5.83%	0.822	0.411	0.83
Error				2	7%	0.987	0.439	
Total				17	100%			

The percentage contribution of different control factors is graphically shown in Figure 8.

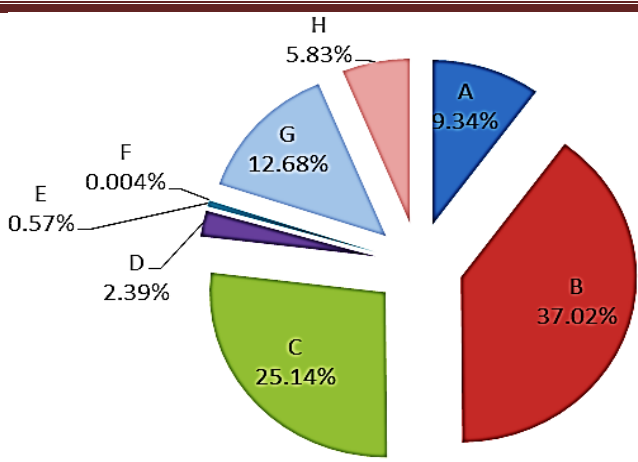

Fig. 8 Percentage contributions of control factors

3. Conclusions

This work presented an experimentation approach to study the impact of machining parameters on the pipe ring flexibility. Most significant interactions were found between nozzle temperature factor B (37.02%), factor C doser expander (25.14%), factor G doser mixture of extruder (12.68%) , factor A speed traction lines (9.34%) and factor H doser mixture of coextruder (5.83%). Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extend. The following are conclusions drawn based on the experimental investigation conducted by employing Taguchi technique to determine the optimal level of process parameters. The optimum value of control factors has been suggested as speed traction lines 8.8 (m/min), nozzle temperature 206(°C), dozer expander 23.2 (o/min), screws speed extruder 16.5(o/min), screws speed coextruder 40.6(o/min), barrel temperature 174 (°C), doser mixture of extruder 28.1 (o/min) and doser mixture of coextruder 38.4(o/min).

Acknowledgment

The technical and logistical support of the research was made possible by the Company Pestan, Aradjelovac, Serbia.

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