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Optimization of Nylon Extrusion Process Parameters for Optical Fiber Cable Applying Matrix Experiment using Taguchi Method

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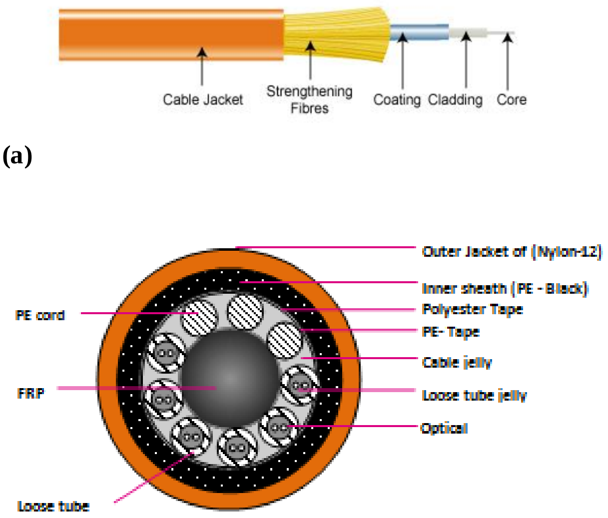
Abstract:
The process used for outer sheathing of Optical Fiber Cable is basically Extrusion of Nylon - 12. The present research is focused on study and optimization of the Nylon extrusion process. The optimization of any process essentially calls for the study of existing process parameters settings and the resultant outputs and defects. Matrix experiment using Taguchi method of DOE has been used in present research work for optimization of the Nylon extrusion process. The required data has been collected from a company manufacturing Optical Fiber Cables of various specifications. The data collection and experimentations are performed of 24 fiber cable nylon sheathing process. The analysis of data has been carried out using commercial statistical software. The expected quality loss has been calculated after prediction of optimum values of process parameters. The research work undertaken concludes that the improved quality, results into substantial reduction in average expected quality loss to the organization.

Keywords: Matrix Experiment, Orthogonal Array, Taguchi Method, DOE, ANOVA, Taguchi Loss Function.

I. INTRODUCTION

The construction of the Optical Fiber Cable is as Shown in Figure 1. The central strength member is usually made of fiber reinforced plastic (FRP), surrounded by stranded loose tubes having 2 or 4 pairs of fibers inside, depending upon type of cable and design. The space between loose tube and fiber is filled with secondary filling compound (SFC) and the loose tubes and FRP is filled with cable filling compound known as 'Jelly'. The stranded loose tubes are held in position by 'Polyester Tape' surrounding the assembly and nylon thread. Two protective layers of sheathings are extruded on the stranded cable. The inner sheathing is made of High Density Polyethylene (HDPE) and outer jacketing is made of Nylon-12 sheathing.



(a)

(b)

FIGURE 1(a) & (b) CONSTRUCTION DETAILS OF OPTICAL FIBER CABLE

The Process used for inner sheathing of (PE) and outer sheathing (N-12) is basically extrusion process. Wherein, the line speed (linear speed) of the cable under sheathing and screw R.P.M. of the extruder are synchronized to give uniform sheath thickness throughout the length of the cable. The raw material for sheathing is loaded in a hopper which is preheated. Temperature of the material to be extruded is controlled in the extruder having series of thermocouples located at various locations. The whole process of the sheathing is computer controlled.

Nomenclature

Notation	Definition	Unit
T_S	Nylon sheath thickness	mm
r	Internal radius of cable	mm
L	Length of cable	km
S	Weld speed	mm/s
Q_L	Quality loss	INR
C_M	Cost of Material (Nylon – 12) per km	INR/kg
C_{PR}	Cost of processing	INR/km
C_R	Cost of Rejection/Re-work	INR/km
C_{SC}	Cost of Nylon sheath stripping per km	INR/km
C_{RI}	Cost of Re-Inspection	INR/km
ρ	Density of Nylon-12	Kg/m^3
C_T	Total Cost	INR
N	Sample size	Nos.
T	Tolerance	mm
LSL	Lower specification limit	mm
USL	Upper specification limit	mm
m	Target value	mm
μ	Mean value	mm
σ	Standard deviation	mm
C_p	Process capability index	-
C_{pkL}	Lower capability index	-
C_{pkU}	Upper capability index	-
C_{pk}	Lowest process capability index	-
C_m	Taguchi capability index	-

II. EXISTING RESEARCH EFFORTS

Kerealme *et al.* (2016) [1], applied Taguchi design of experiment approached using Taguchi Design; L_{27} orthogonal array to the extrusion process for production of UPVC (Un-plasticized Poly Vinyl Chloride) pipes. Khajanchee et al. (2016) [2], applied the Cost of Quality Principle for optimization of process setting variables for Nylon Sheathing process of Optical Fiber Cable manufacturing. Adeel *et al.* (2013) [3], investigated 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 by application of Taguchi's L_{18} orthogonal array, ANOVA and signal-to- noise (S/N) ratio for experimental design. Vidal *et al.* (2012) [4], attempted 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 was used; ANOVA analyses were carried out to identify the significant factors affecting tensile strength, bending toughness and hardness field experiments. Akbarzadeh *et al.* (2011) [5], 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. Narasimha *et al.* (2013) [6], presented a systematic approach to find the root causes for the occurrence of defects and wastes in plastic extrusion process. 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 Ø 50mm and plain pipe Ø 25mm. Kamaruddin *et al.* (2010) [7], conducted 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. Cunsheng Zhang *et al.* (2012) [8], applied Taguchi's design of experiment and numerical simulation in the optimization of an aluminum profile extrusion process. By means of Hyper Extrude 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. Raju *et al.* (2014) [9], reviewed literature on application of various optimization techniques used by different researchers for plastic extrusion process. Various techniques include Genetic algorithms (GA), artificial neural networks (ANN), Fuzzy logic, Response surface methodology, Taguchi method. Dharmendra et al. (2015) [10], applied Taguchi method with orthogonal array and signal to noise ratio to study and optimize process parameters namely melting temperature, extrusion speed, extrusion pressure and winding speed for HDPE material in Extrusion Blow Film machinery. Gadekar et al. (2015) [11], applied optimization of process parameters in plastic extrusion of pipe manufacturing using Taguchi method, signal to noise ratio, ANOVA and application of Taguchi loss function. The process parameters under considerations were Take-off-speed and temperatures. The improvement in the process and quality loss was also evaluated thereby estimating the annual expected savings by the M/s Shivraj HY-Tech Drip Irrigation company. Khajanchee et al. (1992)[12], suggested an approach using Taguchi loss function for determination of optimum machine setting conditions for an Automotive Crank-Shaft Shaft Supplies based on contract terms.

III. PROCESS PARAMETERS

Effective and precise extrusion process requires proper operation of machine and extruder with interlocking and controls. This calls for proper selection and control of process parameters such as temperature, pressure, RPM of the extruder, take-off-speed and the relative speed of the auxiliary. These manufacturing processes require steady state conditions i.e. any action that can stabilize the process parameters and conditions that are favorable to the process.

The Nylon extrusion process is mainly dependent on the process parameters such as;

- ✓ Take off Speed
- ✓ Temperatures
- ✓ Pressures and
- ✓ Relative speed of auxiliary.

1. Rejections due to defects in sheathing process

Common defects or failures leading to rejection in extrusion process are due to three main causes; 1) Improper Part or mould design, 2) Incorrect Material selection and 3) Inappropriate processing setting parameters. The defects of the extrusion process can be classified broadly into following categories.

- ➢ Wall Thickness Variation
- ➢ Diametrical variations
- ➢ Centre off-set
- ➢ Blow Holes
- ➢ Cracks
- ➢ Rough outer surface
- ➢ Others.

The common reasons for defects in extrusion process are; poor understanding of the process, lack of knowledge, training and experience of the operator and inappropriate working environment.

IV. NEED FOR OPTIMIZATION

Extrusion process for HDPE and Nylon sheathing is widely used in cable industry. The commonly observed defects in this process hamper productivity and increase in the quality loss to the manufacturer due to rejection and rework. This leads to the necessity for optimization of the process parameters in order to improve productivity and reduced loss to the company.

V. METHOLODOGY

The methodology followed for optimization of the extrusion process follows following steps.

- ✓ Identifying the process and performance parameters related to Nylon Extrusion for cable sheathing and conducting experiments for collecting data.
- ✓ Performing "***Matrix-Experiment***" with the use of orthogonal arrays.
- ✓ Applying '**Taguchi method**' for determination of "***Signal-to-Noise***" (SN) ratio for facto impact analysis.
- ✓ Applying "***Analysis of Variance***" (ANOVA) to investigate the significance of various input factors on responses.
- ✓ Predicting the optimized process parameters and comparing with previous values without adjustment.

1. Data Collection and Analysis

The annual average production is 9000 kilometers of cable and the average annual rejection data due to various reasons for past three years has been presented in Table I.

TABLE ,I. REJECTION DATA

S.N.	Type of Quality Defect	Frequency	%
1	Un-even wall thickness (A)	54	44.63
2	Diametrical variations (B)	49	40.50
3	Rough outer surface (C)	6	4.96
4	Off-set Centering (D)	4	3.31
5	Blow Holes (E)	2	1.65
6	Cracks (F)	1	0.83
7	Others (O)	5	4.13
8	**Total**	**121**	**100.00**

Distribution of rejection data has been represented pictorially through Pi chart in Figure 2.

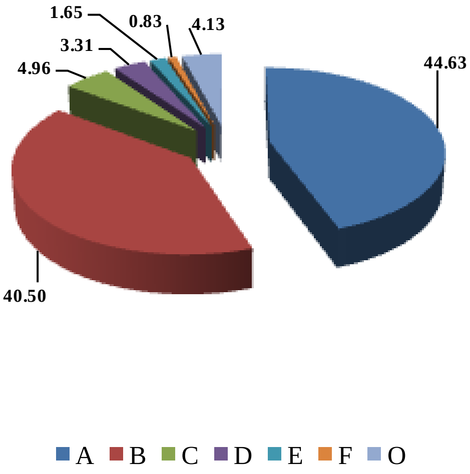


Figure.2. Cable Rejection – Pi Chart

Parato Diagram for rejection is used for identifying the vital few from trivial many is shown in Fig. 3

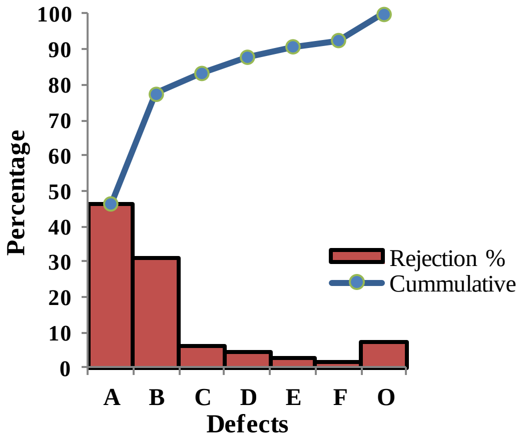


Figure. 3 .Parato Diagram for Defects

Figure 3 depicts that uneven wall thickness and diametric variations are the most vital defects which contribute to about 77% of total defects. These vital defects are the matter of concern and the focus for improvement in this research work.

2. Identification of process parameters

The various process parameters that affect the extrusion process are:

a. Take-off –Speed
b. Temperatures
c. Vacuum Pressure
d. Relative speed of auxiliary

The following three process parameters which are most influencing have been selected for performing the matrix experiment

- ✓ Take-off –Speed (m/min)
- ✓ Temperature 1 (^{O}C)
- ✓ Temperature 2 (^{O}C)

The output variable under consideration for present study is the uneven wall thickness which affects directly the diametric variations i.e. (A) and (B) as per fig. 3 the Parato Diagram. Process settings before experimentation are as indicated in Table II below.

TABLE .II. PROCESS FACTORS AND DESIGNED LEVELS FOR NYLON SHEATHING FOR OFC CABLE

Sl. No	Control Factors	Unit	Level	Settings
1	Take-off –Speed	m/min	1	18
2	Temperature 1	^{O}C	3	188
3	Temperature 2	^{O}C	2	170

Specification for wall thickness of Nylon sheath in (mm):

$$T_S = 0.7 \pm 0.2 \qquad (1)$$

This means that the ***Target* 'm'** = ***0.7 mm, LSL = 0.5 mm USL = 0.9mm,***

Random sample data has been collected for past one month in order to study the state of process with existing in-put parameters as indicated in Table 3 to verify and analyze the statistical state of the process in terms of variability, stability and control. MINITAB 17 Software is used to analyze the data. The same is represented by, Fig. 4 "***Normal Probability Plot*** "and Fig. 5. "**Histogram**"

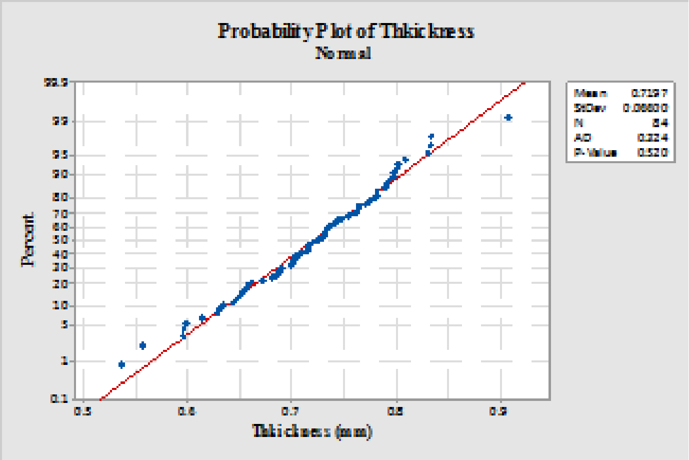


figure. 4. Normal probability plot of nylon sheath thickness (before adjustment)

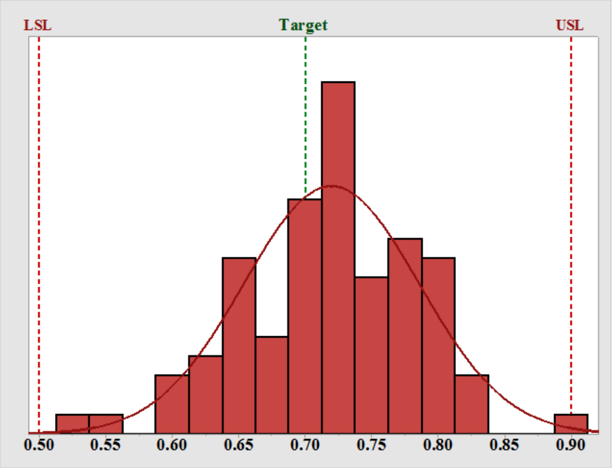


Figure.5.Histogram of Nylon Sheath Thickness (Before adjustment)

The analysis of process capability for the data obtained before adjustment by using MINITAB 17 has been presented in Table III and IV.

TABLE. III.PROCESS CAPABILITY ANALYSIS OF DATA

Process setting	Sample Size	Range (R)	Mean (µ)	Std. Dev. (σ)	C_P	C_{PkL}	C_{PkU}	C_{Pk}	C_{Pm}
W/o Adjustment	84	0.238	0.7196	0.0660	1.010	1.109	0.911	0.911	0.971

TABLE .IV.PROCESS PERFORMANCE (BEFORE ADJUSTMENT)

Process setting	*Rejection*	% > LSL	% < USL	*Total*	*PPM<LSL*	*PPM>USL*	*PPM Total*
W/o Adjustment	*Expected*	0.0436	0.3146	0.3582	436	3146	3582

3. Discussions on process capability analysis

The process capability analysis data presented in Table 3 indicates the variability of the process is large as standard deviation is (σ = 0.0660) and therefore the process capability (C_P= ***1.010***) is less than minimum recommended value of 1.33. Further the value of C_{Pk} = ***0.911),*** leading to higher rejections as indicated in Table 1 and 4 and also represented graphically by 'Pie Chart', Fig.2 and 'Parato Diagram', Fig.3. This leads to conclusion that there is need for process improvement and optimization in order to make the process more robust i.e. less sensitive to '*noise*' and to '*reduce variability'*. This can be achieved through the selection and application of an appropriate and suitable optimization technique from the available wide range of techniques. In the present research authors have selected the '*matrix experiment*' using '*Taguchi's method'* and *'Analysis of variance' (ANOVA)* as the techniques for process improvement and optimization of process parameters to create a *'Robust Design'*.

4. Performing Matrix Experiment

A matrix experiment consists of a set of experiments where the settings of the various process parameters under study can be changed. After conducting the matrix experiment, the data from all experiments in the set taken together are analyzed to determine the effect of various parameters. Conducting matrix experiments using special matrices, called orthogonal arrays, allows the effects of several parameters to be determined efficiently and is an important technique in Robust Design. In the present study, the degrees of freedom owing to the three sets of three-level welding process parameters are analyzed. The degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. In this study, an L9 orthogonal array with three columns and 9 rows is used. This array has eight degrees of freedom and it can handle three-level process parameters. Nine experiments are carried out to study the welding parameters using L9 orthogonal array as shown in Table V.

TABLE.V. PROCESS FACTORS AND DESIGNED LEVELS

Nylon Sheathing for OFC Cable				
Control Factors	Unit	Level		
		1	2	3
Take-off –Speed	m/min	8	0	22
Temperature 1	^{O}C	82	85	88
Temperature 2	^{O}C	68	70	72

5. Applying Taguchi Method "S/N" Ratio

In order to evaluate the influence of each selected factor on the responses, the signal-to-noise ratios (η= S/N) for each control factor have been calculated. The signals have indicated that the effect on the average responses and the noises are measured by the influence on the deviations from the average responses, which would indicate the sensitiveness of the experiment output to the noise factors. The appropriate η must be chosen using previous knowledge, expertise, and understanding of the process. When the target is fixed and there is a trivial or absent signal factor (static design), it is possible to choose the ☐ depending on the goal of the design. In this study, the value of (S/N) ratio η is chosen according to the criterion the-smaller-the-better and the larger-the better, in order to maximize the responses.

The objective function, S/N ratio (η☐ for Nominal-the-best (Target) type quality characteristic response is calculated as follows:

$$\eta = -10log_{10}(y - m)^2 \qquad (2)$$

Where: 'm' is the target value and 'y' the deviation of around its own mean.

TABLE. VI. RESPONSE OF INDEPENDENT VARIABLES FOR MEAN AND η

Exp. No.	Factors Take off Speed (A)	 Temp (1) (B)	 Temp (2) (C)	Mean Thk. (mm)	S/N Ratio for each set of Exp. η=S/N(dB)	
1	18	182	168	0.687	η_1	37.721
2	18	185	170	0.688	η_2	38.416
3	18	188	172	0.686	η_3	37.077
4	20	182	170	0.704	η_4	47.959
5	20	185	172	0.698	η_5	53.979
6	20	188	168	0.693	η_6	43.098
7	22	182	172	0.702	η_7	53.979
8	22	185	168	0.696	η_8	47.959
9	22	188	170	0.689	η_9	39.172
Overall mean value of (η)				$\eta_{(mean)}$	(m)	**44.3735**

Overall mean value of signal-to-noise ratio (η) for the experiment region defined by factor levels in Table 5 is given by:

$$\eta_{(mean)} = \frac{1}{n}\sum_{i=1}^{n}(\eta_i) \qquad (3)$$

Where, 'n' is number of experiments i.e. $n = 9$ in the present case.

The deviation caused by each factor from the overall mean is defined as '*effect of a factor level*'. For example the effect of factors (A) take–of-speed, (B) Temperature – 1 and (C) Temperature – 2 at level -1 are given by:

$$m_{A1} = \frac{1}{3}[\eta_1 + \eta_2 + \eta_3] \qquad (4)$$

$$m_{B1} = \frac{1}{3}[\eta_1 + \eta_4 + \eta_7] \qquad (5)$$

$$m_{C1} = \frac{1}{3}[\eta_1 + \eta_6 + \eta_8] \qquad (6)$$

Hence, the effect of take–of-speed at level -1 (A_1) is given by ($m_{A1} - m$), From Table 4.

Similarly, all the values of factor effects at three levels viz. m_{A1}, m_{A2}, m_{A3} for factor (A), m_{B1}, m_{B2}, m_{B3} for factor (B) and m_{C1}, m_{C2}, m_{C3}, for factor (C) have been calculated and are presented in Table 7.

TABLE .VII. AVERAGE S/N RATIO □□□BY INDEPENDENT FACTOR LEVELS (DB)

Factor Level	Take-off-Speed (A)		Temperature -1 (B)		Temperature- 2 (C)	
1	m_{A1}	37.7383	m_{B1}	46.5531	m_{C1}	42.9620
2	m_{A2}	**48.3454***	m_{B2}	**46.7849***	m_{C2}	41.8491
3	m_{A3}	47.0368	m_{B3}	39.7825	m_{C3}	**48.3454***
Delta	10.6071		7.0023		6.4963	
%	54.48		25.77		19.75	
Rank	**1**		**2**		**3**	

The main effect plots for outer jacket of nylon sheath thickness and signal-to-noise (S/N) ratio are indicated in Figure 6 and 7.

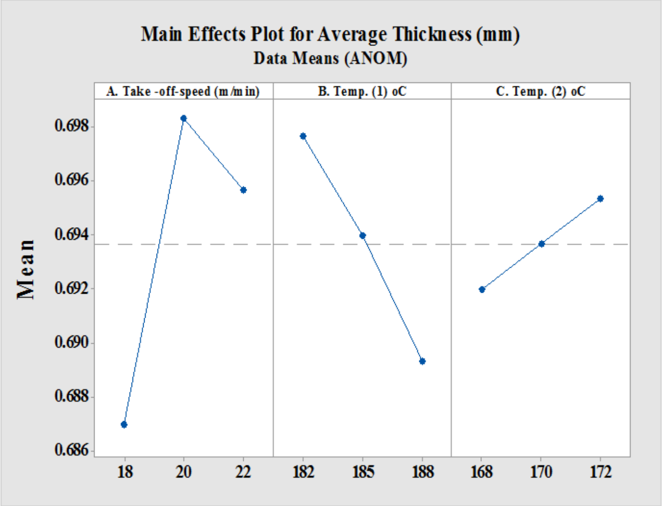


Figure. 6. Main effect plot for average thickness

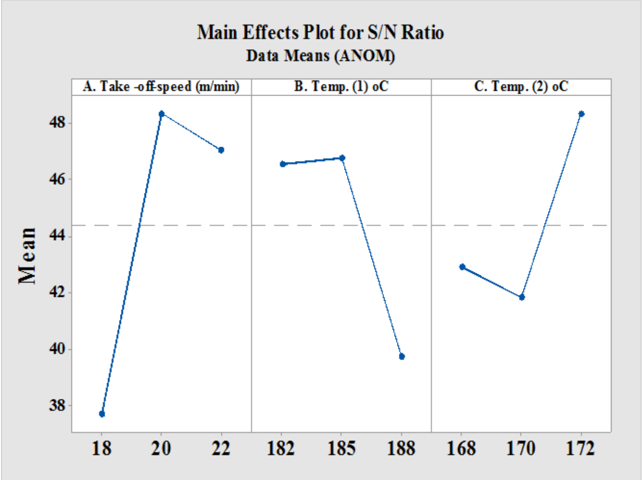


Figure.7. Main Effect Plot for S/N Ratio

6. Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which welding process parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The test for significance of the individual model coefficients and the lack-of-fit test are performed using MINITAB 17 software are presented in Table VIII.

TABLE .VIII. ANALYSIS OF VARIANCE (ANOVA) FOR S/N RATIO

Source	DOF	SS	MS	F	P
Take-off -Speed	2	200.685	100.342	56.26	0.017
Temperature 1	2	94.920	47.463	26.61	0.036
Temperature 2	2	72.732	36.366	20.39	0.047
Error	2	3.567	1.784		
Total	8	371.910			
S = 1.33548			R^2 = 99.04 %		
R^2 (Adjusted) = 96.16 %			R^2 (Predicted) = 80.58 %		

In the present matrix experiment there are three factors with two degree of freedom (DOF) each and the DOF for total sum of squares is (9-1 = 8). The DOF for error variance is 2. Referring to sum of squares column in Table 7, depicts that factor (A) has the largest contribution to the total sum of squares. The next large contribution is by factor (B), followed by factor (C). The main purpose of conducting ANOVA is to find the relative magnitude of the effect of each factor on the objective function S/N ρατιο (η) ανδ to have an estimation of error variance. A probability statement about the significance of a factor, which is usually done in statistics, has purposely been avoided here because, ANOVA in Robust Design is also used to select the most appropriate quality characteristic and S/N ratio for a specific problem from amongst the many available alternatives. The Variance ratio, denoted by **'F'** in Table 7, is the ratio of mean square due to a factor and the mean square due to error. A large value of 'F' indicates that the effect of that factor is large compared to the error variance. Also, the larger the value of 'F'**,** the more important the factor is in influencing the process ρεσπονσε *(η)*. Ιν Robust Design, we use the **F-ratio** for understanding the qualitative and relative factor effect. A value of **F < 1** implies that the factor effect is smaller than the error of the additive model. A value of **F > 2** means that the factor effect is not small. However, a value of **F > 4** indicates that the factor effect is quite large. In present case, Table 7, the value of **F** is much greater than **4** for all the three factors. It is 56.26, 26.61 and 20.39 for factor A, B and C respectively, indicating that all the three factors have large effect and hence should be selected carefully. The value of **P < 0.05** indicates that the coefficients estimates are significant. In present case for all factors the value of P is smaller than 0.05 indicating the high significance level of all three factors.**R^2** provides an estimate of strength of the relation between the model and response variable. Higher value of **R^2** = 99.04% indicates good strength of the relation between the model and response variable.**R^2** (Adj.) is the modified version of R^2 that has been adjusted for the number of predictors in the model. R^2 (Adjusted) is always lower than R^2**.** Higher value of R^2 (Adj.) = 96.06% indicates good adequacy of model. R^2 (Predicted) having reasonably higher value is desirable. Negative value of R^2 (Pred.) is worse and 0% is terrible. In the present case R^2 (Predicted) = 80.58 % indicating good adequacy of predicted model. From the analysis of signal-to-noise (S/N) ratio, the main effect plots as shown in Figure 6 and ANOVA Table 7 factors and their respective optimum values of levels selected for the Nylon-12 Sheathing process of are given below. Summary of factor levels predicted using design of experiment (DOE) is presented in Table IX.

TABLE. IX. SELECTION OF CONTROLLED FACTORS AS PER S/N RATIO

Controlled Factors	Unit	Levels
1. Take-off –Speed	m/min	20 (Level-2)
2. Temperature 1	^OC	185 (Level-2)
3. Temperature 2	^OC	172 (Level-3)

7. Prediction of η under Optimum Conditions

The primary goal of conducting Robust Design experiment is to determine the optimum level for each factor. The relationship between η and the process parameters A, B and C can be quite complicated. However, in most situations, when η is chosen judiciously, the relationship can be approximated adequately by the following additive model:

$$\eta\left(A_iB_jC_k\right) = \mu + a_i + b_j + c_k + d_l + e \qquad (7)$$

The additive model has been used be to make predictions of the value of 'η' under the optimum conditions as denoted by $\eta_{(opt)}$:

$$\eta_{(opt)} = m + \left[\sum\left(m_{A(max)} - m\right)\right] \qquad (8)$$

Substituting the values of $m, m_{A(max)}, m_{B(max)}$, and $m_{C(max)}$ from Table 7 in Eq. 8 we get the predicted value of mean thickness under optimum conditions,

$$\eta_{(opt)} = 54.7287\ (dB) \qquad (9)$$

Substituting the values of mean thickness under optimum conditions $\eta_{(opt)}$ in Eq. 2, the predicted value of response variable (mean thickness) from the analysis of signal-to-noise (S/N) ratio at the above selected levels for the for the process of nylon sheathing has been obtained as below,

Mean Value of Thickness at the optimum Signal-to-Noise (S/N) ratio $\eta_{(opt)} = 54.7287(dB), is\ 0.7018\ mm$

Optimum Mean Thickness $\mu_{(opt)} = 0.7018\ mm \qquad (10)$

8. Anticipated process improvement

The anticipated improvement by change in the process conditions from initial settings $(A_1B_3C_2)$ to the optimum settings $(A_2B_2C_3)$ is given by,

$$\Delta\eta = [\eta_{(opt)} - \eta_{(initial)}] \qquad (11)$$

$$\Delta\eta = [\sum(m_{(max)} - m_{(initial)})] \qquad (12)$$

Substituting the values of, $\eta_{(opt)}, \eta_{(initial)}, m_{A(max)}, m_{A(initial)}, m_{B(max)}, m_{B(initial)}, m_{C(max)}$ and $m_{C(initial)}$ from Table 7 in Eq. 12 the predicted value of mean thickness under optimum conditions is given by equation,

$$\Delta\eta = 24.1057(dB) \qquad (13)$$

9. Process Improvement as a result of DOE analysis

The optimum selected controlled factor levels predicted using design of experiment (DOE) with maximum S/N Ratio as indicated in Table 9 have been set and the extrusion process is carried out. Random sample data has been collected for next one month in order to study the state of process with selected controlled factor levels as indicated in Table X to verify and analyze the statistical state of the process in terms of variability, stability and control. MINITAB 17 Software is used to analyze the data. The same is represented by "***Normal Probability Plot***", Fig. 8 and "**Histogram**", Fig. 9, and Table XI.

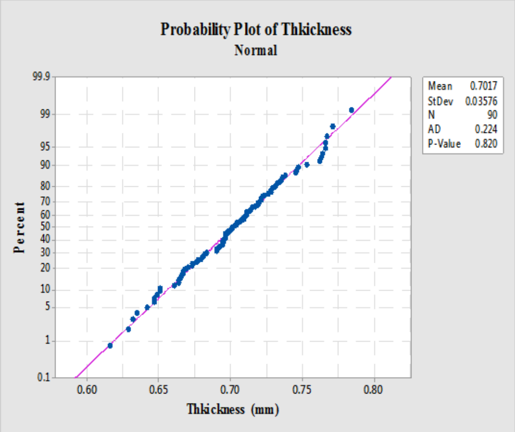


FIGURE.8. NORMAL PROBABILITY PLOT OF NYLON SHEATH THICKNESS (AFTER ADJUSTMENT)

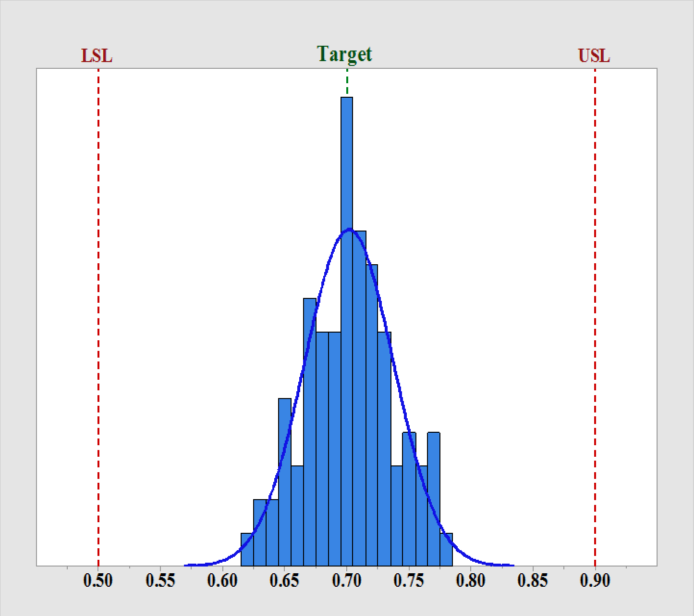


FIGURE. 9. HISTOGRAM OF NYLON SHEATH THICKNESS (AFTER ADJUSTMENT)

TABLE. X. PROCESS CAPABILITY ANALYSIS OF DATA (BEFORE AND AFTER ADJUSTMENT)

Process setting	Sample Size	Range (R)	Mean (μ)	Std. Dev. (σ)	C_P	C_{PkL}	C_{PkU}	C_{Pk}	C_{Pm}
W/o Adjustment	84	0.238	0.7196	0.0660	1.010	1.109	0.911	0.911	0.971
After adjustment	90	0.168	0.7018	0.0357	1.864	1.880	1.848	1.880	1.860

TABLE. XI. PROCESS PERFORMANCE (BEFORE ADJUSTMENT)

Process setting	*Rejection*	% > LSL	% < USL	*Total*	*PPM<LSL*	*PPM>USL*	*PPM Total*
W/o Adjustment	*Expected*	0.0436	0.3146	0.3582	436	3146	3582
After adjustment	*Expected*	0.000	0.000	0.000	0.000	0.000	0.000

10 Comparison of experimental and predicted results

The comparison of actual *(experimental)* values and the predicted values of nylon sheath thickness through the application of 'Taguchi Method' of design of experiments are presented in Table XII.

TABLE. XII. COMPARISON OF ACTUAL VALUES AND PREDICTED VALUES

Actual Process Values (Before Adjustment)			Predicted Process Values (After Adjustment)		
Target *(m)*	Mean *(μ)*	Std. Dev.*(σ)*	Target *(m)*	Mean *(μ)*	Std. Dev.*(σ)*
0.700	0.719	0.0660	0.700	0.7018	0.0357

11. Estimation of costs associated with processing and reworking of Nylon sheathing

The cost of rejection of each km of cable length due to undersize /oversize thickness is termed as reworking cost which includes material cost of Nylon-12 (C_M), processing cost (C_{PR}), sheath stripping cost of Nylon-12 (C_{SC}) and re-inspection Cost (C_{RI}). Evaluation of these costs is described in detail below. Material cost of Nylon-12 is INR 968.00 per kg and density (ρ) is 1030 Kg/m^3 or (1.03 gm/cc). The material cost (C_M) of Nylon-12 per kilometre of cable (at 0.5mm Thickness) is equal to Volume of cable per km (**V**) × Density of Nylon-12 (ρ) × Cost of Nylon -12 in INR/kg, which is = ***INR 18331.30 per km***. Reworking cost (C_R) includes man power cost, power cost, material cost, overhead cost and loss due to rework. The data related to processing cost and re-working cost of 'Nylon Sheathing Process' for Optical Fiber Cable has been obtained from the concerned department and related details are given below:

Processing Cost/km (C_{PR}) = ***14790.00*** *INR/km* and Reworking Cost/km (C_R) = ***9856.00 INR/km***

1.11 Internal quality loss to the manufacturer

The perception, that the 'Taguchi's Quadratic Loss Function' is applicable only with regard to loss to the external customer and the society by and large is only partially understood. According to Phadke M S (1989) [14], "The quality loss function can and should be applied to loss internal to the company and should be applied to every stage of product realization process. The quality loss function should be applied to all these steps of its manufacturing. The efficiency and cost at every Intermediate step are affected by the variation introduced in the preceding steps; the intermediate steps, in turn, affect the efficiency and cost of the subsequent steps. The quadratic Quality loss function provides a reasonable way to evaluate these impacts on cost and efficiency and, thus, facilitates appropriate economic decisions regarding quality improvement at various process steps" Quality loss occurs when the thickness of Nylon-12 is less that the lower specification limit (LSL= 0.50 mm), or more than the higher specification limit (USL = 0.9 mm) and needs to be reworked. When the mean value of thickness is set at 0.50 mm or 0.90 mm, obviously 50% of the cable produced gets rejected because of not meeting the specifications and subsequently subjected to rework. According to Taguchi (1989) [113] and Phadke MS (1989) [14], the average expected quality loss (Q_L) for nominal-the-best type quality characteristic is given by

$$Q_{L1} = K[\sigma^2 + (\mu - m)^2] \qquad (14)$$

Where: 'μ'is the mean value of quality characteristic, 'm' is the target value, 'σ^2 'is the mean squared deviation of 'y' around its own mean and 'K' is a constant called *quality loss coefficient.*

Internal quality loss per km at 0.5mm Thickness of Nylon-12 Jacketing is given by:

$$Q_L = [C_M + C_{PR} + C_R] \times 0.5 \qquad (15)$$

Substituting the values of C_M,C_{PR} and C_R in Eq. 15 the quality loss (Q_L) per kilometer of cable is equal to ***21488.65 INR.*** Substituting the values of $\boldsymbol{Q_{L1}}$, $\boldsymbol{\mu}$ and $\boldsymbol{m}$ in Eq.(14) the value of constant of proportionality (**K**) = ***537216.16***

The average expected quality loss internal to the manufacturer before experimentation and adjustment (Q_{L1}) and after optimization (Q_{L2}) as presented in Table 12 and calculated using Eq. 14 is given below,

$$Q_{L1} = \mathbf{2534.05}\ INR\ per\ km \qquad (16)$$

$$Q_{L2} = \mathbf{686.42}\ INR\ per\ km \qquad (17)$$

Figure 10 represents graphically the average expected quality loss internal to the manufacturer before experimentation and adjustment (Q_{L1}) and after optimization(Q_{L2}).

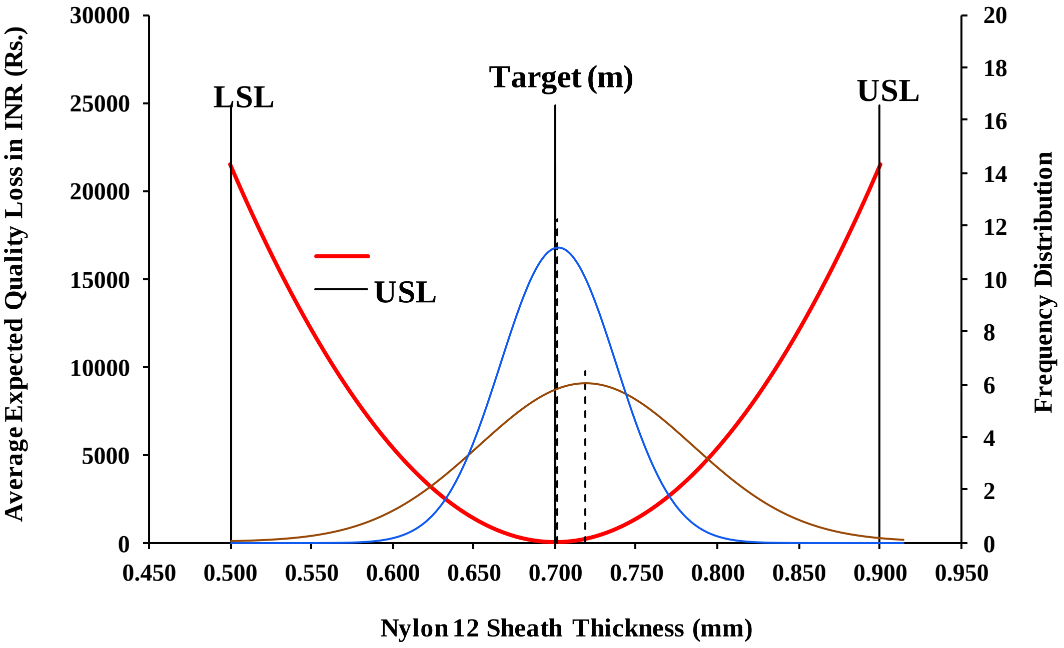


FIGURE .10 .COST SAVINGS WITH TAGUCHI LOSS FUNCTION

The calculation of average expected quality loss internal to the manufacturer before experimentation and adjustment as per Eqns. 16 and 17 lead to the expected annual savings as indicated in Table XIII

TABLE .XIII. ANNUAL SAVINGS IN INDIAN CURRENCY (INR)

Average expected quality loss before adjustment (INR)	2534.05
Average expected quality loss after adjustment (INR)	686.83
Total savings per km length of Cable (INR)	1847.22
Average annual production (km)	9000
Annualized expected savings (INR)	**16624980.00**
Annualized Percentage savings (%)	**72.89**

2. RESULTS AND DISCUSSIONS

The target value of Nylon thickness required to be produced is 0.700 mm. The main effect plots for nylon sheath thickness as per Fig. 6 shows that the setting of the process before adjustment is level A_1 B_3 C_2, i.e. Take-off –Speed is 18 m/min, Temperature, 188°C and Temperature 170°C. However, as per the Taguchi method of "Robust Design', the signal-to-noise ratio (S/N Ratio) for selected parameter settings should be maximum in order to reduce the effect of noise factors. The main effect plots for S/N ratio for nylon sheath thickness as per Fig. 7 shows that the setting of the process before adjustment is level 2-2-3, i.e. Take-off –Speed is 20 m/min, Temperature is 185°C and Temperature (2) is 172°C.

VI. CONCLUSIONS

The study and research work conclude the following:

1. Taguchi's method of design of experiments is a powerful technique in prediction of selection of input factors on the

output responses in case of Extrusion process for Nylon sheathing on OFC Cable.
2. Take-off-Speed has strong effect on Nylon thickness variation. Small change in the value of Take-off-Speed has a large effect on Nylon thickness variation. Therefore, the value of Take-off-Speed should be selected with care.
3. Melting Temperature (1) has second larger effect and has rank 2 as per S/N ratio analysis on the Nylon thickness variation. The selection of temperature (2) should be near to the average melting point of Nylon 12 which is equal to 185°C.
4. It is evident from the analysis that desired Nylon thickness with reduced variability can be achieved by setting the selected input extrusion parameters which have been derived from Taguchi's method of design of experiments.
5. The adopted techniques and the developed models are quite adequate for the prediction of the response variables for the selected input factors.

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