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Plastic Pipe Defects Minimmization

M.Narasimha
Faculty, School of Mechanical and Industrial Engineering Bahirdar University
R.Rejikumar
Faculty, School of Mechanical and Industrial Engineering Bahirdar University

Abstract:

This study present a systematic approach to find the root causes for the occurrence of defects and wastes in plastic extrusion process in the case company. Particularly defects such as surface roughness and scratch, bulging, sink marks, uneven wall thickness, dimensional variation, centering problem, tears and marks were identified defects.

To identify the root causes of these defects, cause-and -effect diagram were implemented. From the diagram, the major root causes of each defect were the extrusion process parameters such as, the vacuum pressure, temperature, take-off speed, screw speed of the extrusion process and raw material properties. According to the data of the company about 76.758% these root causes are caused by operators. This is due to inappropriate setting of operational parameters. The most frequently occurring defects were identified through Pareto chart. After identifying these frequently occurring defects, by applying Taguchi's method of quality engineering for optimum setting of process parameters for the plastic product so that those defects were minimized by reducing variation of performance (quality) from target value.

Bruh Tesfa Irrigation and Water technology PLC (BTIWTPLC) company, used as a case in order to conduct Taguchi's method (design of experiment) together with quality loss function for the selected products.

Particularly, 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 case design of experiment was applied to optimize the process parameters of the four selected products and those products were selected from pipe HDPE1 Ø 50mm and Plain pipe Ø 25mm. Four independent process parameters were investigate, namely Vacuum pressure, Take-off speed ,screw speed and Temperature were considered for DOE. .Commercial Minitab 15 software was used to analyze the result of the experiment based on the result of analysis optimum process parameters were selected.

Here loss function was calculated and compared with the quality loss before applying of design of experiment. From this it was understood that, using Taguchi's method of design of experiment the quality loss because of performance deviation (scrap inclusive) improves by about 85.201% for the selected products, Here also the Structural tests of main pipe mechanical properties (tensile and hydrostatic pressure property) have been tested using the universal testing machine. From the test conducted that, the plastic product characteristic were within the target application without failure.

In addition, to minimize defects caused by non-linear properties (i.e. sharkskin, melt fracture and extrudate swell) mathematical modeling and analytical calculation were made. Accordingly, the best operating parameters including; maximum pressure, residence time, the required operating torque and speed of the extruder screw were determined.

Keywords*: Plastic Extrusion, Nonconformity, Influence Factors, Design of Experiment.*

1.Introduction

Polymers have many advantages as they are light in weight, provide design flexibility, offer electrical insulation, and have relatively low overall and manufacturing cost. Hence the advantages of synthetic polymers are over competent than other materials like metals, it is reasonable to predict that polymers will take an even greater allocation of the total material market in the future [1]. In plastic manufacturing ,industries produce reasonable amount of waste during production ,scrap plastics are generated from the manufacturing of plastic products and packaging ,and from manufactured materials .plastic manufactures are responsible for the generation of these scraps and wastes and some performance problems are occurring, accordingly the amount of waste generated by plastic industrial plants becomes an increasingly costly problems for manufacturers lose of customer confidence on the products. one and the only solution of those problems are to analyze and minimize the waste as its source and improve the performance of the products, as a result this thesis work is going to focuses strictly to minimize the generation of waste & improve the performance of the products ,especially by focusing on the Berhu Tesfa plastic factory this is because when you visit the factory on an operation the products are laid on the ground and when you look those products there are a lot of defects on the products internal and external surface ,and the machine which is crushing the defected product was not rest the whole day this indicate that there are allot of defected products ,so that the factory rework cost is high this finally hinder the company to lose its market share and costumers are changing their choices into other competitor's.

It is estimated that the material used in extrusion can account for 50%-70% of total costs, and if the costs of labour are included, these altogether can vary within an order of 60%-80% of total costs. Any technique that can reduce labour costs, minimize material wastage and attain the requested quality is undoubtedly an important factor for consideration [2]**.** The research starts with identifying, analyzing of defects (quality problems) and observing of performance problems of products from the factory and from site. And those quality problems will be optimized through the well-known quality engineering tools called Taguchi's methods design of experiment. Taguchi's loss functions were calculated for the selected products before and after the application of this tool in conjunction with Mintab15software for analysis.. This process involves the following sequence; heating and melting the polymer, pumping the polymer to the shaping unit, forming the melt in to the required shape and dimensions, cooling and solidification (Fig.1).

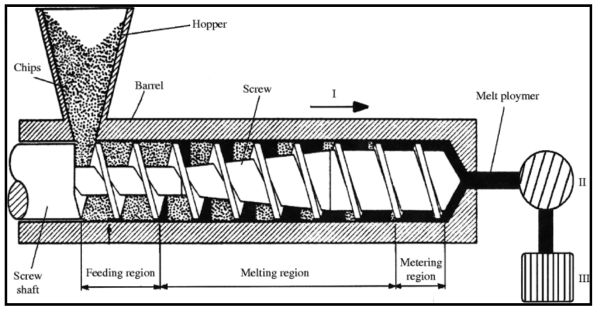


Figure 1: Schematic illustration of a typical Single-screw extruder

Good quality of extrusion is ideally carried out under the design condition of constant screw rotational speed and temperature and uniform composition. Poor extradite quality for a given designed extruder can be related to the inappropriate setting of processing conditions [3].

2.Literature Review

To show how the inappropriate setting of processing conditions affected the product quality, Maddock [4] in his work described the case of quality requirement for the extrusion of 1.0 mm thick film. Due to temperature difference the viscosity is affected and the viscosity variations act to produce pressure changes and so caused large thickness variations. High extrusion rates and good extrusion quality are often two extremes and thus incompatible. Tadmor and Klein [5] classified bad mixing of the components forming the product can result in bad appearance and a non-uniform product. Non-uniformity in products can lead to weakness of mechanical strength. Poor extrusion quality for a given extruder is frequently related to random difference of temperature, pressure, and flow rate. Dowd [6] and young [7] reported that the product properties are depends on the extrudate temperature. Fenner, et al. [8] also stated that screw cooling reduces throughput, thus eliminating these fluctuations without cooling the screw will allow these extruders to achieve a higher level of productivity. And extrusion experts identify five factors that limit product throughput and quality: power or screw speed, temperature, feed, vacuum pressure, and downstream processing [9].

3.The Planning Of The Experiment

In this case design of experiment was applied to study of influence of the factors (process parameters) in plastic extrusion process, which were considered to be the main causes for defect of products. The products HDPE1 Ø 50mm, plain pipe ϕ25 mm products were selected as shown in Fig. 2.

Figure 2: The sample products

2.1.Defects In Extrusion Process

Defect is any form of deviation of the product's characteristic from the specification set up by the manufacturing process. It can be caused by a single source or the cumulative effect of several factors, which may arise at any stage of the processing. The Common failure or defects which are normally occurring in plastic extrusion process are due to three main causes are part and mold design, material selection, and processing. In many cases, the failures occur during the processing and these failures causes some defects that can be found in extruded parts such as: warpage, sink mark, residual stress, air trap, weld line, sink marks, low gloss, uneven surface gloss, spotted surface, rough surface, extruder surging, thickness variation, uneven wall thickness, diameter variation, centering problem as shown in fig. 2. In extrusion products, defects due to processing include, poor understanding of the processing method, use of inadequate or old machines, lack of trained staff, machine break down, and inappropriate working environments.

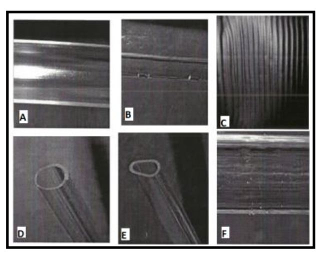


Figure 3: Observed defects

- A - Surface roughness
- B - Marks
- C - Bulging
- D - Dimensional variation
- E - Out of round
- F - Sink marks

Here data was collected from reported data and from personal observation of the case factory in this particular section, the collected data are presented, analyzed and corrective actions will be selected, suggested and developed.

2.2.Indentify Major Defect Of The Products

The total defects occurring on the specific product type (categories) with in a six month was recorded and this is analyzed using the Pareto chart to know the most frequently occurring. The detailed analysis of this major extrusion defect for a specific product is made very precisely.

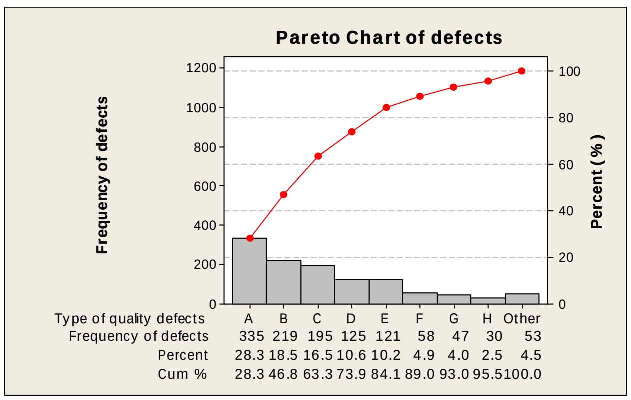


Figure 4: Pareto chart for defects happening frequently in pipe products

Type of quality defects
Uneven Wall thickness (A)
Centering problem(off-center) (B)
Diameter variation (C)
Sink marks(D)
Scratching (E)
Discontinuity (F)
bend(G)
Poor surface finishing (H)

The highest frequency percentage is 63.3% that indicates the defects occurring on pipe products are wall thickness variation, centering problems (off-centering) and diameter variation. In this case great attention is given for those defects in order to minimize those defects. In pipe products the following defects are frequently occurring defects, they are, Uneven wall thickness, Centering problems, Diameter variation

From those defects when we see their level of impact on customer satisfaction and increasing cost of production, diameter variation and wall thickness variation are the main concerns of the company. As a result, attention has been given for this product category in reducing diameter variation for HDPE1 Ø 50mm, plain pipe ϕ25 mm products is chosen as a case because this product is produced frequently.

2.3.X -Chart Analysis Of The Selected Products

From the data collected of each product of our case study, X - Chart analysis is developed for some samples in order to show clearly whether the production process is out of limit or control. The data collected for each product was given below with X –Chart form.

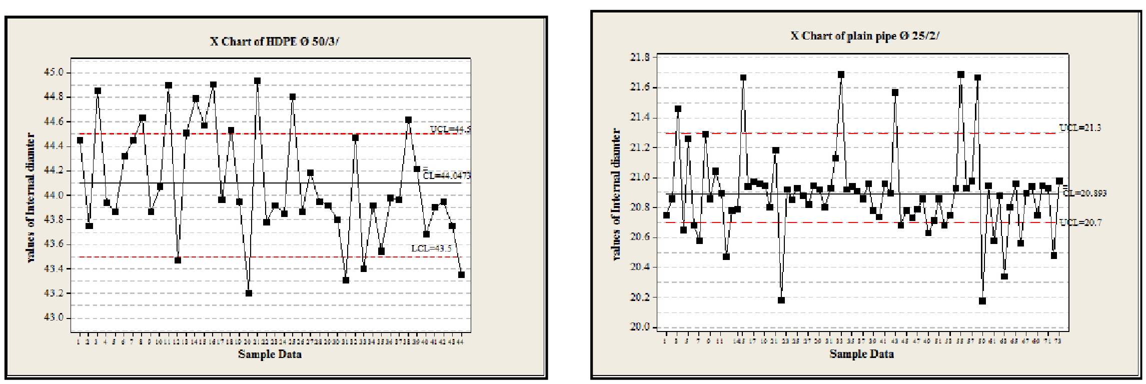


Figure 5: Observed defects and plain pipe ϕ25 mm

3. Analysis Of Quality Loss For Determining The Influence Of Process Parameters

From the results of the Pareto data analysis and X – Chart from the above sections, type and frequency of defects that occurred in those products were identified. Taguchi's loss function has been functional to calculate the quality loss of the chosen products.

3.1. Selection Of Process Parameters For The Products

The optimum operating condition for different extrudates is varied so as to get quality product. Based on the above to minimize the selected defects, the main process parameters should be selected and those are residence time, temperature zones, screw speed, vacuum pressure and cooling time. In this case, this study will give emphasis to vacuum pressure, take-off speed, screw speed and temperature zones settings for getting quality products, and setting other parameters constant.

High density polyethylene Pipe (HDPE1 Ø 50/3.0/ 10bar PE- 100) -The Process parameters used in the experiment for this product are vacuum pressure 1, take-off speed 2 and Temperature 3 Temperature 4, Temperature 5 and Temperature 6 Temperature7 Temperature 8 are the process parameters in this case the response value or target value is internal diameter & uneven wall thickness.

Plain pipe (IR Ø 25/1.8/16bar PE-100) - The process parameters used in the experiment for this product are vacuum pressure 1, take-off speed 2 Temperature 3, Temperature 4, Temperature 5 and Temperature 6 while the performance measures are internal diameter wall thickness.

3.2. Quality Loss Calculation

For this paper, Nominal-The-Best (NTB) quality loss measurable characteristic has been used for analysis and decision confirmation for the optimization the critical process parameters that influence the campiness product quality. Here to calculate the loss function for the selected product using the theory of Taguchi's loss function the value of L (failure cost) used in this calculation is taken from the following table 1.

Types of products	**Six month production(Kg)**	**Mass of a product per piece (Kg)**	**Cost of raw material (birr/Kg)**	**Production cost (birr)**
HDPE PIPE Ø50 mm	163,407.00	0.458	35.0849	12.551
Plain pipe Ø25 mm	89,652.00	0.139	35.0849	4.3232

Table 1: Six month production details

This company loses a lot in each month and the total cost could be multiplied with the current market of Ethiopia shortly illustrated on table 2. The general formula used to calculate the failure cost for all selected products is;

$$\text{Failure cost} = \text{production cost (birr/pc)} - (\text{mass of aproduct (Kg/pc)} * \%\ \text{recyclable} * \text{cost of raw material (birr/Kg)})$$

Product	**Failure Cost**
Plain Pipe Ø25 mm	1.53birr/pc
HDPE Pipe Ø50 mm	2.484 birr/pc

Table 2: Failure cost of sample products per a unit or weight

To calculate the quality loss some assumptions should be set and they are;

1. Failure cost = production cost - cost saved by recycling scraps
2. Maximum loss was occur at the two tolerance

SD = Standard deviation, μ = mean value of samples, m = target value, TL = tolerance limit, L = failure cost of the product.

3.2.1.<u>High density polyethylene Pipe (HDPE1 Ø 50/3.0/ 10bar PE-100</u>**)**

SD= 0.265, μ=44.0473mm, m=44mm, TL=44±0.5mm and L=2.484 birr (data taken) (Failure costs of the selected products, taking into consideration there is recyclable scraps) so this loss is calculated as the following, for a single product.

$L(y)=k(y-m)^2 = 2.484=k(44.5-44)^2$ k= 9.936

Average quality loss for this specific product is L = 0.7199 Birr/pc

3.2.2. <u>Plain Pipe Dia25/2/ 16bar PE-100)</u>

SD =0.1932, μ=20.893mm, m=21mm, L=1.53birr, TL=21±0.3mm

$L(y)=k(y-m)^2 = 1.214=k(14.3-14)^2$ k= 13.44

Therefore, the average quality loss function for this product is L= 0.468 Birr/pc

3.3.Design Of Experiment

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi (DOE). Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. The process parameters considered in DOE of the case company's production process were vacuum pressure, Take-off speed, screw speed and temperature but here we have to give more emphasis to temperature. Table 3 shows the details of experiment.

High density polyethylene Pipe (HDPE dia50/3/ 10bar PE- 100)					**Plain pipe (IR Ø 25/2.0/16bar PE-100)**			
Control factors (Temperature zones in ℃ ,vacuum pressure in bar and take-off speed in m/min)	Levels				Levels			
	1	2	3	4	1	2	3	4
pressure 1	-50.5	*-55.0*	-58.5	*-62.5*	-5.5	*-6.5*	*-7.5*	*-9.0*
take-off speed 2	1.6	1.8	2.0	2.4	5.0	*6.0*	*7.5*	*8.5*
Temperature 3	125	130	135	140	110	115	120	125
Temperature 4	130	135	140	145	125	130	135	140
Temperature 5	140	145	150	155	125	130	140	145
Temperature 6	155	160	165	165	130	145	150	155
Temperature 7	155	160	*165*	*170*				
Temperature 8	160	165	170	175				
Response variable: Internal diameter & wall thickness								

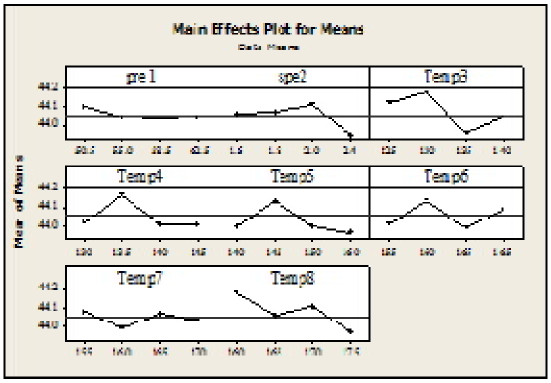
Table 3: Parameters used for conducting the experiment (DOE)

From the data obtained from the experiments for each selected products, mean response and signal to noise ratio (S/N) analysis were done. So that Corresponding S/N ratio equation for nominal the best (NTB) is given as:

$$S/N = 10\log\left(\frac{(\text{ybar})^2}{s^2}\right)$$

4. Result And Discussion

4.1. High Density Polyethylene Pipe (HDPE Dia50/3/ 10bar PE- 100)



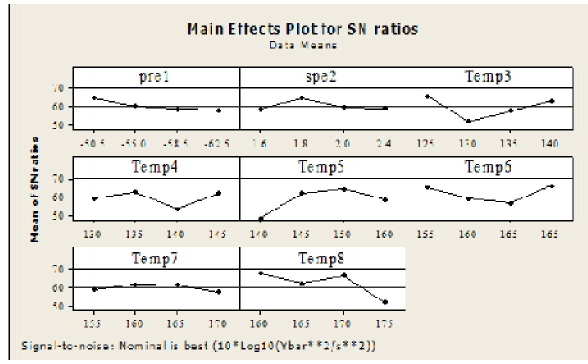


Figure 6: High density polyethylene Pipe

Figure 6. shows the response variable (internal diameter) and the companies required nominal dimension was 44.0mm. from the graph above vacuum pressure 1 value -58.5, take-off speed 2 value 1.6, temperature 3 value 135, temperature 4 value 145, temperature5 value150, temperature 6 value 165 ,temperature7 value 160, temperature 8 value 165, are the process parameters which are used to produce HDPE pipe nearby to the target value. To select the optimum processing parameters, it will also need to consider settings their effect on SN ratio. The response S/N ratio is required to be large or should not be significantly minimized for any type of design of experiment analysis, In this case from the figure below vacuum pressure 1 value -50.5, take-off speed 2 value 1.8, temperature 3 value 125, temperature 4 value 145, temperature5 value150, temperature 6 value 155, temperature 7 value 160, temperature 8 value 165 makes the response signal to noise ratio larger than the other parameters.

Therefore, the optimum operational processing parameters, a mean response value nearer to the target value and that has a large or not much reduced signal to ration is better to be selected. In this case vacuum pressure 1 value -50.5 (level 1), take-off speed 2 value 1.8(level 2) temperature 3 value 140(level 4), temperature 4 value 145(level 4), temperature5 value150 (level 3), temperature 6 value 155(level 1), temperature7 value 160(level 2), temperature8 value 165 (level 2), are the appropriate processing parameters.

4.2. Plain pipe (IR Ø 25/2.0/16bar PE-100)

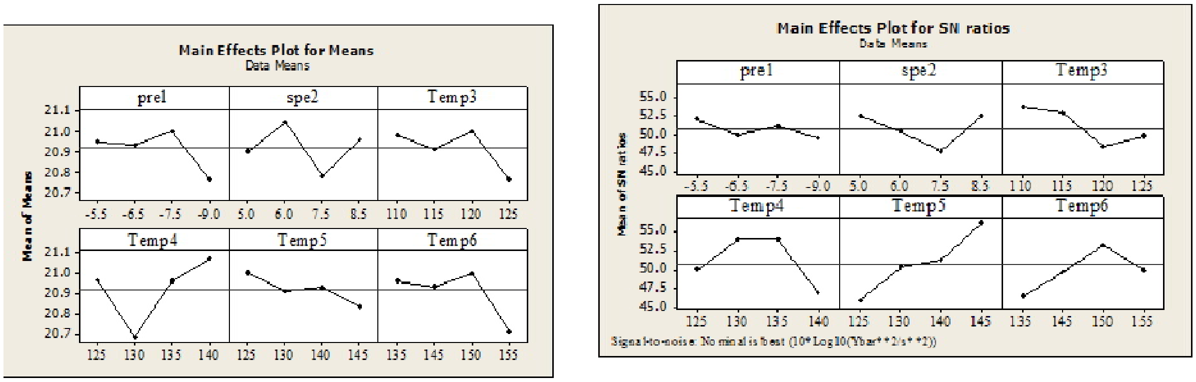


Figure 7: plain pipe

Figure 7. shows the response variable, internal diameter and the companies required nominal dimension was 21.0mm. So from Mean response graph of above vacuum pressure 1 value -7.5, take-off speed 2 value 6.0, temperature 3 value 120, temperature 4 value 135, temperature5 value125, temperature 6 value 150 are the process parameters which are used to produce plain pipe nearby to the intention dimension. Not only by this have to select will the optimum processing parameters, but it also consider settings their effect on SN ratio. The response S/N ratio is required to be large or should not be significantly minimized for any type of design of experiment analysis, In this case from the S/N ratio Response Graph below vacuum pressure 1 value -5.5 take-off speed 2 value 5.0, temperature 3 value 115 temperature 4 value 135, temperature5 value140, temperature 6 value 150 makes the response signal to noise ratio larger than the other parameters.

Therefore, the optimum operational processing parameters, a mean response value nearer to the target value and that has a large or not much reduced signal to ration is better to be selected. In this case vacuum pressure 1 value -5.5 (level 1), take-off speed 2 value 5.0(level 1) temperature 3 value 120(level 3), temperature 4 value 135(level 3), temperature5 value140 (level 2), temperature 6 value 150(level 3) are the appropriate processing parameters.

The Summary of factor settings selected using the design of experiment is shown in table 4 and 5.

Controllable factors	HDPE1 Ø 50/3.0/ 10bar PE -100 Level selected	Value of the level	Rank of affecting the response	Plain pipe Ø 25/2.0/16bar PE-100 Level selected	Value of the level	Rank of affecting the mean response
Vacuum pressure 1	1	-50.5	8	1	-5.5	4
Take-off speed 2	2	1.8	3	1	5.0	5
Temperature 3	4	140	1	3	120	1
Temperature 4	4	145	5	3	135	3
Temperature 5	3	150	4	2	140	6
Temperature 6	1	155	6	3	150	2
Temperature 7	2	160	7			
Temperature 8	2	165	2			

Table 4: Summary of factor settings selected using the design of experiment

4.3. Forecasting Of Response Recommended Values Of Selected Products

Product type	Predicted values: Mean, Diameter/ Width	Predicted values: Mean, Wall thickness	Predicted values: Standard deviation, Diameter/ Width	Target value (mm)	Actual mean value (mm)	Predicted mean value(mm)
HDPE1 Ø 50mm	43.9766	accepted	0.120385	44.00	44.0473	43.9766
Plain pipe Ø 25mm	20.9642	accepted	0.065068	21.00	20.893	20.9642

Table 5: The Predicted values and actual mean values of the products

Here with the help of the forecasted (predicted) value and the actual average value of the recorded data production of the company (X –Chart analysis of the products) we compare these two values as the table 6.

- Total average loss
- HDPE Ø 50mm = 0.1494 Birr/piece
- Plain pipe Ø 25mm = 0.0943 Birr/piece

To summarize the quality loss function after and before the application of Taguchi's method of design of experiment (DOE) the following table. 9 show briefly.

Type of product	**Loss before experiment/Pc of product (birr)**	**Loss after experiment /pc of product (birr)**	**Percentage Improvement (%)**
HDPE1 Ø 50mm	0.7199	0.1494	79.25
Plain pipe Ø 25mm	0.8292	0.0943	88.63

Table 6: Comparison of quality loss before and after experimental analysis

From this table 6 that is the percentage of loss improvement for the selected products was dramatically improved through the application of Taguchi's method of design of experiment.

5.Conclusion

From the result of the X-chart analysis all of the production process of the product is out of control, so that improvement should be made by minimizing its causes for the best target values. And it can be observed on cause and effect diagram that the root causes of these quality problems (defects) are inappropriate setting of operational parameters. By the application of Taguchi's method of design of experiment the percentage of loss has shown a dramatic improvement, as predicted, for the selected products. These process parameters are recommended. Therefore, as a consequence of processing the statistic data obtained, the influence of four process parameters is determined on the Extrusion processes, (vacuum pressure, take-off speed, screw speed and temperature). The greatest importance belongs to temperature in general for all products.

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