Optimization of Tensile Strength and Young’s Modulus in 3D-Printed Polycarbonate/Graphene/Carbon Powder Composites using Taguchi Method

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**Abstract:** This study investigates fused deposition modelling (FDM) 3D printing settings were optimized to improve the mechanical performance of 90% polycarbonate (PC) composites mixed with 5% graphene and 5% carbon powder. A Taguchi L9 orthogonal array was used to assess the effect of three critical process parameters—nozzle temperature, bed temperature, and printing speed—on tensile strength and tensile Young's modulus. Tensile testing were carried out in line with ASTM D638 norms. Signal-to-noise ratio (S/N) study found that nozzle temperature was the most important factor, followed by bed temperature, with printing speed having little influence on mechanical performance. The best parameter combination found was a nozzle temperature of 210°C, a bed temperature of 70°C, and a printing speed of 20 mm/s, yielding a maximum tensile strength of 105 MPa and a Young's modulus of 5500 MPa. ANOVA showed that nozzle temperature significantly influenced tensile strength and Young's modulus, accounting contribution is 86.56% and 78.72% of the variance, respectively (P < 0.05). Regression modelling showed a good correlation (R² values of 98.35% and 97.89%), indicating consistent model performance. Contour plots confirmed that higher mechanical characteristics were obtained with lower nozzle temperatures and moderate bed temperatures. The work gives an in-depth understanding of thermal-mechanical correlations in PC-based composite FDM printing, emphasizing the significance of thermal parameter management in obtaining excellent component performance. These findings provide important insights into increasing the quality and functioning of 3D-printed structural components.

**Keywords**: Carbon powder, Graphene, Polycarbonate, Coefficient of correlation, Tensile strength, Tensile Youngs modulus,Contribution, ANOVA, Regression model and contour plot.

# Introduction

Additive manufacturing is a strong technology for the manufacture of mechanical machine components. Nowadays, the medical field relies heavily on mechanical engineering components to print human tissues and organs using additive manufacturing technology [1]. The dental industry also uses 3D printing machines to print jaws, artificial teeth, and many human parts using additive manufacturing technology [2]. As a result, the 2025 additive manufacturing market expansion is fast growing the share values of the additive manufacturing industry [3]. The 3D printing business is quickly generating human main organs, saving countless human lives [4]. This technology is one of the most important and effective life-saving devices in the mechanical engineering industry. As a result, numerous scholars are focusing on this business [5]. Polycarbonate materials are used in a variety of sectors, particularly the medical industry, to create implants and surgical instruments of many types. Polycarbonate is commonly used in various medical fields. It possesses strong mechanical qualities, good chemical resistance, great transparency capabilities, and high electrical resistance [6]. The downside of polycarbonate materials is that they are rather expensive. Additionally, polycarbonate materials are employed in a wide range of local and foreign applications [7]. Graphene is also widely used in various sectors to improve the strength of human organs, tissue engineering, dental tooth implants, and bone applications [8]. This graphene is primarily used in medicine, drug applications, sports game parts, and a variety of industries. This material offers several advantages [9].

Graphene powder's negative aspects is its high cost. Processing costs are considerable per gram. As a result, many researchers do not focus primarily on these materials [10]. This material has several advantages for use in construction since it has a high-grade value and is lightweight. Carbon powder is also used in various sectors, particularly in the medical business, where it is used to build scan machines and surgery machines within hospitals for medical equipment [11]. Carbon powder has a high heat resistance, but processing costs are expensive. As a result, many academics do not focus on these materials for their study. In this three-material combination, the construction of these materials is a significant problem, and the operation costs are quite high. The prior work did not address the literature gap of polycarbonate, graphene, and carbon powder merging combination printed samples for tensile strength and tensile young's modulus [12-17]. The prior study only examined polycarbonate and graphene, not polycarbonate and carbon powder. To discuss the restricted mechanical qualities, they use a single polycarbonate composite filler. Now, work is being done on these Polycarbonate, graphene, and carbon powder mixed printed samples to discuss tensile strength according to ASTM standards. The printed tensile strength samples and young's modulus were not covered in the earlier study. As a result, the literature gap is significant in comparison to past study [18-23]. This gap is more likely to provide adequate strength for this three-way combination of labor. This merging Polycarbonate multi filler composite printed tensile sample and tensile young’s modulus utilizing ASTM standards have not been described in earlier studies. The use of the Taguchi L9 orthogonal array for level 9 tests, as well as the parameters and levels for nozzle temperature, printing speed, and bed temperature, have not been mentioned in previous study. Prior research has not examined the use of the Taguchi technique for tensile strength and tensile young’s modulus in an orthogonal array for signal to noise ratio. Prior study did not accomplish an analysis of variance for polycarbonate multi composite filler printed samples with tensile strength and tensile young’s modulus coefficient of correlation values greater than 95% [24-29].

Regression model for tensile strength and tensile young’s modulus for enhancing mechanical performance using regression model to discover correct results for Polycarbonate composite multi filler with the assistance of regression model analysis. Contour plots are used to discover the maximum tensile strength and tensile Youngs modulus. The usage of contour plots has not been thoroughly discussed in previous works. Previous research has not adequately discussed the Taguchi approach for improving the mechanical behavior of polycarbonate printed samples. These are the gaps in the literature for this experimental study. The objective of the research is to test printed samples of polycarbonate 90%, 5% graphene, and 5% carbon powder for tensile strength and tensile Youngs modulus in accordance with ASTM standards [30-38]. This ASTM standard printed samples for tensile strength and tensile Youngs modulus using the Taguchi method for nine levels of experiment and parameters, as well as levels for nozzle temperature, printing speed, and bed temperature for tensile strength and tensile Youngs modulus and signal to noise ratio for these two properties. The larger the value, the higher the tensile strength and tensile Youngs modulus. These two properties utilize level 9 experiments designed for Nozzle temperature, printing speed, Bed temperature, Tensile strength and tensile Youngs modulus, Signal to noise ratio, signal to noise ratio1 [39-45]. FITS and FITS 1 were responsible for creating this entire source in order to increase the mechanical qualities and strength of all sorts of properties. Analysis of variance was used to raise the tensile strength and tensile Youngs modulus, resulting in a high contribution value and coefficient of correlation for both tensile strength and tensile Youngs modulus [46-49]. This is a standard process for increasing strength and structural integrity. The regression model for tensile strength and tensile Youngs modulus shows the highest strength. Contour plots show the high mechanical strength for tensile strength and tensile Youngs modulus. This Taguchi approach can increase the mechanical strength, quality, and resistance of this printed polycarbonate composite filament.

# Materials and Methods

## Materials

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**Figure 1: Polycarbonate multi filler Printed Tensile samples**

The printed samples for the combination of 90% polycarbonate, 5% carbon powder, and 5% graphene are displayed in figure 1 of this experiment. Tensile strength and Young's modulus are as per ASTM standards in this printed sample. The ASTM standard for tensile strength in this case is D638. This sample complies with this ASTM standard.

In this experiment table 1 shows the parameter level for three stages. Level 3 for Printing speed is 25 mm/s,Bed temperature is 80 degree Celsius and Nozzle temperature is 230 degree Celsius.Level 2 for Printing speed is 20 mm/s,Bed temperature is 70 degree Celsius and Nozzle temperature is 220 degree Celsius.Level 1 for Printing speed is 15 mm/s,Bed temperature is 60 degree Celsius and Nozzle temperature is 210 degree Celsius**.**

**Table 1: Parameters and Levels**

|  |  |  |  |
| --- | --- | --- | --- |
| Factor | Type | Levels | Values |
| Printing speed | Fixed | 3 | 15, 20, 25 |
| Bed Temp | Fixed | 3 | 60, 70, 80 |
| Nozzle Temp | Fixed | 3 | 210, 220, 230 |

## ****Experimental Design****

**In this experiment table 2 shows the design for 3 parameters. In this design level 9 for Printing speed is 25 mm/s, Bed temperature is 70 degree Celsius and Nozzle temperature is 230 degree Celsius. In this design level 8 for Printing speed is 20 mm/s, Bed temperature is 60 degree Celsius and Nozzle temperature is 230 degree Celsius. In this design level 7 for Printing speed is 15 mm/s, Bed temperature is 80 degree Celsius and Nozzle temperature is 230 degree Celsius. In this design level 6 for Printing speed is 25 mm/s, Bed temperature is 60 degree Celsius and Nozzle temperature is 220 degree Celsius. In this design level 5 for Printing speed is 20 mm/s, Bed temperature is 80 degree Celsius and Nozzle temperature is 220 degree Celsius. In this design level 4 for Printing speed is 15 mm/s, Bed temperature is 70 degree Celsius and Nozzle temperature is 220 degree Celsius. In this design level 3 for Printing speed is 25 mm/s, Bed temperature is 80 degree Celsius and Nozzle temperature is 210 degree Celsius. In this design level 2 for Printing speed is 20 mm/s, Bed temperature is 70 degree Celsius and Nozzle temperature is 210 degree Celsius. In this design level 1 for Printing speed is 15 mm/s, Bed temperature is 60 degree Celsius and Nozzle temperature is 210 degree Celsius.**

**Table 2: Design for 3 parameters**

|  |  |  |  |
| --- | --- | --- | --- |
| **Level no** | **Printing speed mm/s** | **Bed Temperature degree Celsius** | **Nozzle Temperature degree Celsius** |
| 1 | 15 | 60 | 210 |
| 2 | 20 | 70 | 210 |
| 3 | 25 | 80 | 210 |
| 4 | 15 | 70 | 220 |
| 5 | 20 | 80 | 220 |
| 6 | 25 | 60 | 220 |
| 7 | 15 | 80 | 230 |
| 8 | 20 | 60 | 230 |
| 9 | 25 | 70 | 230 |

## ****Response Measurement****

**Tensile strength and Tensile Young's modulus are being prepared in accordance with ASTM standards. The optimal output value for both tensile strength and tensile Youngs modulus is a bigger value for the signal to noise ratio. Tensile strength and tensile Young's modulus ASTM standards are D638.**

# ****Result and Discussion****

## ****Taguchi Analysis****

In this experiment, Table 3 presents the analysis of nine levels of trials for tensile strength and tensile Young’s modulus using the Taguchi method. At a nozzle temperature of 210 °C, performance was consistently higher across the first three levels. At Level 1 (210 °C, 15 mm/s, 60 °C bed), the tensile strength was 103 MPa with a Young’s modulus of 5430 MPa, supported by a signal-to-noise (S/N) ratio of 40.26 and 74.69. Increasing the speed and bed temperature at Level 2 (210 °C, 20 mm/s, 70 °C) improved the tensile strength to 105 MPa and modulus to 5500 MPa, the highest values among all experiments, confirming the beneficial role of moderate speed and bed settings. At Level 3 (210 °C, 25 mm/s, 80 °C), the properties slightly reduced to 104 MPa strength and 5450 MPa modulus, though still higher than later levels. These results show that 210 °C nozzle temperature consistently produced the best overall mechanical performance, especially at Level 2.

As the nozzle temperature increased to 220 °C and 230 °C, both tensile strength and modulus gradually declined, indicating thermal softening of the polymer matrix. At Level 4 (220 °C, 15 mm/s, 70 °C), the tensile strength reduced to 102 MPa and modulus to 5420 MPa, while Level 5 (220 °C, 20 mm/s, 80 °C) further dropped to 101 MPa and 5400 MPa. The weakest response at 220 °C occurred at Level 6 (25 mm/s, 60 °C), with strength only 100 MPa. At the highest nozzle temperature of 230 °C, deterioration became more evident: Level 7 (95 MPa, 5350 MPa) and Level 8 (96 MPa, 5370 MPa) showed reduced values, though Level 9 (99 MPa, 5385 MPa) partially recovered due to balanced process settings. These results confirm that 210 °C is the optimal nozzle temperature, as higher temperatures (220–230 °C) decreased tensile properties, while printing speed and bed temperature provided secondary influences.

**Table 3: Experiment analysis for three parameters, Tensile strength, Youngs modulus**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Level no** | **Nozzle Temp** | **Printing speed mm/s** | **Bed Temp** | **Tensile strength MPa** | **TS-Youngs modulus MPa** | **S/N ratio for Tensile strength** | **S/N ratio for Youngs modulus** |
| 1 | 210 | 15 | 60 | 103 | 5430 | 40.25674449 | 74.69599659 |
| 2 | 210 | 20 | 70 | 105 | 5500 | 40.42378598 | 74.80725379 |
| 3 | 210 | 25 | 80 | 104 | 5450 | 40.34066679 | 74.72793005 |
| 4 | 220 | 15 | 70 | 102 | 5420 | 40.17200344 | 74.67998573 |
| 5 | 220 | 20 | 80 | 101 | 5400 | 40.08642748 | 74.6478752 |
| 6 | 220 | 25 | 60 | 100 | 5410 | 40 | 74.6639453 |
| 7 | 230 | 15 | 80 | 95 | 5350 | 39.55447211 | 74.56707564 |
| 8 | 230 | 20 | 60 | 96 | 5370 | 39.64542466 | 74.59948571 |
| 9 | 230 | 25 | 70 | 99 | 5385 | 39.91270389 | 74.62371415 |

## Tensile strength and Youngs modulus for response ratio of signal to noise ratio

### Tensile strength

In this experiment table 4 shows the signal to noise ratio for tensile strength. In this tensile strength level 1 for Nozzle temperature is 40.34 degree Celsius, Printing speed is 39.99 mm/s and Bed temperature is 39.97 degree Celsius. level 2 for Nozzle temperature is 40.09 degree Celsius, Printing speed is 40.05 mm/s and Bed temperature is 40.17 degree Celsius. level 3 for Nozzle temperature is 39.70 degree Celsius, Printing speed is 40.08 mm/s and Bed temperature is 39.99 degree Celsius.

Table 4: Tensile strength signal to noise ratio

|  |  |  |  |
| --- | --- | --- | --- |
| Level | Nozzle Temp | Printing speed mm/s | Bed Temp |
| 1 | 40.34 | 39.99 | 39.97 |
| 2 | 40.09 | 40.05 | 40.17 |
| 3 | 39.70 | 40.08 | 39.99 |
| Delta | 0.64 | 0.09 | 0.20 |
| Rank | 1 | 3 | 2 |

The plot's greatest wave of ranking is represented by the nozzle temperature delta value of 0.64 in figure 2. The lowest plot wave with a delta value of 0.09 mm/s is displayed by printing speed, while the second-highest plot wave with a delta value of 0.20 is displayed by bed temperature.



Figure 2: Signal to noise ratio plot for Tensile strength

### Tensile Youngs modulus

In this experiment table 5 shows the signal to noise ratio for tensile Youngs modulus. In this Tensile Youngs modulus level 1 for Nozzle temperature is 74.74 degree Celsius, Printing speed is 74.65 mm/s and Bed temperature is 74.65 degree Celsius. level 2 for Nozzle temperature is 74.66 degree Celsius, Printing speed is 74.68 mm/s and Bed temperature is 74.70 degree Celsius. level 3 for Nozzle temperature is 74.60 degree Celsius, Printing speed is 74.67 mm/s and Bed temperature is 74.65 degree Celsius.

Table 5: Tensile Youngs modulus for signal to noise ratio

|  |  |  |  |
| --- | --- | --- | --- |
| Level | Nozzle Temp | Printing speed | Bed Temp |
| 1 | 74.74 | 74.65 | 74.65 |
| 2 | 74.66 | 74.68 | 74.70 |
| 3 | 74.60 | 74.67 | 74.65 |
| Delta | 0.15 | 0.04 | 0.06 |
| Rank | 1 | 3 | 2 |

The plot's greatest wave of ranking is represented by the nozzle temperature delta value of 0.15 in figure 3. The lowest plot wave with a delta value of 0.04 mm/s is displayed by printing speed, while the second-highest plot wave with a delta value of 0.06 is displayed by bed temperature.



Figure 3: Signal to noise ratio plot for Tensile Youngs modulus

## Analysis of Variance (ANOVA)

### Tensile strength

Tensile strength, as shown in analysis of variance (ANOVA) table 6, suggests that nozzle temperature has the most significant impact of all the process factors taken into consideration. Its contribution to the variance in tensile strength is 86.56%, and its statistically significant effect is confirmed by a high F-value of 52.43 and a P-value of 0.019, both of which are less than 0.05. On the other hand, bed temperature and printing speed only make up 10.14% and 1.65% of the total, respectively, and are not statistically significant (both P-values are > 0.05, with 0.5 and 0.14, respectively). Additionally, the error term contributes 1.65%, suggesting that the model has a low degree of unexplained variance. With a high R-squared (R²) coefficient of correlation value of 98.35%, the tensile model summary demonstrates the model's dependability by explaining a significant amount of the variance in tensile strength. Even after taking the number of predictors into consideration, the adjusted R2 is 93.40%, suggesting an excellent match. The model's prediction ability is reasonable, but it might be enhanced, as indicated by the anticipated R2 of 66.57%. Moderate predictive inaccuracy is indicated by the residuals' standard deviation (S) of 0.881917 and PRESS value of 31.5. Overall, the most important factor influencing tensile strength is nozzle temperature; within the studied range, printing speed and bed temperature have very little bearing [50-51].

Table 6: ANOVA for Tensile strength

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Seq SS** | **Contribution** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
| Nozzle Temp | 2 | 81.556 | 86.56% | 81.556 | 40.7778 | 52.43 | 0.019 |
| Printing speed | 2 | 1.556 | 1.65% | 1.556 | 0.7778 | 1 | 0.5 |
| Bed Temp | 2 | 9.556 | 10.14% | 9.556 | 4.7778 | 6.14 | 0.14 |
| Error | 2 | 1.556 | 1.65% | 1.556 | 0.7778 |  |  |
| Total | 8 | 94.222 | 100.00% |  |  |  |  |

The tensile strength residual plots in Figure 4 demonstrate that the ANOVA's assumptions are mostly met. The points on the Normal Probability Plot primarily follow a straight line, suggesting that the residuals are roughly normally distributed. The Versus Fits plot confirms constant variance by displaying a random scatter of residuals devoid of any discernible pattern. The normalized residuals histogram supports normalcy since it is approximately symmetrical. Since there is no discernible pattern in the Versus Order plot, the residuals are independent across time. The residuals indicate that the model is generally sound and provides a good fit to the data.



Figure 4: Plot for ANOVA Tensile strength

### Tensile Youngs modulus

Tensile Youngs modulus is displayed in ANOVA analysis table 7. Nozzle temperature is the most significant variable, contributing to 78.72% of the overall response variance, according to Young's modulus. This factor has a large effect on the tensile modulus, as evidenced by its high F-value of 37.3 and statistically significant P-value of 0.026 (less than 0.05). P-values of 0.131 and 0.288 (higher than 0.05) indicate that bed temperature and printing speed are statistically unimportant, with corresponding contributions of 13.94% and 5.22%. Low experimental noise is reflected in the error, which only makes up 2.11%. The dependability of the regression model is confirmed by the model summary, which shows a strong fit with a high R-squared value of 97.89% for the coefficient of correlation and 91.56% for the adjusted R-squared. Though the model does a good job of fitting the experimental data, its predictive power might be further enhanced, as indicated by the anticipated R-squared of 57.26%. Moderate predictive error is indicated by the PRESS value of 6862.5 and the standard deviation (S) of 13.0171. In this investigation, the primary and statistically significant factor influencing Young's modulus is the nozzle temperature.

Table 7: ANOVA for Tensile Youngs modulus

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Seq SS** | **Contribution** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
| Nozzle Temp | 2 | 12638.9 | 78.72% | 12638.9 | 6319.4 | 37.3 | 0.026 |
| Printing speed | 2 | 838.9 | 5.22% | 838.9 | 419.4 | 2.48 | 0.288 |
| Bed Temp | 2 | 2238.9 | 13.94% | 2238.9 | 1119.4 | 6.61 | 0.131 |
| Error | 2 | 338.9 | 2.11% | 338.9 | 169.4 |  |  |
| Total | 8 | 16055.6 | 100.00% |  |  |  |  |

The model assumptions are satisfactorily satisfied, as shown by the residual plots of the tensile Youngs modulus in figure 5. The majority of the residuals, as displayed by the Normal Probability Plot, sit around the straight line, suggesting that they are roughly normally distributed. A random dispersion of points with no discernible pattern is displayed in the Versus Fits plot, indicating homoscedasticity, or constant variance. The assumption of normalcy is supported by the Histogram's reasonable symmetry. The absence of any discernible trend in the Versus Order plot suggests that the residuals are time-independent. All things considered, the residual analysis confirms that the ANOVA model for Young's modulus is accurate.



Figure 5: Plot for Tensile Youngs modulus

## Regression model

### Tensile strength

Tensile strength is determined by the regression equation using varying nozzle temperature, printing speed, and bed temperature. Every phrase denotes the impact of a particular setting, with the base value being 100.556. Tensile strength is decreased (–3.889) at 230°C, but 210°C has a positive impact (+3.444) among the nozzle temperatures. Printing speed has a little effect; strength increases slightly (+0.444) at 25 mm/s and decreases somewhat (-0.556) at 15 mm/s. While 60°C and 80°C have detrimental impacts on tensile strength, 70°C increases it (+1.444) at bed temperature. The model's overall findings indicate that printing speed has the least impact, while nozzle temperature has the greatest impact, followed by bed temperature.

## Regression equation

|  |  |  |
| --- | --- | --- |
| Tensile strength | = | 100.556 + 3.444 Nozzle Temp\_210 + 0.444 Nozzle Temp\_220 - 3.889 Nozzle Temp\_230 - 0.556 Printing speed\_15 + 0.111 Printing speed\_20 + 0.444 Printing speed\_25 - 0.889 Bed Temp\_60 + 1.444 Bed Temp\_70 - 0.556 Bed Temp\_80 |

## Tensile Youngs modulus

Tensile Young's modulus is calculated using the regression equation using changes in bed temperature, printing speed, and nozzle temperature. 5412.78 is the constant base value. Young's modulus is improved by lower nozzle temperatures, as evidenced by the highest positive effect (+47.22) of 210°C and the worst negative impact (–44.44) of 230°C. While 15 mm/s lowers the modulus (–12.78), 20 mm/s increases printing speed (+10.56). The modulus decreases at 60°C and 80°C (–9.44 and –12.78, respectively), whereas the bed temperature at 70°C has a notable beneficial impact (+22.22). With ideal values of about 210°C for the nozzle and 70°C for the bed, the model suggests that nozzle and bed temperatures are important factors influencing Young's modulus.

|  |  |  |
| --- | --- | --- |
| TS-Youngs modulus | = | 5412.78 + 47.22 Nozzle Temp\_210 - 2.78 Nozzle Temp\_220 - 44.44 Nozzle Temp\_230 - 12.78 Printing speed\_15 + 10.56 Printing speed\_20 + 2.22 Printing speed\_25 - 9.44 Bed Temp\_60 + 22.22 Bed Temp\_70 - 12.78 Bed Temp\_80 |

## Contour plot for Tensile strength and Youngs modulus

The contour plot in Figure 6 shows the link between tensile strength and changes in bed and nozzle temperatures, with different shades of green representing different strength ranges. The deepest green shows the maximum tensile strength (more than 105.0), which occurs at lower nozzle temperatures (210°C-215°C) and higher bed temperatures (70°C-75°C). Tensile strength diminishes as the hues lighten: dark green (102.5-105.0), medium-dark green (100.0-102.5), and medium green (97.5-100.0) are found in mild temperature zones. Light green (95.0-97.5) and lightest green (less than 95.0) dominate areas with higher nozzle temperatures (225°C-230°C) and lower bed temperatures (60°C-65°C), suggesting that these circumstances produce the lowest tensile strength. This shows that a colder nozzle and warmer bed result in optimum strength, but departures from this equilibrium impair tensile performance. The "Contour Plot of figure 6 shows the Tensile Young's Modulus vs Bed Temp, Nozzle Temp" contour plot illustrates how TS-Young's modulus changes with respect to bed and nozzle temperatures.

Nozzle temperature (°C) ranges from 210°C to 230°C on the x-axis, while bed temperature (°C) ranges from 60°C to 80°C on the y-axis. The following ranges are used to depict the various hues of green that correspond to the TS-Young's modulus values: Less than 5370: Dark green,Between 5370 and 5400: Dark green,5400–5430: Green, medium-dark, 5460–5430: Mildly green.Between 5460 and 5490: Light green 5490: Extremely pale green. The observer is able to determine the modulus values based on colour intensity because the legend is properly stated. Whereas brighter green areas show greater Young's modulus values, darker green areas show lower values. The graphic sheds light on how variations in temperature during a procedure such as 3D printing might affect the final material's mechanical stiffness (modulus).

 

Figure 6: Contour plot for Tensile strength and Tensile Youngs modulus

# Conclusion

This study investigated the Taguchi technique was used to investigate the effects of nozzle temperature, bed temperature, and printing speed on the mechanical characteristics of 3D-printed 90% polycarbonate composites supplemented with 5% graphene and 5% carbon powder. Experimental results and statistical analysis reveal that the nozzle temperature is the most important factor determining both reactions. The signal-to-noise ratio (S/N) study revealed that for both tensile strength and Young's modulus, the nozzle temperature had the largest delta values (0.64 and 0.15, respectively), making it the primary factor in obtaining greater mechanical performance. Printing speed had the least effect in both circumstances. The ANOVA results confirmed these findings: for tensile strength, nozzle temperature explained 86.56% of the variation (P = 0.019), but bed temperature and printing speed were not statistically significant. Similarly, for Young's modulus, nozzle temperature explained 78.72% of the variance (P = 0.026), with other factors remaining insignificant. The regression models designed for both replies were very reliable. The correlation coefficients (R²) for tensile strength and Young's modulus were 98.35% and 97.89%, respectively, indicating a strong fit to experimental data. The corrected R² values (93.40% for tensile strength and 91.56% for modulus) demonstrate the model's robustness. However, the anticipated R² values (66.57% and 57.26%) show potential for improvement in prediction.

Contour plots confirmed that lower nozzle temperatures (about 210°C) and moderate bed temperatures (approximately 70°C) resulted in the maximum tensile strength (>105 MPa) and Young's modulus (≈5500 MPa). Deviating from these ideal thermal conditions, notably increasing nozzle temperature, resulted in lower mechanical performance. To summarize, regulating nozzle temperature is essential for improving the mechanical qualities of polycarbonate composite parts made with FDM. This study presents a statistically proven approach for optimizing critical 3D printing parameters to optimize part performance, with implications for high-strength, high-stiffness applications.

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