Parameter Optimization of Extrusion Machine Producing UPVC Pipes using Taguchi Method: A Case of Amhara Pipe Factory

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***Abstract*: In this study, an extrusion process that is used for production of UPVC (Un-plasticized Poly Vinyl Chloride) pipes at APF was studied. The study begins: 1st: By identifying possible product quality problems that adversely affect rate of rework or recyclability; 2nd: By prioritizing those quality problems which needs company top management intervention to minimize as much as possible, and 3rd: By performing cause and effect analysis to strengthen and diagnose causes corresponding to the identified, prioritized quality problems. Finally, Taguchi design of experiment is systematically approached from the existing APF extrusion machine temperature set- points to identify the possible Response output values approaching or nearest to the Taguchi Design; L27 OA. Additionally, Taguchi's loss function was also discussed in detail.**

The study quality characteristics focused on are variation on thickness of pipe. One method of reducing UPVC pipes thickness variation problem is by applying and using Taguchi method. "Nominal-The-Better" approach is selected for both S/N ratio & loss function analysis. Afterwards 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 and analysis of variance (ANOVA) are conducted to evaluate the results of the experiments. Using ANOVA, the significant factors impacting the quality characteristics of UPVC Pipes are obtained at a 90% confidence interval of recorded data.

Furthermore, the extrusion die is initially modeled with Solid Works to demonstrate the distribution of pressure and velocity inside the die to investigate does they have effect on the Quality Characteristics selected in the study using SW Flow simulation.

Key Words*: *UPVC Pipe, Pareto Diagram, Cause and Effect Diagram, Loss Function Analysis, Taguchi Method, ANOVA, Flow Simulation

I. INTRODUCTION

Organizations are created to achieve a goal, mission or objective but they will only do so if they satisfy the needs, requirements and expectations of their stakeholders. Their customers, as one of the stakeholders, will be satisfied only if they provide products and services that meet their needs, requirements and expectations. Their other stakeholders (shareholders, employees, suppliers and society) will only be satisfied if the products and services provided to customers are produced and supplied in a manner that satisfies their needs, requirements and expectations – in other words, it makes a profit [1].

Improving quality is very often regarded as an activity which is going to increase cost. This view confuses the terms used in industry concerning quality and grade. Improving or raising the grade of products relates to the use of more expensive materials or processes to produce a product and will raise product costs. Improving quality means among other things, making less faulty products with the same amount of effort or cost which usually gives a lower unit cost [2].

In our country quality assurance is adopted at the stage of inspection after the product leaves production process and /or passed to next step (if it is in the range of tolerance limit of the specification). Otherwise, it might be scrap or rework (if it is not in the range of tolerance limits) which both incur loss for the factory. The purpose of this thesis is to put Quality Engineering (Taguchi's Method) into perspective and to highlight its importance in quality improvement at the early stage of product and process design, as well as to present an optimum combination of process parameters setting that yield a sound product with better quality performance characteristics.

There are a lot of literatures written for optimization of manufacturing process parameters using Taguchi Method. Some of these are:

Adeel Ikram *et al*. [3] reports the effect and optimization of eight control factors on material removal rate (MRR), surface roughness and kerf in Wire Electrical Discharge Machining (WEDM) process for tool steel D2. The experimentation is performed under different cutting conditions of wire feed velocity, dielectric pressure, pulse on-time, pulse off-time, open voltage, wire tension and servo voltage by varying the material thickness. Taguchi's L18 orthogonal array is employed for experimental design. Analysis of variance (ANOVA) and signal-to- noise (S/N) ratio are used as statistical analyses to identify the significant control factors and to achieve optimum levels respectively.

Narasimha & Rejikumar [4] 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 their paper design of experiment (DoE) was applied to optimize the process parameters for the extrusion of high-density polyethylene (HDPE) pipe Ø50mm and plain pipe Ø25mm. Four independent process parameters involving 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.

Krishankant et al. [5] studies optimization of turning process by the effects of machining parameters by applying Taguchi methods to improve the quality of manufactured goods. EN24 steel is used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. they select three machining parameters i.e. Spindle speed, Feed rate, and Depth of cut. Different experiments are done on single point cutting tool made of high speed steel on Lathe by varying one parameter and keeping other two fixed so maximum value of each parameter was obtained. Operating range is found by experimenting with top spindle speed and taking the lower levels of other parameters. Taguchi orthogonal array is designed with three levels of turning parameters with the help of Minitab 15 software i.e., L9.

Mekonnen L. Nekere et al. [6] took two groups of aluminum blank sand casting processes for comparison of 1st : Single aluminum blank sand casting and 2nd : double aluminum blank sand casting aluminum blank green sand (green) casting process to optimize the process parameter using Taguchi's robust design approach. By changing different sittings of the casting process, they attempt to obtain optimal settings of parameters that affect the various quality characteristics of the product made from aluminum. test.

Cunsheng Zhang et al. [7] applied Taguchi's design of experiment and numerical simulation in the optimization of an aluminum profile extrusion process. By means of HyperXtrude simulation software, the extrusion process was simulated and the effects of process parameters on the uniformity of metal flow and on the extrusion force were investigated with the signal to noise ratio and the analysis of variance.

Alireza Akbarzadeh et al. [8] have studied optimization of parameter in Injection Moulding using Statistical Methods and IWO Algorithm statically. They tried to convince the effect of changing injection moulding parameters on the shrinkage behavior of polypropylene (PP) and polystyrene (PS) plastic materials.

S. Kamaruddin et al. [9] conduct a study to improve the quality level of an injection molding plastic tray product, made from blends plastic (75% polypropylene (PP) and 25% low density polyethylene (LDPE)) by optimizing the injection molding parameters using the Taguchi method. An orthogonal array (OA), main effect, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are used to analyze the effect of injection molding parameters on the behavior of the plastic Tray. Their study shows that the optimal combination of parameters that gives a sound product (Plastic Tray) are low melting temperature, high injection pressure, low holding pressure, long holding time and long cooling time.

Vidal et al. [10] in their study attempt to optimize The Friction Stir Welding (FSW) process which is a solid state mechanical processing technology enabling high quality joints in materials previously considered with low weldability such as most of the aeronautic aluminum alloys. The Taguchi method was used to find the optimal FSW parameters for improvement of mechanical behavior of aluminum alloy. The parameters considered were vertical, downward forging force, travel speed and pin length. An orthogonal array of $L_9\,(3^4)$ was used; ANOVA analyses were carried out to identify the significant factors affecting tensile strength, bending toughness and hardness field experiments.

II. TAGUCHI METHOD

DoE is a popular product and process improvement tool for Engineers and scientific professionals that allow easily learning and applying the technique product design optimization and production problem investigation. It provides a method for simultaneously investigating the effect of multiple input factors (process parameters) on the desired output, or response variable. DoE is useful for obtaining information about processes so that critical product and process characteristics can be identified, monitored, and kept on target. The design of experiment is selected to identify the best set of parameter combination among the effective factors by cutting down a number of experiment trials in to smaller number of experiments using orthogonal array.

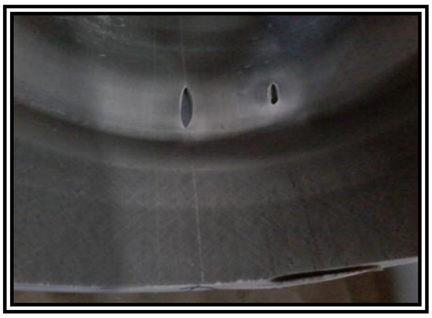
As Dr. Taguchi devote his life on searching of quality improvement strategy, he pointed out that by applying design of experiment techniques one could improve the performance of a particular product and process design in such a way that helps by improving consistency of performance & save cost, and building Robustness, or insensitivity of process parameters towards uncontrollable or noise factors.

Here in this study data were collected for UPVC pipe products of the company and by using Minitab software, process factors mostly affecting the response output i.e., thickness variation in this case would be determined. Minitab provides a lot of statistical function for easily analyzing data and ease to use statistical tools. One of its applications involves using DoE (Taguchi method).

III. DATA COLLECTION AND INTERPRETATION

Here an assessment on the finished product quality characteristics and the possible defects associated with product was investigated

(A)Shrinkage

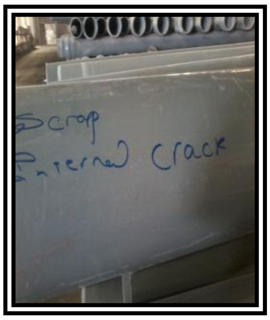


(B)Scratching & Pin Hole

(C) Thickness variation

(D) Inner diameter variation

Others (1) Tearing (2) Folding



(3) Cracking (4) chamfering problem

Figure 1: Quality defect of UPVC pipe

Due to an insertion of Mandrel and Calibrator the outer diameter of the pipe is not changed. The Calibrator keeps the pipe to hold its outer diameter. The Mandrel allows to produce different internal diameter pipe i.e., different thickness as well. The length of the pipe may vary due to inadequate supply of weight of raw material required during production process, and it is not taken as a defect characteristic since it’s compensated by some other pipe that would be produced with a little longer than the required length or vice versa. So such a length variation happen, the pipe would have been isolated not being rejected. For small pipe dimension mostly seen defect problem is shrinkage due to improper working of rubber hose at the vacuum chamber that sprays water inadequately, or not fully for cooling. Internal diameter variation on pipe is mainly caused by overloading of pipes together and poor material handling and storage. Burnt problems are merely caused by sudden electric power fluctuation, overheating of die and Extruder

.

Therefore, the product quality defects of UPVC pipe were tried to be assessed and represent by statistical quality control tools.

Hence, for UPVC product data about the total frequency of defects was taken and analyzed using Pareto chart to identify the most frequently occurring defect.

Total customer order = 450 pipe
OD= 110mm; Nominal pressure = 4 bar; Thickness = 2.2 – 2.7 mm; Length= 6m

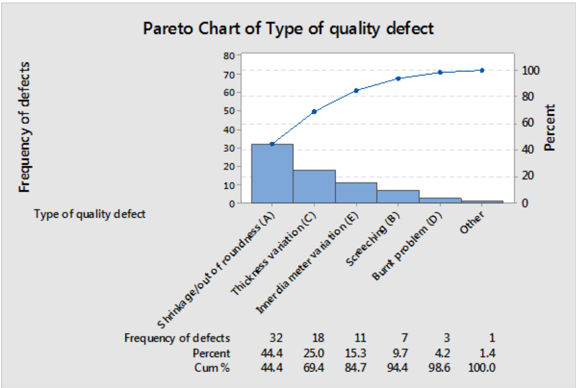


Figure 2: Pareto chart

Among UPVC pipe defects about 44.4% of defects are contributed by shrinkage. Thickness variations, inner diameter variation, screeching are also other contributors of the company's pipe defects. Burnt problems and others (Cracking, Tearing, Color variation etc…) are less contributing type of defects on UPVC pipe product type P_{N_4}.

Cause and effect diagram constructed using Minitab software as shown in Figure 3 that helps to find out the main and root causes having effect on UPVC pipe thickness variation problem. In Figure 3, some of the causes for thickness variation have also effect on other possible quality defects.

The main causes for thickness variation problem are identified and put down to measurement, labor, method, machine performance, and material. The table below shows the cause and sub-causes that have an effect on UPVC Pipe thickness variation problem at APF.

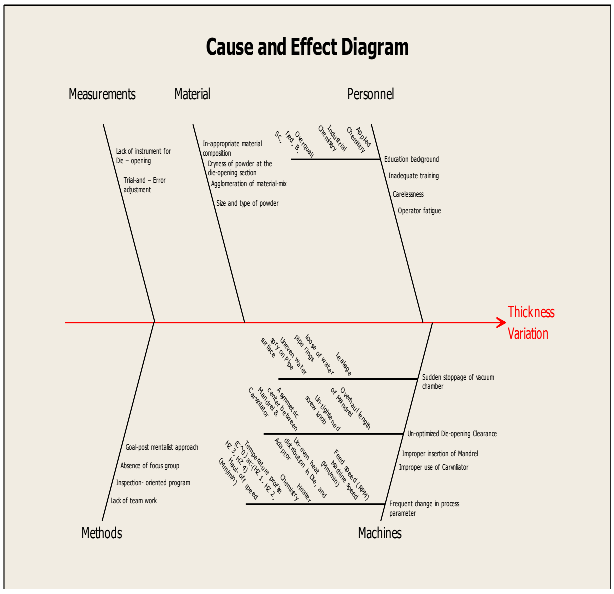


Figure 3: Cause and Effect Diagram

As shown in the diagram the main cause of thickness variation problem for UPVC pipe was different machine performance due to frequent change in process parameters by operators to bring the product in to a desired specified dimension through experience. The company runs its production in three shifts. During each shift operators are changed so as possible existence of change in process parameters. Therefore, the effects of these process parameters would be investigated and an optimal setting would be proposed to minimize thickness variation problem and loss ($) associated with desired performance characteristics would be determine by applying Taguchi DoE Approach.

IV. LOSS FUNCTION ANALYSIS

According to Taguchi Loss Function, Society incurs a loss when the product is shipped not on target To demonstrate the impact of deviation from target value, Taguchi introduce quality loss function, L(y) such that:

$$L(y) = k(y - m)^2;$$

Where:
L(y) - The loss, $ due to failure, repair, recycling
k - The proportionality constant
y - Actual performance value
m - The target value

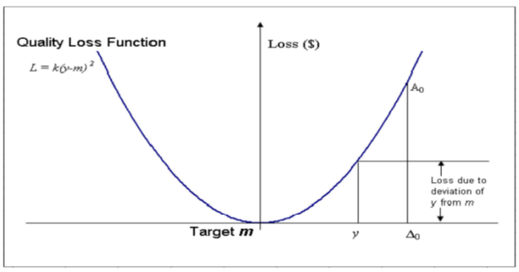


Figure **4**: Quality loss Function [11].

Table 1: Raw materials and associated over all purchasing cost used for UPVC pipe production.

S. no	Raw Material	Purchasing Cost (Birr/kg)
1	PVC resin	25.33774
2	Stabilizer	46.77736
3	Calcium carbonate, $ca(co)_3$	7.35659
4	Titanium dioxide, $Ti(o)_2$	92.16678
5	Carbon Black	39.62537

Estimated Raw material cost = $\frac{407.3601}{12.9125}$ = 31.54774 Birr/ kg using SWA. Then, the production cost is estimated as 465.104 Birr/pc. By dividing 465.104 Birr/pc to 6, we get 77.517 Birr/ m. And, the rate of defect for UPVC pipe is reaching above 17% of the total amount of production. Since once defect on a product is obtained, it would be recycled and reworked that in turn add an extra production cost and even contribute to the final selling price of the product. This makes an assumption that 17% of pipe goes back to the production process to be recycled.

Failure cost = production cost (Birr/pc) – (mass of a product (kg/pc) $*$ % of recyclable cost of raw material (Birr/kg))

= 465.104 $Birr/pc$ - (12.54 kg/pc* 17%* 31.54774 Birr/kg)

= 397.851 Birr/pc

As we calculate above, the failure cost that the company incurred for producing UPVC pipe (P_{N_4}) determined to be 397.851 Birr/pc.

Taguchi investigated in his quality loss function the loss in quality quantified in a parabolic relationship with the deviation of performance characteristics from the target value. From quality control daily report, 156 number of sample data was taken to estimate the mean and standard division.

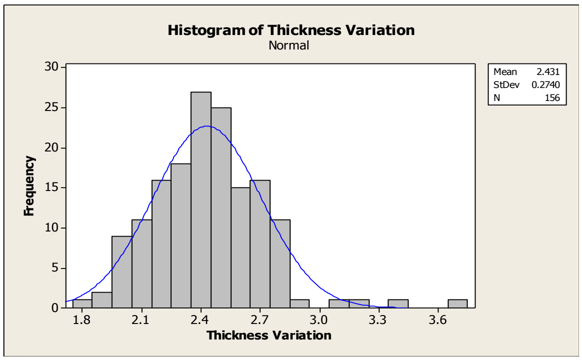


Figure 5: Histogram of Thickness Variation

The average quality loss for a product is calculated using a formula;

L_{avg} = k (s^2 + $(\mu - m)^2$); since μ = 2.431and s = 0.2740

L_{avg} = 6365.616* ($(0.2740)^2$ + $(2.431 - 2.45)^2$)

L_{avg} = 480.203 Birr/pc

As we calculated above the average amount of money the company loss due to quality problem is estimated to be 480.203 Birr per each UPVC Pipe of product.

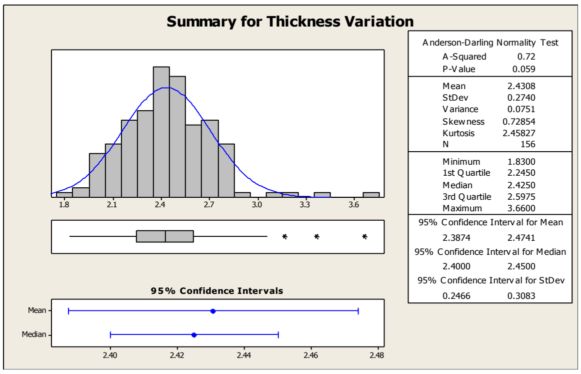


Figure 6: Summery Report

V. EXPERIMENTAL PROCEDURE

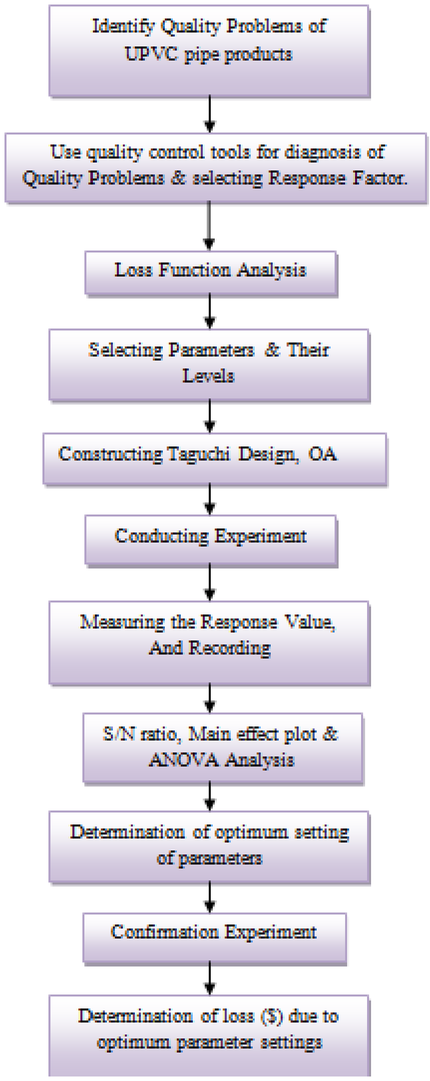


Figure 7: Flow Chart of Taguchi - DoE for Extrusion Process

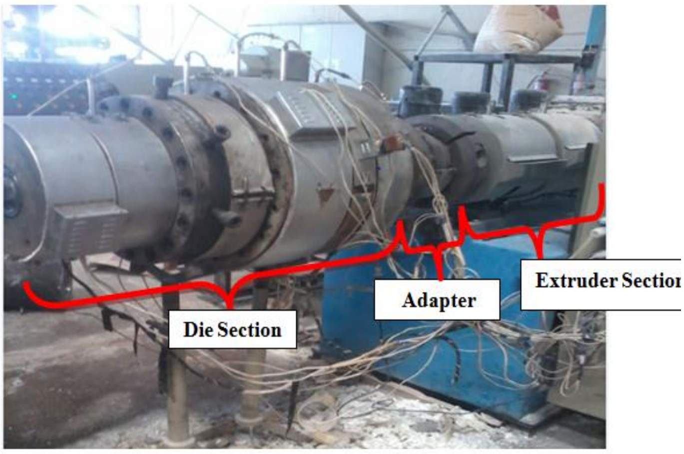


Figure 8: APF Extrusion machine components - Die Heater, Adapter and Extrusion Section

The table below summaries the variables and associated levels used in the experiment together with their assignments as shown in Table 2.

Table 2: Extrusion process parameters and their levels

	Control parameters	Section	Unit	Levels		
				Min (1)	Nom (2)	Max (3)
A	Feed Drum Heat – 1 (HZ_1)	Feeding	^oC	130	135	139
B	Feed Drum Heat – 2 (HZ_2)	Feeding	^oC	186	192	197
C	Feed Drum Heat – 3 (HZ_3)	Transition	^oC	183	188	193
D	Feed Drum Heat – 4 (HZ_4)	Metering	^oC	175	183	189
E	Core Heat (CH_1)	Adaptor	^oC	168	173	179
F	Mold Heat (MH_2)	Die	^oC	163	175	185
G	Mold Heat (MH_3)	Die	^oC	162	180	187
H	Mold Heat (MH_4)	Die	^oC	179	185	190
Response factor: Thickness variation						

The level should be chosen sufficiently far apart to cover a wide experimental region because sensitivity to noise factors doesn't usually change with small changes in control factor sittings. Although by choosing a wide experimental region, we can identify good regions as well as bad regions, for control factors [12].

In our case there are eight factors each with three levels are selected. From standard table of orthogonal array the preferable OA selected would be $L_{27}(3^8)$. Minitab software helps to generate Taguchi orthogonal array.

The letters A, B, C, D, E, F, G and H describe the control factors under study.
The number 1, 2, & 3 represent associated levels for each control factor.

Table 3: Experimental setup

Run	A	B	C	D	E	F	G	H
1	130	186	183	175	168	163	162	179
2	130	186	183	175	173	175	180	185
3	130	186	183	175	178	185	187	190
4	130	183	188	183	168	163	162	185
5	130	183	188	183	173	175	180	190
6	130	183	188	183	178	185	187	179
7	130	197	193	189	168	163	162	190
8	130	197	193	189	173	175	180	179
9	130	197	193	189	178	185	187	185
10	135	186	188	189	168	175	187	179
11	135	186	188	189	173	185	162	185
12	135	186	188	189	178	163	180	190
13	135	183	193	175	168	175	187	185
14	135	183	193	175	173	185	162	190
15	135	183	193	175	178	163	180	179
16	135	197	183	183	168	175	187	190
17	135	197	183	183	173	185	162	179
18	135	197	183	183	178	163	180	185
19	139	186	193	183	168	185	180	179
20	139	186	193	183	173	163	187	185
21	139	186	193	183	178	175	162	190
22	139	183	183	189	168	185	180	185
23	139	183	183	189	173	163	187	190
24	139	183	183	189	178	175	162	179
25	139	197	188	175	168	185	180	190
26	139	197	188	175	173	163	187	179
27	139	197	188	175	178	175	162	185

UPVC pipe were produced from the material mix on the Jinhu Extrusion machine as per the temperature set- points shown in Table -3. Immediately after manufacturing each pipe, samples are taken and its thickness was measured with the help of Digital Micrometer instrument.

The difference between their targeted thickness and the actual thickness dimension indicated the amount of variation that took place in the pipe. The thickness variation that occurred in the peripheral dimension of the pipe was recorded and that is why thickness variation was considered as a response variable/output characteristic in this study. Less thickness variation means high dimensional stability and vice-versa. It should be noted that the thickness was measured at eight positions with each divided at 45 Degree as it is shown below in Figure 9.

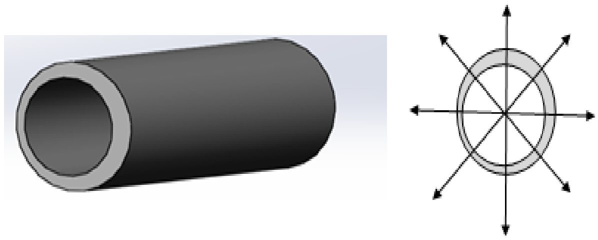


Figure 9: UPVC Pipe Thickness Measuring Positions

To locate measurement positions on pipe cross section, a string of length 42.08mm is used.

Then, it is possible to separate out the effect of each parameter at different levels. By using Minitab software, each values of the response output are inserted in the worksheet and evaluated using a special Module to obtain response table for signal to noise ratio and response table for means.

Table 4: Possible factor combinations and their corresponding response outputs

Run	A	B	C	D	E	F	G	H	Response output	
									Avg. N1	Avg. N2
1	130	186	183	175	168	163	162	179	2.48	2.501
2	130	186	183	175	173	175	180	185	2.506	2.50
3	130	186	183	175	178	185	187	190	2.544	2.494
4	130	183	188	183	168	163	162	185	2.576	2.525
5	130	183	188	183	173	175	180	190	2.453	2.475
6	130	183	188	183	178	185	187	179	2.555	2.53
7	130	197	193	189	168	163	162	190	2.569	2.508
8	130	197	193	189	173	175	180	179	2.551	2.443
9	130	197	193	189	178	185	187	185	2.544	2.464
10	135	186	188	189	168	175	187	179	2.545	2.501
11	135	186	188	189	173	185	162	185	2.558	2.51
12	135	186	188	189	178	163	180	190	2.623	2.525
13	135	183	193	175	168	175	187	185	2.584	2.471
14	135	183	193	175	173	185	162	190	2.569	2.508
15	135	183	193	175	178	163	180	179	2.511	2.475
16	135	197	183	183	168	175	187	190	2.554	2.505
17	135	197	183	183	173	185	162	179	2.52	2.514
18	135	197	183	183	178	163	180	185	2.529	2.491
19	139	186	193	183	168	185	180	179	2.541	2.443
20	139	186	193	183	173	163	187	185	2.623	2.525
21	139	186	193	183	178	175	162	190	2.56	2.501
22	139	183	183	189	168	185	180	185	2.598	2.468
23	139	183	183	189	173	163	187	190	2.596	2.455
24	139	183	183	189	178	175	162	179	2.496	2.453
25	139	197	188	175	168	185	180	190	2.51	2.448
26	139	197	188	175	173	163	187	179	2.453	2.464
27	139	197	188	175	178	175	162	185	2.50	2.463

Table 5: The S/N ratio Response Table

- Response Table for Signal to Noise Ratios
- Nominal is best (10*Log10(Ybar**2/s**2))

Symbol	Parameters / factors	Section	Signal to Noise Ratios			Delta	Rank
			Level				
			1	2	3		
A	Feed Drum Heat – 1 (HZ_1)	Feeding	39.97	38.27	35.32	4.65	5
B	Feed Drum Heat – 2 (HZ_2)	Feeding	38.02	36.05	39.48	3.43	6
C	Feed Drum Heat – 3 (HZ_3)	Transition	40.47	39.53	33.56	6.91	2
D	Feed Drum Heat – 4 (HZ_4)	Metering	40.75	39.38	33.41	7.34	1
E	Core Heat (CH_1)	Adaptor	35.26	40.83	37.46	5.58	4
F	Mold Heat (MH_2)	Die	37.44	38.73	37.38	1.35	8
G	Mold Heat (MH_3)	Die	39.85	37.25	36.45	3.40	7
H	Mold Heat (MH_4)	Die	41.19	36.88	35.48	5.72	3

ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

Table 6: Response Table for Mean

- Response Table for Means
- Nominal is best (10*Log10(Ybar**2/s**2))

Symbol	Parameters / Control Factors	Section	Means Level 1	Means Level 2	Means Level 3	Delta	Rank
A	Feed Drum Heat – 1 (HZ_1)	Feeding	2.512	2.527	2.505	0.022	4
B	Feed Drum Heat – 2 (HZ_2)	Feeding	2.527	2.517	2.502	0.025	2
C	Feed Drum Heat – 3 (HZ_3)	Transition	2.511	2.512	2.522	0.010	7
D	Feed Drum Heat – 4 (HZ_4)	Metering	2.499	2.523	2.523	0.024	3
E	Core Heat (CH_1)	Adaptor	2.518	2.512	2.514	0.006	8
F	Mold Heat (MH_2)	Die	2.524	2.503	2.518	0.020	5
G	Mold Heat (MH_3)	Die	2.517	2.505	2.523	0.018	6
H	Mold Heat (MH_4)	Die	2.499	2.524	2.522	0.026	1

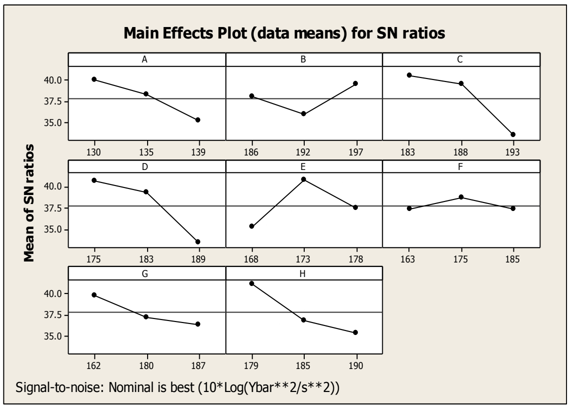


Figure 10: Main Effects Plot for S/N Ratio

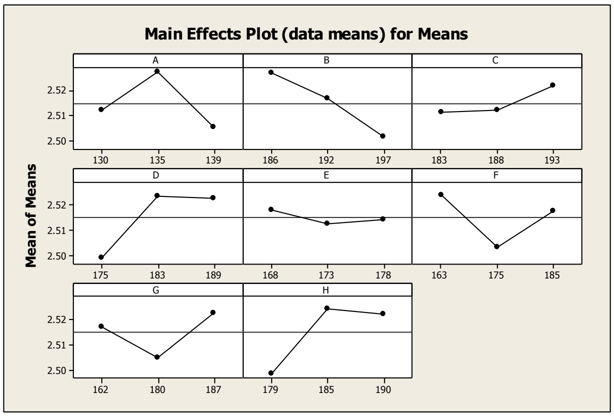


Figure 11: Main Effects Plot for Means

By Looking at the response tables and main effects plots for the signal-to-noise (S/N) ratios to see which factors have the greatest effect on S/N ratio, which in this case is Nominal-is-best is used. In this case, the factor with the biggest impact on the S/N ratio is Feed Drum Heat-4 (Delta = 7.34, Rank = 1). And the factor with the least effect on S/N ratio is Mold Heat (MH_2) (Delta = 1.35, Rank = 8). In order to reduce the impact of noise on response (i.e., reducing variation around the thickness of pipe), possible parameter combination settings are the one with higher S/N ratio in each factor. Therefore, from response tables of S/N ratio we can decide that A_1 , B_3 , C_1 , D_1 , E_2 , F_2 , G_1 , H_1 are the possible parameter combinations for reducing the variation around thickness of pipe.

Here in the response table and main effects plots for mean both show that the factor with the greatest effect on the mean is Mold Heat (MH_3) (Delta = 0.026, Rank = 1). And the factor with the least effect on the mean is core heat, or Adaptor (CH_1) (Delta = 0.006, Rank = 8).Since main effect plots for means is helpful for adjusting the mean on target value, those parameter levels with near or close to the desired target thickness of pipe that means A_1 , B_2 , C_2 , D_3 , E_3 , F_3 , G_1 , H_3 would be taken as a possible parameter combinations for adjusting, or approaching the mean on targeted thickness of pipe to maintain its symmetry as much as possible.

VI. ANALYSIS OF VARIANCE (ANOVA)

The purpose of the analysis of variance (ANOVA) was to find which parameters significantly affected the quality characteristic. By making analysis of each response values: General Linear Model Noise 1, Noise 2 against factor A, B, C, D, E, F, G and H; ANOVA results indicate whether or not there is statistically significance difference in output characteristics. Since ANOVA analysis involves one of the P values was below 0.05, then we go for validation of the result in either of three cases. I.e., Normality, Constant Variance, and Independence Test.

Table 7: ANOVA Table

Col# / Factor	DoF (f)	Sum of sqrs. (s)	Variance (v)	F – Ratio (F)	Pure sum (s')	Percent P (%)
1 1	2	99.971	49.985	1.606	37.723	2.779
2 2	2	52.925	26.462	0.85	0	0
3 3	2	252.353	126.176	4.053	190.104	14.008
4 4	2	273.282	136.641	4.39	211.033	15.55
5 5	2	141	70.5	2.265	78.751	5.803
6 6	2	10.54	5.27	0.169	0	0
7 7	2	56.791	28.395	0.912	0	0
8 8	2	158.961	79.48	2.553	96.712	7.126
Other/ Error	10	311.242	31.124			54.734
Total:	26	1357.07				100%

Table 8: ANOVA Table with Corresponding CL

Col# / Factor	DoF (f)	Sum of sqrs. (s)	Variance (v)	F – Ratio (F)	Pure sum (s')	Percent P (%)
1 1	(2)	(99.971)		POOLED	(CL=75.55%	
2 2	(2)	(52.925)		POOLED	(CL=*NC*)	
3 3	2	252.353	126.176	4.053	190.104	14.008
4 4	2	273.282	136.641	4.39	211.033	15.55
5 5	(2)	(141)		POOLED	(CL=86.25%	
6 6	(2)	(10.54)		POOLED	(CL=*NC*)	
7 7	(2)	(56.791)		POOLED	(CL=*NC*)	
8 8	(2)	(158.961)		POOLED	(CL=89.95%)	
Other/ Error	22	831.43	37.792			70.442
Total:	26	1357.07				100%

Column # / Factor	Level Description	Level	Contribution
1 1	1	1	2.119
2 2	3	3	1.623
3 3	1	1	2.614
4 4	1	1	2.893
5 5	2	2	2.968
6 6	2	2	0.883
7 7	1	1	1.996
8 8	1	1	3.334
Total contribution from all factor…		18.432	
Current Grand Average of Performance…		37.843	
Expected Result At Optimum Condition…		56.275	

VII. RESULTS AND DISCUSSIONS

To reduce variation around thickness of pipe (control factor with the biggest impact on the S/N ratio) is identified to be Feed Drum Heat-4 (Delta = 7.34, Rank = 1). And the factor with the least effect on S/N ratio is Mold Heat (MH_2) (Delta = 1.35, Rank = 8).

In the response table and main effects plots for mean both show that the factor with the greatest effect on the mean is Mold Heat (MH_3) (Delta = 0.026, Rank = 1). And the factor with the least effect on the mean is core heat, or Adaptor (CH_1) (Delta = 0.006, Rank = 8).

To demonstrate the distribution of pressure and velocity inside the die, the study begins with creating the Solid Works part (APF Extruder Die).
The extrusion die is initially modeled with Solid Works; Figure 12 illustrates the assembled die in 180^0cut section view in order to show all the parts that constitute it.

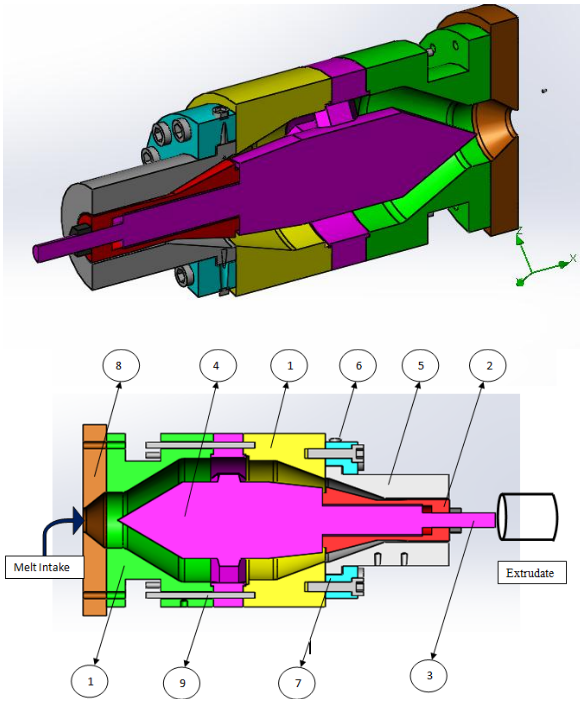


Figure 12: Sectional View of APF Extruder Die Machine Showing Melts Flow Channel, And Melt Intake

General Description
A 3D model is developed for non-Newtonian materials being processed in the extrusion die based on the configuration of Figure 33 that its part dimensions were taken by direct measurement using Tape meter. In this study, an assumption that a homogeneous High Density Polyethylene (HDPE) and solid Epoxy resin melt with a uniform temperature are flowing into the die channel. The temperature of the die wall is kept constant and the volumetric flow rate of the polymer melt is fixed.

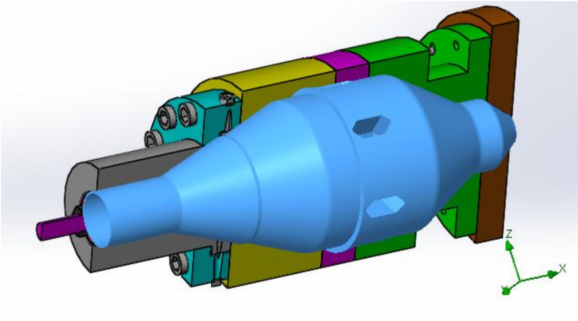


Figure 13: Schematic illustration of solid flow volume inside the die channel

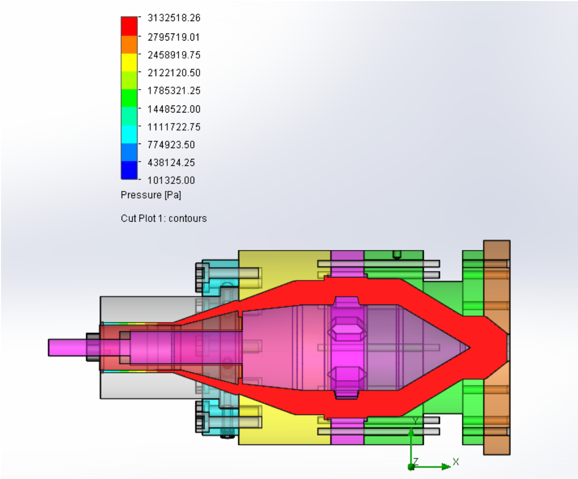


Figure 14: Pressure Distribution at the Die Channel

To look out the distribution of pressure inside the channel, and to see which regions of the die opening have gained lower pressure and which one was maximum pressure an equation goal is made by using the formula of pressure drop.

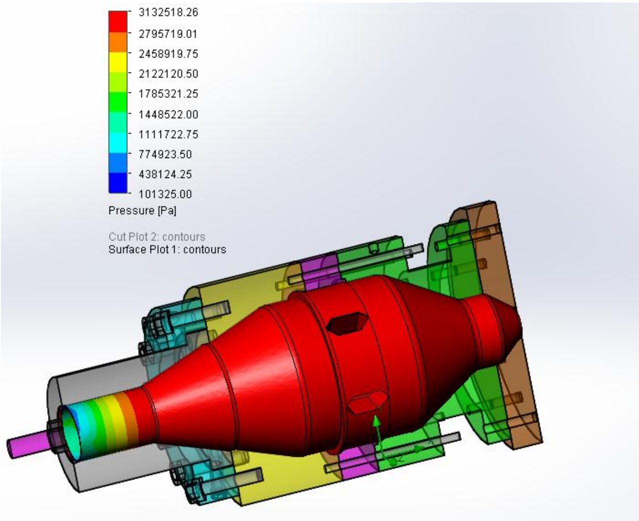


Figure 15: Fully Open Surface Plot of Pressure Distribution at the Die

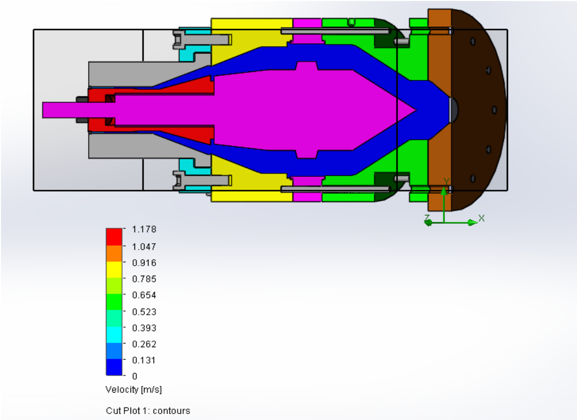


Figure 16: Velocity Profile Showing Points where Velocity Varies

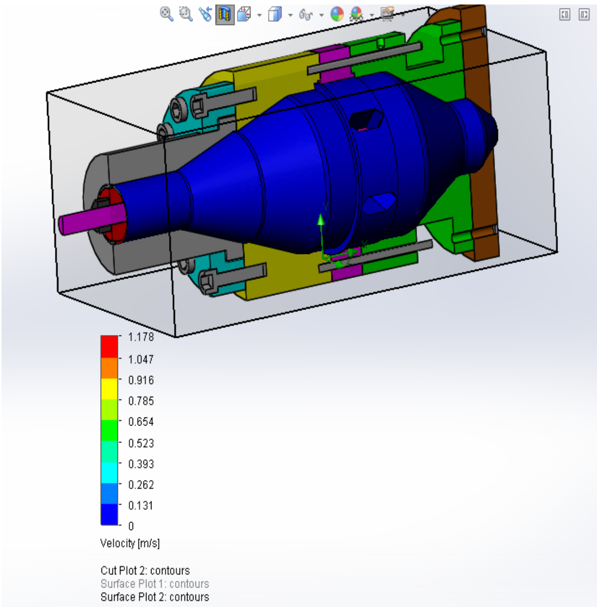


Figure 17: Fully Open Surface Plot of Velocity Distribution at the Die

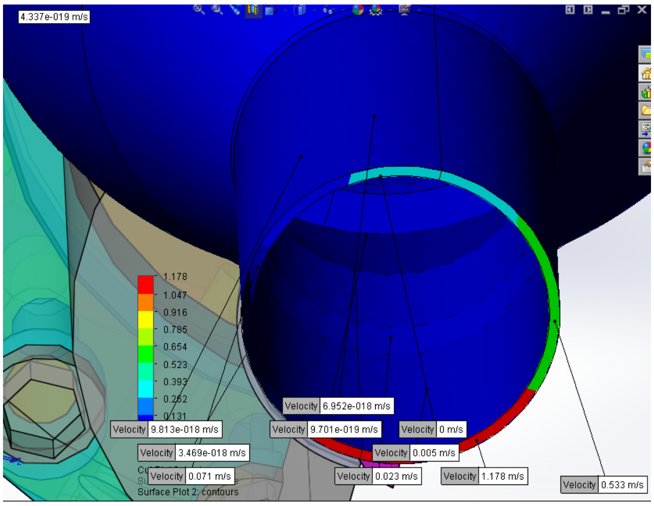


Figure 18: Velocity Variation at Different Points of the Melt

The velocity of the melt as it is shown in the figure above varies at different points of the melt which plays a vital role for the existence of production of pipes with different thickness even if it is smaller to quantify. To elaborate more what the velocity profile inside the die channel looks like, a plot is made as the melt passes through the channel for a certain prolonged period of time.

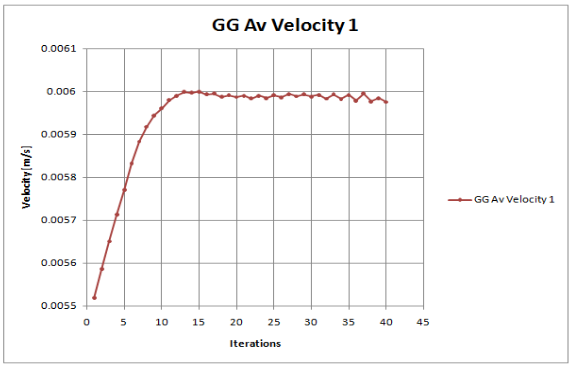


Figure 19: Average velocity distribution via iteration

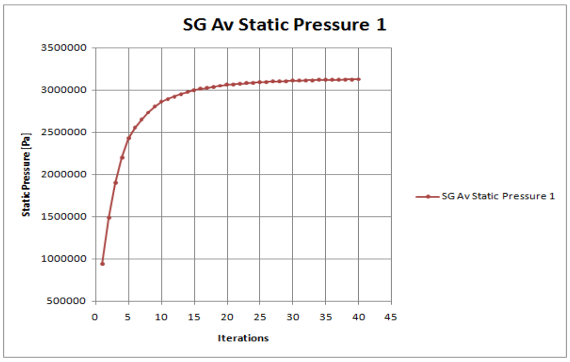


Figure 20: Static Pressure inside the Die Channel via Iteration

The pressure inside the die channel via iteration has a profile as it is shown in the figure above. Due to conduction effect of temperature between the melt and Heater pads the pressure distribution varies. At the start of production, most of the Extrudate have smaller injecting velocity via iterations and it have also smaller melt pushing pressure at the die outlet which both contributes highly defective pipe production at the beginning of machine start up.

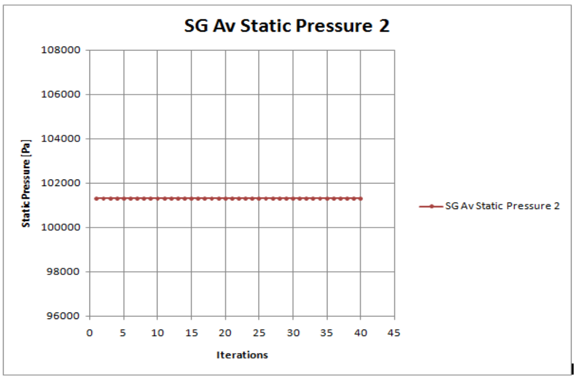


Figure 21: Static Pressure at the end of Extruder DIE outlet via iteration

VIII. CONCLUSIONS

As part of the general outcome of this study, Taguchi method plays a vital role in any companies (whether engaged in manufacturing of tangible output or service rendering) to satisfy their customer needs, expectations by producing quality product or delivering services in a manner through reduction of unnecessary costs either prior to production or after the item was shipped to customers - meaning TM is helpful for reduction of unit manufacturing cost (UMC) and quality loss ($) respectively through incorporating ideas either at the product development or process design stage and also identifying optimum control parameter combinations. And, rather than directly choosing the response output, pareto analysis and cause and effect diagram needs to be incorporated to make the study visible so as it creates worth for the company profitability etc..

Beyond the factors set in TM, Melt pressure and Melt flow velocity have identified to be one of the contributing factors for production of defected products of Extrusion machine especially at the beginning of machine start up time till it's stable.

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