Taguchi Optimization of Fused Deposition Modeling Process Parameters on Mechanical Characteristics of PLA+ Filament Material

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Abstract

In this study, it was realized to determine effects of Fused Deposition Modeling (FDM) process parameters on mechanical characteristics with Taguchi optimization method. Three different FDM process parameters used for modified Polylactic Acid (PLA+) filament material; filling structures (Rectilinear, Triangular, and Full Honeycomb), occupancy rates (10, 30, and 50 %) and table orientation (0, 60, and -45°) was specified as variable parameters for experiments. Other parameters kept fixed for each tensile and izod impact test samples were printed according to the ISO 527 – Type IV and ISO 180-Type I standards. The results found tensile strength values and izod impact values directly proportionate with occupancy rate. The difference between the estimation model and the results of experiments did not exceed the maximum value of 1.8 %. Thus, using the equations derived from this optimization, printing parameters can be determined for the desired tensile strength and izod impact values. By improving the material properties using modified PLA+ filament material as observed in the results, it will be possible to provide support for researchers, design engineers and manufacturer to optimize raw-material usage and margin.

Keywords: FDM, PLA, Tensile strength, Taguchi, Optimization
1. Introduction

In every sector of manufacturing, technological innovations play a very important role in order to keep the companies competitive by shortening release time of the products to the market [1]. Recently, the use of Rapid Prototyping (RP) technologies in industrial applications is increasing. Three-dimensional (3D) printers, known as one of the Additive Manufacturing (AM) methods, are used both academic and industrial areas [2]. This technology allows a preliminary prototype of the design can be produced easily and quickly [3]. Production with 3D printing has become a focus of interest in many fields such as automotive, civil aviation, medical devices and dental applications. In addition, the use of tissues and implants in the field of medicine and dental are becoming widespread with 3D printing [4]. 3D printing, is a production process of deposition materials by layering on layers to produce parts from computer aided designed model instead of subtractive manufacturing methods [5]. 3D printing has major advantages about decreasing both process time and used raw material. There are many methods in this technology, and the differences between the them are generally related to how the materials are formed. Stereolithography (SLA), Selective Laser Sintering (SLS), Digital Light Processing (DLP) are among the most applied methods for 3D printing [6]. 3D printing uses heat-formable thermoplastic materials in this method (PLA, ABS etc.) [7]. FDM technology is a complex process that affected by many parameters. Generally, filament material, build orientation, extrusion temperature, layer thickness, raster width and raster angle are preferred as effective parameters on mechanical properties.

In a study conducted in FDM method, by using ABS material, layer thickness, build orientation, and filling structure and occupancy rate parameters were examined and the effect of process parameters on compressive strength were optimized. Result of the study, it was stated that the
3D printed product with 80% occupancy rate, gryoid filling structure and 90° built orientation parameters gave very close results to the fully filled product [8].

In another study investigates the effects of filling structures on 3D printed parts. Five filling structures (honeycomb, solid, grid, wiggle, and linear) were combined to investigate their effect on tensile strength analysis. PLA material samples were produced in two different directions; straight and edge. They stated that grid and honeycomb filling structure have the highest strength, their weight is lighter than solid, and the power decreases by increasing the construction orientation in the study [9].

Another study was performed on PLA material using experimental design. In addition, other process parameters – layer thickness, material deposition speed, occupancy rate, and filling structures are taken into account. They stated that layer thickness parameter significantly affected the tensile properties [10].

In similar studies, the relationships between mechanical properties and surface roughness values and system vibrations were investigated. 50% occupancy rate is fixed in the form of rectilinear filling from Polyethylene Terephthalate Glycol (PET-G) material for different raster angles and printing speeds. As a result, it has been said that the printing speed of 3600 mm/s with 60° and 30° raster angle is optimum in terms of mechanical properties and vibration. [11, 12].

In similar studies on mechanical properties, PET-G filament material was used and in different filling types (Grid, Rectilinear, Wiggle, Triangular, Honeycomb), the results reported that printing patterns effects mainly on the product strength. The strength values obtained in the products manufactured as rectilinear filling were approximately 15% higher than other filling structures. In addition, it is reported that honeycomb filling style has more elongation than other filling structures [13 - 15].

Optimization is a process adopted by scientists to reduce the change in a product by controlling parameters and features related to product design and development. The selected input parameters have a serious effect over the final performance of a product with no doubt. Many methods like Taguchi’s Orthogonal Array, Response Surface Methodology (RSM) are generally adopted by scientists to create the experimental setup and the experimental data is further analyzed to obtain the optimum parameters and also the significant parameters which have the maximum effect over final results for study [16 - 17].
In another study, mechanical properties and product cost were examined; layer thickness (0.15, 0.20 and 0.25 mm), raster angle (15°, 45° and 75°), table orientation (flat, horizontal and vertical) are selected as effective parameters. In addition, the results were subjected to Taguchi optimization. The results reported that the 45° raster angle had the highest mechanical properties. The results also report optimum 3D printing process parameters for product cost were horizontal table orientation, 0.25 mm layer thickness, and 75° raster angle [18].

The effects of ABS and Nylon materials on the tensile strength values and dimensional accuracy of parameters by 3D printing is examined in another study. The effective parameters chosen are part orientation on table, layer height and shell numbers. To reduce the number of experiments, different combinations and levels of different parameters were determined using the taguchi’s L9 orthogonal array. They reported that orientation angle of part and shell numbers had a significant effect on tensile strength and moderately affected dimensional accuracy [19].

In a separate study, the mechanical properties of composites consisting of flexible plastic and natural fibers were studied. In this study, the impact strength and tensile strength values of the samples obtained from fiber and rubber in layers were examined. For decision-making, multi-objective optimization methods are used [20].

In a detailed review study, reports that reducing the layer thickness does not give a practical result as it extends the production time excessively. Many studies analyzed the effects of parameters such as printing speed, filling structures and occupancy rate on mechanical properties. Contrary to other studies in reviewed, in these studies, maximizing the occupancy rate does not increase the strength much after 50% occupancy rate and also increases the printing time difficult to apply in practice. Another issue addressed in these studies is that the filling structure, which gives the best mechanical properties according to the type of material, varies. In fact, different filling structures are recommended to improve different mechanical properties according to type of filament material. On the other hand, fused deposition modeling is a complicated process which have many affective parameters for product quality and material properties. According to the reported results, in terms of mechanical properties, the use of optimization is an important requirement that has arisen and is strictly dependent on the material and how it is applied. [21].

In literature, filling structure, occupancy rate and table orientation are the most effective 3D printing parameters for the strength of products with 3D printing method [16-25].
Generally examined studies are on the tensile strength values of ABS material and there is no study examining the effects of the most important 3D printing process parameters (filling structure, occupancy rate and table orientation) for the new modified PLA + material. In addition, in general, izod impact values for PLA + material are not mentioned in the studies [17, 26]. In the literature researches focused on tensile strength, ultimate strength and percentage elongation. In this study, it is aimed to present experimentally and statistically the damping ability of the parts that will work in impact environments where impact resistance tests have been performed, in order to set an example for the industry employees.

In this context, test samples were produced from PLA + material with three different filling structures, different occupancy rates and table orientations using the FDM method. Within the scope of the study, experimental and statistical analyzes were carried out by applying the Taguchi methodology to maximize strength, percent elongation and Izod impact values. Effect of FDM process parameters on mechanical characteristics were examined by Taguchi optimization of process parameters. Thanks to the derived equations of optimization results, it is aimed to provide the people who will work in this field to predict the tensile strength and izod impact values they will obtain when they change the effective parameters.

2. Material and Method

In this study, mechanical characteristic of the 3D printed PLA filament material samples were investigated experimentally and statistically. PLA filament material used in the scope of the study is manufactured by ESUN and can be found under the trade name PLA + with 1.75 mm diameter. The mechanical properties of this filament material which is suitable for using with 3D printing are given in Table 1. The main reason for using PLA within the scope of the research this plastic material has more advantages than ABS [27]. PLA is a biodegradable thermoplastic polyester material derived from cleaner sources, containing less toxic and requiring lower temperatures with 3D printing, thus positively influence consumption of energy. PLA+ based tensile and Izod test samples were produced on a Cartesian 3D printer. 3D printer has a 0.4 mm nozzle diameter, working with open source software is a commercial device. In this study, test samples were prepared for tensile tests according to ISO 527 and Izod impact tests according to ISO 180 standards. For this purpose, solid model of test samples were created in Solidworks design software and converted into STL file format for 3D printer slicing operation. The solid models of the samples were converted to Geometric Code (G-code) files with Simplfy3D slicing software and made ready for production.
2.1. Experimental design and optimization

The mechanical properties of produced samples are related to decision of process parameters by the FDM method. Occupancy rate is the most effective parameter for determining the strength of the product. Of course, the type of filament material used also affects the strength. In 3D printing, the dimensions of the gaps from 30-40% to 100% full change very little. For this reason, 50% occupancy rate is sufficient to produce high-strength models with less material. Therefore, in our study, the occupancy rate was determined as 10%, 30% and 50%.

Filling structure is the shape of the material inside of a 3D printed part. Ranging from lines to geometric shapes, filling structures can affect a directly mechanical properties, weight, and printing time. Like occupancy rate, some filling structures are better than others. Depending on the slicing software used there are different types of filling structures, but the three most used (Rectilinear, Triangular and Full Honeycomb) appear in all slicing programmes. The table orientation indicates the direction in which the part will be positioned on the printing table along the X and Y axes. The table orientation angle and the filling structure of the part determines the shape of the inner structure. 3D prints are created layer by layer, but how the layers are created has a big impact on mechanical properties.

In this context, three different occupancy rates (10, 30 and 50%) and filling structures (triangular, rectilinear and full honeycomb) and three different table orientation angles (0, 60 and -45°) were determined and the Taguchi L9 experimental design is applied for printing test samples. All 3D printing parameters used in this experimental study are given in Table 2.

For each test three samples were produced for in same time. Detailed images of 3D printing process and dimensions of the ISO 527-Type IV sample are given in Figure 1. Tensile strength value is an important physical specification of material in any application. FDM process parameters and levels of test samples is given in Table 3.
Dimensions of the ISO 180 – Type I sample are given in Figure 2. Cross-sectional images of different filling shapes (Rectilinear, Triangular, Full Honeycomb) and table orientation of samples are given in Figure 3.

Tensile tests were conducted in UTEST brand 10 tonnes tensile testing device in Düzce University, Mechanical Engineering laboratory. The tensile test process is given in Figure 4. Tensile test speed of 5 mm/min chosen according to ISO 527 test standard and all tests carried out under equal conditions.

Izod tester is given in Figure 5. The tests were repeated three times according to ISO 180 test standard.

Izod test device has; 2.75 Joule pendulum's energy, 150 degrees movement angle, 4 mm width, 2 mm notch thickness.

In order to minimize experimental errors, three tests were repeated for each condition and obtained evaluations were averaged of the tensile strength values. In the last stage of this study, statistical analysis and optimization has been made depending on tensile strength of the 3D printing parameters with PLA + material. In this context, ANOVA was applied with 95% ($\alpha = 0.05$) confidence level to the experimental results, and the effect levels of the filling structure, occupancy rate, and table orientation on the tensile strength were defined.

Maximum tensile strength value, elongation value and izod impact values as performance characteristic is required for the FDM method. “larger is better” function of Taguchi was used in optimization as shown in Eq. 1. Taguchi determines goal function of signal / noise (S / N) ratio to state the effect of the levels of printing parameters [29].

\[
S/N = -10\log\left(\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2}\right) \quad (\text{Eq. 1})
\]
3. Assessment of Experimental and Statistical Results

3.1. Tensile and Izod Test Results of Experiments

Taguchi L9 experiment layout and signal to statistical results are given in Table 4. Tensile strength and elongation data obtained from tensile tests are given in Table 5.

Table 5 shows that the average tensile strength increases proportionally as the occupancy rate increases with each filling structures. The biggest average tensile strength value was provided in sample 6. And also, the highest average percentage elongation value was provided in sample 6. The least average tensile strength value was provided in sample 1. The lowest average percentage elongation value was observed in sample 5. In addition, the average percentage elongation of full honeycomb filling structure is not affected by other parameters.

Table 6 shows that the average Izod impact values increases proportionally as the occupancy rate increases with triangular and full honeycomb filling structures. The highest average Izod impact value was acquired in sample 6. The lowest average Izod impact value was observed in sample 7. Rectilinear filling structure, Izod impact values vary independently of parameters. In applications where Izod impact values are important, it is not appropriate to work at 30% occupancy rate or below.

3.2. Statistical Results

Results of variance analysis are shown in Table 7. Main Signal to Noise plot for the effects and levels of the 3D printing parameters is given in Figure 6. In order for the strength and impact values to be the highest, the larger is better optimization function for the Signal to Noise ratio was determined with Minitab18 program. The optimized 3D printing parameters and their equivalent values are shown in Table 8 and Table 9. R² regression coefficient was calculated as 96.96% and standard deviation as 0.256661. Linear Regression Equation is given in for estimation of tensile strength values, percentage elongation at break and Izod impact values in...
95% confidence interval below. When using the extracted equations, instead of filling structure, numerical data; The numbers 1 should be used for full honeycomb, 2 for rectilinear and 3 for triangular as shown in Table 3.

Linear Regression Equation used in the estimation of tensile strength values,

\[
Tensile\;Strength\; (MPa) = 20.42 + 0.1685 \times Occupancy\;Rate \]
\[ -0.0142 \times Table\;Orientation + 2.572 \times Filling\;Structure \] (Eq. 2)

Linear Regression Equation used in the estimation of tensile elongation at break,

\[
Elongation\;at\;Break\; (%) = 0.02040 + 0.00005 \times Occupancy\;Rate \]
\[ -0.000002 \times Table\;Orientation - 0.000333 \times Filling\;Structure \] (Eq. 3)

Linear Regression Equation used in the estimation of izod impact value,

\[
Izod\;Impact\;Value\; (kJ/m^2) = 1.39 + 0.0311 \times Occupancy\;Rate \]
\[ -0.00632 \times Table\;Orientation - 0.036 \times Filling\;Structure \] (Eq. 4)
As seen in Table 7, when the P values are examined, only the value of the table orientation parameter is above 0.05. This situation shows that the effect of table orientation on mechanical properties is very low compared to other parameters.

Table 8 shows that responses for signal to noise ratios. The optimum 3D printing process parameters as rectilinear filling structure, 50% occupancy rate and 0° table orientation with PLA+ filament was obtained. In a similar study, optimization study was examined in terms of compression strength, but instead of the rectilinear filling structure, which gives the best results, gyroid filling method was preferred and ABS material was preferred as the material. 80% occupancy rate is suggested, but this occupancy rate is not effective in terms of printing speed and production costs. Our study has chosen the tensile and impact strength values, which are the most important mechanical characteristics required from 3D printed parts, as multi criteria optimization and reveals the most suitable parameters in terms of printing cost for the most suitable modified filament for manufacturers [30].

Using the equations (Eq. 2, Eq.3 and Eq.4) derived form this study, the tensile strength, percentage elongation and izod impact value were calculated for the proposed optimum process parameters, and the average test results of 3 test samples produced in these optimum parameters were compared. Thus, the results obtained in the study were verified as shown in Table 9. It is seen that high convergence values of 97.53% for tensile strength, 95.88% for percentage elongation and 93.47% for izod impact value are obtained. In this context, it is noteworthy that the difference between the results of the verification experiment and the results obtained from the Taguchi approach is negligible. Based on these results, it is possible to say that Taguchi optimization was successfully applied at the 0.05 significance level. In addition, in a optimization study for tensile strength and material weight for unmodified PLA material, the 37 MPa tensile strength, which is the strength obtained at 80% occupancy, can be obtained at
50% occupancy rate with the modified PLA + material and the parameters optimized in our study [31].

Table 10. shows that the difference between the estimation model and the experimental did not exceed the maximum value of 1.8 %. In the new studies, optimization proposed as future works was taken into consideration and the mechanical characteristics of the newly modified PLA material and the optimum operating parameters to be used by the manufacturers were examined. In addition to this, another future work suggested in the review studies is, in addition to the selected parameters, practical equations have been obtained for the strength values if different degrees are selected [32]. Similar results were obtained compared to studies conducted in the literature [33].

4. Conclusion

Results of experiments were conducted for occupancy rate, filling structure, and table orientation, which are selected as 3D printing parameters, and the effects on mechanical characteristics were examined with the help of these Taguchi optimization. The following main results can be listed as below;

- Statistical calculations required for the optimum selection of tensile strength values, percentage elongation and Izod impact values, rectilinear filling structure, 50 % occupancy rate and 0° table orientation were determined. This study has chosen the tensile strength and impact strength, which are the most important mechanical characteristics taguchi optimization and reveals the most suitable parameters in terms of printing cost for the most suitable modified PLA filament for manufacturers.

- In addition to the selected parameters, practical equations have been obtained for the strength values if different degrees are selected. As a result of this study, the difference
between the estimation equation and experimental results did not exceed the maximum value of 5%.

- The average tensile strength increases proportionally as the occupancy rate increases with each filling structures. The average percentage elongation of full honeycomb filling structure is not affected by other parameters, and the most effective parameter for the mechanical characteristic is occupancy rate.

- The average Izod impact values increases proportionally as the occupancy rate increases with triangular and full honeycomb filling structures unlike that rectilinear filling structure. Rectilinear filling structure, Izod impact values vary independently of parameters. In applications where Izod impact values are important, it is not appropriate to work at 30% occupancy rate or below.

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Figure List

Figure 1. Printing process of samples and ISO 527-Type IV test sample dimensions (mm)

Figure 2. ISO 180-Type I test sample dimensions (mm).

Figure 3. Filling structures: 1-Rectilinear, 2-Triangular, 3- Full honeycomb; table orientations: 60°, -45° and 0°.

Figure 4. Tensile testing device and tensile test process.

Figure 5. Izod impact test device and test sample.

Figure 6. S / N ratios of parameters for optimum 3D printing process parameters.

Table List

Table 1. Properties of PLA+ filament material [28].

Table 2. FDM process parameters and 3D printer features.

Table 3. Printing process parameters and levels (Taguchi L9).

Table 4. Taguchi L9 experiment layout and statistical results.

Table 5. Tensile strength values and percentage elongation values of tensile tests.
Table 6. Izod impact tests results.

Table 7. Variance analysis values.

Table 8. Signal to Noise ratios according to “larger is better” criteria.

Table 9. Comparison of verification test results and calculated results for optimum parameters.

Table 10. Comparison of measured and estimated signal to noise and mean values using Taguchi method.

Figures

Figure 1. Printing process of samples and ISO 527-Type IV test sample dimensions (mm).

Figure 2. ISO 180-Type I test sample dimensions (mm).

Figure 3. Filling structures: 1-Rectilinear, 2-Triangular, 3- Full honeycomb; table orientations: 60°, -45° and 0°.
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Tables

Table 1. Properties of PLA+ filament material [28].

| Printing Temperature (°C) | Density (g/cm³) | Maximum Service Temperature (°C) | Ultimate Strength (MPa) | Elongation at break (%) | Flexural Strength (MPa) | Izod Impact Strength (kJ/m²) |
|---------------------------|-----------------|----------------------------------|------------------------|------------------------|------------------------|----------------------------|
| 190-220                   | 1.24            | 60                               | 45.6                   | 6                      | 103                    | 5.1                        |

Table 2. FDM process parameters and 3D printer features.

| Features                        | Values                        |
|---------------------------------|-------------------------------|
| Nozzle diameter (mm)            | 0.40                          |
| Extruder temperature (°C)       | 205                           |
| Table temperature (°C)          | 60                            |
| Extrusion width (mm)            | 0.35                          |
| Layer height (mm)               | 0.2                           |
| Printing speed (mm/min)         | 3600                          |
| Idle running (mm/min)           | 4800                          |
| Ambient temperature (°C)        | 24 ± 1                        |
| Model                           | Rigid3D Zero2                 |
| Printing Volume                 | 200*200*200 mm                |
| Machine Dimension               | 390*460*460 mm                |
| Tolerance                       | 0.05-0.3 mm                   |
| Power                           | 600 W                         |
| Extruder nozzle                 | 1                             |
| Processor                       | Arduino processor             |

Table 3. Printing process parameters and levels (Taguchi L9).

| Factors        | Unit | Levels | Output                              |
|----------------|------|--------|-------------------------------------|
| Filling Structures |      | 1. Full Honeycomb, 2. Rectilinear, 3. Triangular | Tensile strength values (MPa), Percentage Elongation at break (%), Izod impact values |
| Occupancy Rates | %    | 10, 30, 50 |                                      |
| Table Orientation | °    | 0, 60, -45 |                                      |
### Table 4. Taguchi L9 experiment layout and statistical results.

| Samples | Filling Structures | Occupancy Rate (%) | Table Orientation (°) | Signal to Noise (S/N) | Mean Value |
|---------|-------------------|--------------------|-----------------------|----------------------|------------|
| 1       | RC                | 10                 | 0                     | -29.2087             | 8.9300     |
| 2       | RC                | 30                 | 60                    | -29.6540             | 10.2500    |
| 3       | RC                | 50                 | -45                   | -28.3809             | 11.9943    |
| 4       | TA                | 10                 | 60                    | -29.3809             |            |
| 5       | TA                | 30                 | -45                   | -30.1238             |            |
| 6       | TA                | 50                 | 0                     | -27.2702             |            |
| 7       | FH                | 10                 | -45                   | -28.3814             |            |
| 8       | FH                | 30                 | 0                     | -28.3806             |            |
| 9       | FH                | 50                 | 60                    | -28.3805             |            |

### Table 5. Tensile strength values and percentage elongation values of tensile tests.

| Samples | Tensile Strength (MPa) | Elongation at break (%) |
|---------|------------------------|-------------------------|
|         | 1. Test                | 2. Test                | 3. Test | Average | 1. Test | 2. Test | 3. Test | Average |
| 1       | 25.60                  | 24.76                  | 24.59   | 24.98   | 0.020   | 0.023   | 0.020   | 0.021   |
| 2       | 28.58                  | 28.66                  | 28.08   | 28.44   | 0.020   | 0.021   | 0.018   | 0.019   |
| 3       | 35.06                  | 33.44                  | 33.62   | 34.04   | 0.024   | 0.020   | 0.023   | 0.022   |
| 4       | 29.11                  | 31.22                  | 30.95   | 30.42   | 0.021   | 0.022   | 0.021   | 0.021   |
| 5       | 31.77                  | 32.26                  | 33.61   | 32.54   | 0.018   | 0.017   | 0.019   | 0.018   |
| 6       | 37.62                  | 38.89                  | 38.92   | 38.47   | 0.023   | 0.030   | 0.022   | 0.025   |
| 7       | 27.40                  | 28.44                  | 27.27   | 27.70   | 0.021   | 0.023   | 0.024   | 0.022   |
| 8       | 29.36                  | 25.02                  | 28.10   | 27.49   | 0.021   | 0.024   | 0.021   | 0.022   |
| 9       | 31.31                  | 29.95                  | 31.68   | 30.81   | 0.023   | 0.026   | 0.019   | 0.022   |

### Table 6. Izod impact tests results.

| Samples | Izod impact values (kJ/m²) |
|---------|----------------------------|
|         | 1. Test | 2. Test | 3. Test | Average |
| 1       | 1.692   | 1.987   | 1.692   | 1.790    |
| 2       | 2.336   | 2.390   | 2.148   | 2.291    |
| 3       | 1.520   | 1.799   | 2.444   | 1.921    |
| 4       | 1.826   | 1.584   | 1.960   | 1.790    |
| 5       | 1.638   | 2.014   | 1.745   | 1.799    |
| 6       | 4.001   | 4.377   | 2.336   | 3.571    |
| 7       | 1.504   | 1.369   | 1.423   | 1.432    |
| 8       | 2.121   | 3.625   | 2.336   | 2.694    |
| 9       | 4.001   | 3.840   | 1.907   | 3.249    |
Table 7. Variance analysis values.

| Source                  | DF | Adj SS  | Adj MS  | F – Değeri | P - Değeri |
|-------------------------|----|---------|---------|-------------|------------|
| Regression              | 3  | 111.191 | 37.064  | 8.94        | 0.019      |
| Occupancy Rate          | 1  | 68.141  | 68.141  | 16.44       | 0.010      |
| Table Orientation       | 1  | 3.369   | 3.369   | 0.81        | 0.409      |
| Filling Structures      | 1  | 39.681  | 39.681  | 9.57        | 0.027      |
| Error                   | 5  | 20.722  | 4.144   |             |            |
| Toplam                  | 8  | 243.104 |         |             |            |

Table 8. Signal to Noise ratios according to “larger is better” criteria.

| Level | Filling Structures | Occupancy Rate (%) | Table Orientation (°) |
|-------|--------------------|--------------------|-----------------------|
| 1     | -28.38             | -28.79             | -28.96                |
| 2     | -29.08             | -29.39             | -28.29                |
| 3     | -28.73             | -28.01             | -28.94                |
| Delta | 0.70               | 1.38               | 0.68                  |
| Rank  | 2                  | 1                  | 3                     |

Table 9. Comparison of verification test results and calculated results for optimum parameters.

| Output                  | Estimated Values | Verifying Test Results |
|-------------------------|------------------|------------------------|
| Tensile Strength (MPa)  | 33.99            | 33.15                  |
| Elongation (%)          | 0.024            | 0.023                  |
| Izod Impact Value (kJ/m²)| 3.017            | 2.82                   |

Table 10. Comparison of measured and estimated signal to noise and mean values using Taguchi method.

| Sample No | Signal to Noise (S/N) | Mean Value | Predicted Signal to Noise (S/N) | Predicted Mean Value |
|-----------|-----------------------|------------|----------------------------------|----------------------|
| 1         | -29.2087              | 8.9300     | -28.7005                         | 9.2979               |
| 2         | -29.6540              | 10.2500    | -29.9483                         | 9.8688               |
| 3         | -28.3809              | 11.9943    | -28.5949                         | 12.0076              |
| 4         | -28.7850              | 10.7437    | -28.9990                         | 10.7569              |
| 5         | -30.1238              | 11.4523    | -29.6156                         | 11.8203              |
| 6         | -27.2702              | 14.0220    | -27.5645                         | 13.6408              |
| 7         | -28.3814              | 9.7180     | -28.6756                         | 9.368                |
| 8         | -28.3806              | 10.0687    | -28.5946                         | 10.0819              |
| 9         | -28.3805              | 11.3603    | -27.8723                         | 11.7283              |
Biographies

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