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Taguchi Optimization of Screw Flight Bending Operation

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***Abstract**: The optimizations of screw flight bending operating parameters have been successfully carried out. The optimization of the screw flight bending operation, aims at determining optimal values for key parameters using Taguchi Design and Genetic Algorithm (GA) optimization tools. The parameters investigated include bending radius, diameter of screw, flight thickness, and bending force. Through the systematic application of Taguchi methodology and GA optimization, optimal values of 79.99 mm for bending radius, 69.997 mm for diameter of screw, 5.005 mm for flight thickness, and 232.62 N for bending force were identified. The effectiveness of the optimized parameters was assessed through analysis of variance (ANOVA), revealing an R-squared value of 84.78 % and an adjusted R-squared value of 75.64 %. These results indicate that the developed model explains a significant portion of the variability in the response variable, providing confidence in the reliability and significance of the optimized solutions. Overall, the integration of Taguchi methodology with GA optimization has proven to be a powerful approach for systematically exploring parameter space and identifying optimal solutions in screw flight bending operations. The optimized parameter values offer the potential for enhanced performance, accuracy, and efficiency in the bending process, contributing to improved product quality and manufacturing productivity.*

Keywords: *Taguchi Design, Optimization, Genetic Algorithm, Screw Flight, Bending Operation, ANOVA*

1. INTRODUCTION

Screw flight bending, a critical process in the fabrication of screw conveyors used for material handling, presents challenges in terms of achieving precise dimensions, uniformity, and strength of the bent flights [1]. Screw conveyors are widely used in various industries for bulk material handling, including agriculture, mining, food processing, and construction. The efficiency and reliability of screw conveyors depend largely on the design and fabrication of screw flights, which are helical blades responsible for propelling materials along the conveyor [2]. The bending of screw flights from flat sheet metal is a critical process that determines the performance and longevity of screw conveyors. Properly formed screw flights ensure smooth material flow, minimal wear and tear, and efficient operation of the conveyor system. Therefore, optimizing the bending operation is essential for improving the quality and functionality of screw conveyors, ultimately enhancing productivity and reducing downtime in industrial applications [3].

The bending of screw flights poses several challenges due to the complex geometry and material properties involved. Achieving precise dimensions and uniform curvature in the flights is crucial for ensuring consistent performance and minimizing material wastage. However, factors such as variations in material thickness, springback effects, and tool wear can lead to dimensional inaccuracies and surface defects in the bent flights [4]. Additionally, manual adjustment of bending parameters and lack of standardized processes contribute to inconsistencies in production and increase the risk of defects. These challenges underscore the need for systematic optimization techniques to improve the accuracy and repeatability of the bending operation [5].

The optimization of manufacturing processes is crucial for improving product quality, reducing production costs, and enhancing overall efficiency [6]. Taguchi optimization, a robust statistical method developed by Genichi Taguchi, offers a systematic approach to optimize manufacturing processes by identifying the optimal combination of input parameters to minimize variation and achieve desired performance characteristics. This background provides an overview of the significance of screw flight bending, challenges encountered in the process, and the potential benefits of applying Taguchi optimization techniques to enhance the operation [7].

Taguchi optimization, based on the principles of robust design and statistical analysis, offers a systematic approach to optimize manufacturing processes and improve product quality [8]. The Taguchi method involves identifying the significant factors influencing process performance, conducting experimental trials to evaluate the effects of these factors, and determining the optimal combination of parameters to achieve desired performance characteristics [9]. By applying orthogonal arrays and signal-to-noise ratios, Taguchi optimization enables the identification of robust process settings that are less sensitive to variations and external factors. This approach facilitates the development of robust and reliable manufacturing processes, leading to improved product quality, reduced costs, and enhanced customer satisfaction [10].

The application of Taguchi optimization techniques to screw flight bending offers several potential benefits. By systematically evaluating the effects of process parameters such as material thickness, bending angle, roller speed, and lubrication on the quality of bent flights, it is possible to identify the optimal settings that minimize dimensional variations and surface defects [11]. Moreover, Taguchi optimization enables the determination of robust process settings that are less sensitive to variations in material properties and operating conditions, ensuring consistent performance and reliability in production. By optimizing the bending operation, manufacturers can improve the quality and efficiency of screw conveyor fabrication, leading to cost savings, enhanced productivity, and increased competitiveness in the market [12].

Furthermore, the optimization of screw flight bending operation using Taguchi optimization techniques presents a promising approach to improving the quality and efficiency of screw conveyor fabrication. By systematically identifying the optimal combination of process parameters, manufacturers can minimize dimensional variations and surface defects in bent flights, leading to improved product quality and reliability [13]. The application of Taguchi optimization enables the development of robust and reliable manufacturing processes that are less sensitive to variations and external factors, ultimately enhancing productivity and reducing production costs. Therefore, the study of Taguchi optimization of screw flight bending operation holds significant potential for advancing manufacturing practices and enhancing the performance of screw conveyors in various industrial applications. This study is aimed at optimizing the screw flight bending operation parameters.

The success of the Taguchi optimization approach coupled with GA underscores the importance of employing advanced optimization techniques in engineering and manufacturing processes. By combining the strengths of Taguchi methodology with GA optimization, organizations can systematically identify and refine key process parameters, leading to improved product quality, reduced variation, and enhanced efficiency.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this study are mild steel sheet, vernier caliper, micrometer screw gauge, meter rule and stop watch. The equipment used for the making of screw flight is the fabricated Screw flight bending machine at Auchi Polytechnic, Nigeria.

2.2 Methods

Design of Experiments (DOE) is a systematic approach used in various fields, including engineering, manufacturing, healthcare, and social sciences, to optimize processes, improve product quality, and understand the relationships between input variables and output responses [13]. DOE involves planning, conducting, analysing, and interpreting controlled experiments to identify significant factors and their interactions affecting the response variable(s) of interest.

2.3 Experimental Design and Set up:

The first step in a DOE is to clearly define the objectives of the experiment. This involves specifying the response variables (what you want to measure or optimize) and the factors (input variables or parameters) that may affect the response. Identify and select the factors that could potentially influence the response variable(s). Factors can be qualitative (e.g., material type, operator skill level) or quantitative (e.g., temperature, pressure) [14].

An appropriate experimental design based on the number of factors, their levels, and the desired level of precision was chosen. Common designs include full factorial, fractional factorial, response surface, and Taguchi designs. The design determined how the experiments were conducted, including the combinations of factor levels to be tested. The experiments were set up according to the chosen design. Ensure that the experimental conditions are controlled and reproducible. Randomization and blocking techniques were be used to minimize the effects of extraneous variables and increase the precision of estimates

Table 1: Process parameters and their various levels

Process parameters	Levels		
	Level 1	Level 2	Level 3
Bending radius, R (mm)	50	65	80
Diameter of screw, D(mm)	50	60	70
Thickness of screw, t (mm)	3	5	7

2.4 Taguchi Design

The experimental operation of Taguchi Design with 3 levels and 3 input parameters typically follows a systematic approach to conduct a series of experiments efficiently while covering a wide range of factor combinations. The three input parameters (factors) for this study are flight thickness (t), bending radius and diameter of the screw cylindrical shaft. The parameters and their three levels were determined from literature. An appropriate orthogonal array based on the number of factors and levels was carefully chosen. Taguchi designs are typically represented by orthogonal arrays, which ensure that all factor combinations were tested efficiently [15]. For three factors with three levels each (3^3 = 27), an L9 (3^4) orthogonal array is commonly used. This array allows for 9 experiments to be conducted efficiently. The orthogonal arrays were filled with the factor levels according to the chosen design[16]. Each row in the array represents a unique combination of factor levels (experiment).The experiments were performed according to the settings specified in the orthogonal array and the measured response variable for each experiment were determined accurately. The data recorded accurately, ensuring that it corresponded to the factor levels specified in the orthogonal array.

2.5 Data Collection

The conducted experiments and collection of data on the response variable and the corresponding factor levels was duly observed in the Machine shop using the Screw Flight Bending machine. The Screw Flight bending Machine used for the study is shown on Figure 1.

Figure 1: The screw flight bending machine

The bending operation of screw flights involves several parameters that affect the final outcome and performance of the screw conveyor or auger [2][18]. The parameters used in this study include

i. Flight Thickness: The thickness of the screw flights determines their strength and resistance to bending. Thicker flights generally provide more structural integrity but may require more force to bend.
ii. Diameter of Screw: The diameter of the screw influences the bending process, as larger diameter screws may require more force to bend due to their increased surface area and material volume.
iii. Bending Radius: The desired bending radius determines how tightly the screw flights will be bent. It is essential to consider the bending radius to avoid material deformation or damage during the bending process.
iv. Bending Force: The force required to bend the screw flights depends on various factors such as material properties, flight thickness, and desired bending radius.

2.6 Determination of Bending Force

The bending force required to bend the screw flight was determined by Equations (1) and (2) obtained from [19].

$$F = \frac{M}{Z} \times A \tag{1}$$

$$F = \frac{L \times R}{\frac{\pi}{32} \times \{D^4 - (D-2t)^4\}} \times \frac{\pi \times \{D^2 - (D-2t)^2\}}{4} \tag{2}$$

Where F=bending force in N, A= Cross sectional area of cylinder screw flight, M=Bending moment, Z=Section Modulus, R=Bending radius in mm, D=Diameter of screw in mm, t = thickness of screw, and L=constant load in N.

2.7 Genetic Algorithm Technique

Genetic algorithms (GAs) are optimization techniques inspired by the principles of natural selection and genetics. They mimic the process of natural evolution to find solutions to optimization and search problems. The biological processes applied by the Genetic [21] Algorithm technique are Cross over, mutation, selection, reproduction. In the selection phase, individuals from the current population are chosen to become parents for the next generation. The probability of selection is usually proportional to an individual's fitness score, favoring solutions that perform better. Common selection methods include roulette wheel selection, tournament selection, and rank-based selection. During crossover, pairs of selected parent solutions exchange genetic information to create offspring. This process mimics genetic recombination in biological reproduction. After crossover, some level of random variation, known as mutation, is introduced to the offspring's genetic material. Mutation helps maintain genetic diversity within the population and prevents premature convergence to suboptimal solutions. The algorithm iterates through the selection, crossover, mutation, and replacement steps for a predefined number of generations or until a termination criterion is met [22].

Genetic algorithms offer several advantages, including their ability to explore a large search space efficiently, handle complex, nonlinear, and multimodal optimization problems, and robustness in finding near-optimal solutions even in the presence of noise or uncertainty. They have been successfully applied in various fields, including engineering, finance, biology, and artificial intelligence [23]

3. RESULT AND DISCUSSION

The collected data was analysed using statistical methods to determine the effects of individual factors, interactions between factors, and any significant trends or patterns. Common analysis techniques include analysis of variance (ANOVA), regression analysis, and graphical methods such as scatter plots [20].

Table 2: Experimental design matrix

S/N	Bending radius, R(mm)	Diameter of screw, D(mm)	Flight thickness, t (mm)	Bending Force, F (N)
1	50	50	3	170
2	50	60	5	178
3	50	70	7	179
4	65	50	5	175
5	65	60	7	180
6	65	70	3	195
7	80	50	7	210
8	80	60	3	220
9	80	70	5	246

3.1 Statistical Modelling

Statistical mathematical model that describe the relationship between the input factors and the response variable(s) was developed. The model identified optimal settings for the factors that maximize or minimize the response(s) within specified constraints. For this study a case of maximization was adopted because the bending force is targeted at the larger the better constraints. The developed equation is shown in Equation (3)

$$F = 28 + 1.656R + 1.083D - 1.33t \quad (3)$$

Where F= Bending force
R=Bending radius
D=Diameter of screw
t= Flight thickness

3.2 Presentation of the ANOVA Result

The ANOVA result is shown in Table 3.

Table 3: ANOVA result for the Screw Flight bending operation

Source	**DF**	**Adj. SS**	**Adj MS**	**F-value**	**P-value**
Regression	3	4447.00	1452.33	9.26	0.017
R	1	5700.17	3700.17	23.17	0.005
D	1	704.17	704.17	4.41	0.009
t	1	42.67	42.67	0.27	0.427
Error	5	798.56	159.71		
Total	6	5245.56			

The R^2 and R^2 (adj) values are 84.78 % and 75.64 %.respectively. The analysis of variance (ANOVA) results had an R^2 value of 84.78% and an adjusted R^2 value of 75.64%. This indicates that the developed mathematical model explains a significant portion of the variability in the bending force response variable. A statistical model with an R^2 value of 84.78 % and an adjusted R^2 value of 75.64 % indicates that the model explains a large proportion of the variability in the dependent variable. The R^2 value (coefficient of determination) represents the proportion of variance in the dependent variable that is predictable from the independent variables. The adjusted R^2 value is a modified version of R^2 that adjusts for the number of predictors in the model, providing a more accurate assessment of the model's goodness of fit, especially in the presence of multiple predictors.

Given that the p-value associated with the regression model is 0.017, which is less than the significance level of 0.05 (assuming a two-tailed test), we can conclude that the regression model is statistically significant. In other words, there is strong evidence to reject the null hypothesis that all regression coefficients are equal to zero, indicating that at least one of the independent variables has a significant effect on the dependent variable.

The Signal to noise ratio plot shown in Figure 2 indicates that 80mm, 70mm and 5mm are the optimal levels for bending radius, diameter of screw and flight radius respectively.

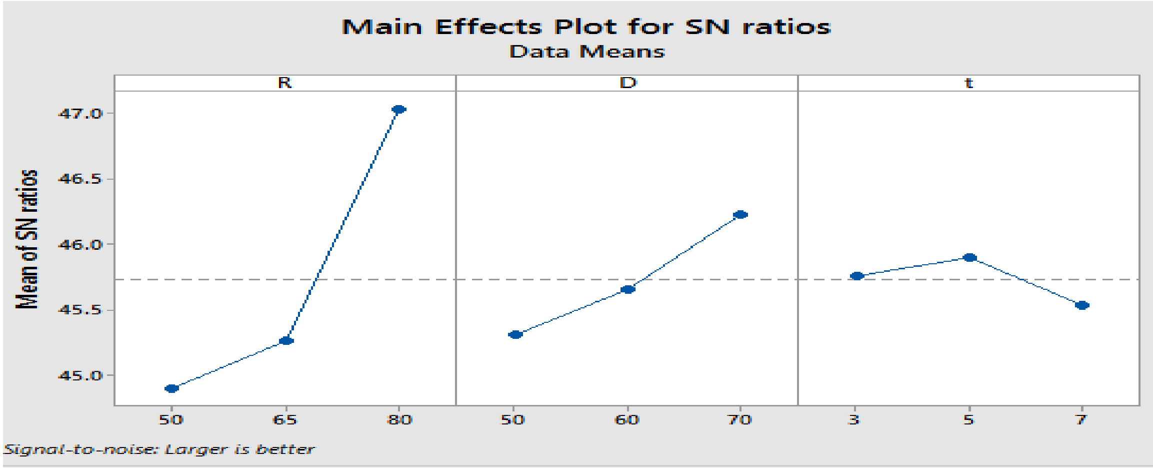

Figure 2: Signal to Noise ratio plot

The normal probability plot shown in Figure 3 portrays that the residual points are evenly distributed and are close to the diagonal distribution line. In addition, no outlier is found within the distribution. It shows that the developed model is adequate

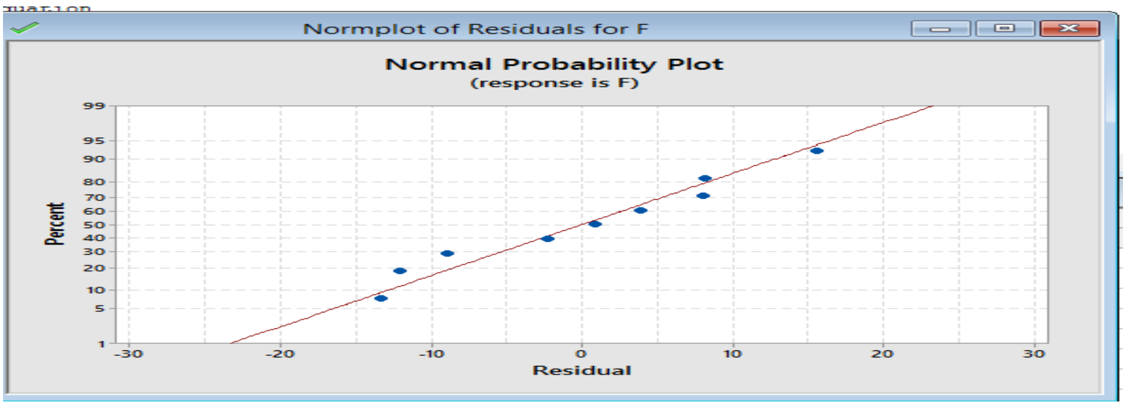

Figure 3: Normal probability plot

3.3 Presentation of Genetic Algorithm Outcome

The optimal values of the parameters obtained from the genetic algorithm and the Taguchi design are shown in Table 4. It is shown in the Table 4 that the results from the two optimization techniques are approximately the same. The genetic algorithm results were expressed to three decimal places. The results obtained from the optimization of the Screw flight bending operation are similar to that developed in [1].

Table 4: Genetic algorithm and taguchi design results

Parameter	Optimal value for GA	Optimal values from Taguchi Design
Bending radius, R(mm)	79.998	80
Diameter of screw,D(mm)	69.997	70
Flight thickness, t(mm)	5.005	5
Bending Force, F (N)	232.62	232.64

The genetic algorithm plot shown in Figure 4 indicates a fitness value of 232.62 for the bending force response parameter. The fitness value developed for the operation is found to be close to the bending force applied in [2] and [21].

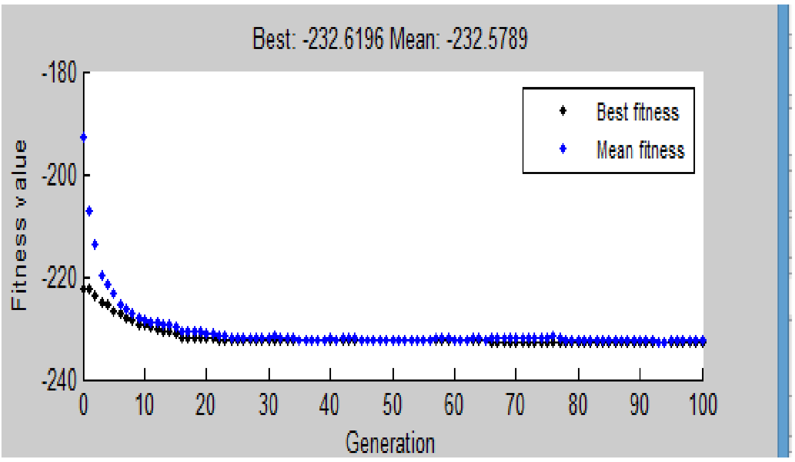

Figure 4: GA plot for fitness value against generation

3.4 Validation of Results

The experimental results were validated by applying the optimal values determined in a screw flight bending operation. It was discovered that the optimal values of the input and response parameters from the Taguchi Design and Genetic algorithm optimization tools used during validation experiment were found to be in accordance with that obtained during experimentation.

4. CONCLUSION

The Taguchi optimization of screw flight bending operation has yielded significant insights and improvements, resulting in optimal values for the bending radius, diameter of the screw, flight thickness, and bending force. Through the systematic application of Taguchi design optimization tools, the following optimal values have been identified: 80mm for bending radius, 70 mm for diameter of screw, 5 mm for flight thickness, and 232.62 N for bending force.

Also, the implementation of Genetic Algorithm (GA) optimization in the screw flight bending operation has resulted in the determination of optimal values for key parameters, including the bending radius, diameter of screw, flight thickness, and bending force. Through the utilization of GA, the optimal values were determined to be 79.99 mm for bending radius, 69.997 mm for diameter of screw, 5.005 mm for flight thickness, and 232.62N for bending force. The GA results were found to be almost similar with that obtained from the Taguchi Design.

The utilization of GA optimization has provided a robust and efficient approach to exploring the parameter space and identifying optimal solutions. By leveraging the principles of natural selection and genetic variation, GA has effectively searched for the combination of parameter values that yield the best performance in terms of bending accuracy, structural integrity, and production efficiency.

Moreover, the analysis of variance (ANOVA) results with an R-squared value of 84.78 % and an adjusted R-squared value of 75.64 % indicates that the developed model explains a significant portion of the variability in the response variable. This suggests that the optimized parameter values identified through Taguchi Design and Genetic Algorithm are statistically significant and reliable, providing confidence in their effectiveness in achieving the desired outcomes.

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