**Influence of Process Parameters on Mechanical Properties of 3D-Printed Polycarbonate/Basalt Fibre Composites Using Taguchi Design**

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**Abstract:** The aim of the research is to improve the mechanical characteristics of 3D-printed polycarbonate (PC) reinforced with 5% basalt fiber (BF) using Fused Deposition Modeling. Specimens were created using an Ultima Ker S5 Pro 3D printer, and mechanical testing was performed in accordance with ASTM D2240 for hardness and ASTM D695 for compression strength. A Taguchi L9 orthogonal array was used to assess the effects of three critical process parameters: nozzle temperature (200°C, 210°C, 220°C), bed temperature (60°C, 70°C, 80°C), and printing speed (15 mm/s, 20 mm/s, 25 mm/s). The experimental findings showed that nozzle temperature had the greatest influence on both hardness and compressive strength, as validated by ANOVA. The best parameter combination was discovered as 200°C nozzle temperature, 75-80°C bed temperature, and 20-25 mm/s printing speed, resulting in maximum hardness (88.5 Shore D) and compression strength (100 MPa). Regression models and contour plots were created to back up the findings and aid future process optimization for fiber-reinforced thermoplastic composites.

**Keywords:** Polycarbonate, Basalt fiber, ANOVA, Regression model, Parameters, Contour plot, Hardness and Compression.

# Introduction

Additive manufacturing is one of the fastest-growing technologies in the world. Basalt fiber is derived from volcanic rock and provides materials with high strength, fire resistance, sustainability, quality, and chemical resistance [1]. This material has the potential to provide better performance as a secondary material. This Basalt fiber consists primarily of very thermally stable elements [2]. As a result, basalt fiber is now used in a variety of industries to improve material toughness and strength. This Basalt fiber is pricey, and there is only a limited supply on the market [3]. This polycarbonate material is used to make laptops, home parts, and many other major components. Polycarbonate and basalt fiber have different applications and properties [4]. Both of these materials are well advanced in the material sector. The materials industry is primarily focused on merging primary and secondary materials to improve environmental hazard protection, heat resistance, road durability, and realistic materials to sustain strength [5]. As a result, the polycarbonate and basalt fiber merging combination filament is making tremendous progress in the materials industry [6]. The previous work did not discuss polycarbonate and basalt fiber merged combination printed samples for hardness and compression samples in accordance with ASTM standards [7]. Previous research is restricted in this study, as it only discusses polycarbonate and basalt fiber. Printing samples for the integrated polycarbonate and basalt combination is a tough undertaking [8]. Because 3D printing machines are generally damaging, many researchers are not focusing on this work to create Polycarbonate composite filament printing samples [9]. This is the most important reason for avoiding the researcher for this work. Nowadays, businesses are focusing on novel material combinations to improve the strength and durability of all materials [10]. Prior research did not go into depth regarding compression and hardness samples employing polycarbonate and basalt fiber merged composite filament printing samples to collect these two samples. This sample's printing job is restricted in this sector. According to the literature research, these two combined printing examples have generally good strength, resistance, and wear. This printing sample provides a significant benefit in terms of mechanical qualities while implementing the technique. The previous study did not include work on Taguchi analysis for PC merged printing samples. This work creates significant novelty, but no research has been conducted in this field. The earlier studies did not include polycarbonate and basalt fiber merged composite printed samples, which is the experiment's literature gap. They do not provide detailed information on the hardness and compression strength of the combined polycarbonate composite printed samples [8-13]. Prior research has shown limitations in this mix of work. Taguchi analysis was used to determine the hardness and compression of a printed polycarbonate and basalt fiber combination; prior studies had not done this. Prior studies did not include all of the optimization effort. This combination of work employing the Taguchi technique to calculate the signal-to-noise ratio, regression model, analysis of variance, and contour map does not provide an in-depth review of previous works [14-20]. This mix of work consists of 95% polycarbonate and 5% basalt fiber. Prior studies are not in-depth, and no work has been done in that time. One of the most cutting-edge material pairings is polycarbonate with basalt fiber. The prior study did not carry out this task. The earlier study only provides a few specifics about the mix of basalt fiber and polycarbonate. This combo work represents a significant innovation in the materials sector. One of the key components for improving the mechanical strength and quality is Taguchi analysis [21-25]. However, previous research does not provide a detailed explanation of this Taguchi analysis. These represent the study's gaps in the literature. Polycarbonate composite filament is the objective of this study. 95% polycarbonate and 5% basalt fiber make up this polycarbonate composite filament. In accordance with ASTM standards, this combined printed sample employs compression strength and hardness [26-32]. ASTM D2240 for hardness and ASTM D695 for compression strength are used in these printed samples. Both samples are being used in this ASTM standard. In these two samples, the Taguchi Optimization method was used to design the L9 experiment with three levels of parameters using the signal to noise response ratio, and obtain data for both compression and hardness. For this endeavor, more data is being collected. Analysis of variance is utilized to analyze the data, and for both compression strength and hardness, the coefficient of correlation is more than 95%. Only then do both coefficients of correlation provide the accurate values for compression strength and hardness. Only the Hardness and Compression values in this work are correct when the contribution value is primarily more than 1%. The regression equation must determine the relationship between hardness and compression values. Lastly, the contour plot displays the greatest color strength attained for both compression strength and hardness. Initially, the printing speed, bed temperature, and nozzle temperature are designed for L9 studies [33-36], with the maximum nozzle and bed temperature contributing to the improvement of the mechanical characteristics for this investigation. This Taguchi technique is assisting in lowering operating costs, labor costs, waste, and time consumption. It is capable of carrying out the number of operations. The maximum performance of both compression and hardness strength may be found using the Taguchi technique. Every stage of this Taguchi analysis offers a fresh perspective on the accomplishments. Every stage is a key component of our study project. Enhancing the process's mechanical strength and quality is the aim of the study. In order to reach the next level of success, this experimental effort focuses on the printed samples' strength, quality, stability, accuracy, ASTM Standards, and good bonding structure employing optimization techniques. One of the materials industry's greatest innovations is this work. The new strength of materials is the primary subject of this study. The Taguchi technique of additive manufacturing offers several benefits for developing future technologies [37-40].

# Materials and Methods

## Materials

In this experiment figure 1 (a and b) shows the printing sample for the combination of 95%Polycarbonate and 5% Basalt fibre. It uses an Ultima Ker S5 Pro bundle 3D printer to print the Hardness and Compression sample in this Hardness and Compression sample using ASTM standard . Compression sample ASTM standard is D695 and Hardness sample ASTM standard is **D2240**



(a)



(b)

**Figure 1: (a)**Polycarbonate Composite hardness samples: (b) **Polycarbonate composite Compression samples**

In this experiment, Table 1 shows the parameters and levels for Bed temperature, Nozzle temperature, and Printing speed. In this Bed, the temperature levels 1 to 3 are 60, 70, 80. Nozzle Temperature for levels 1 to 3 is 200, 210, and 220 degrees Celsius. Printing speed for Levels 1 to 3 is 15, 20, 25 mm/s. These parameters are used for designing these experiments.

**Table 1: Parameters and Levels**

|  |  |  |  |
| --- | --- | --- | --- |
| Factor | Type | Levels | Values |
| Bed Temp | Fixed | 3 | 60, 70, 80 |
| Nozzle Temp | Fixed | 3 | 200, 210, 220 |
| Printing speed | Fixed | 3 | 15, 20, 25 |

## ****Experimental design****

**In this work, table 2 shows the experimental design for 3 parameters for L9 Experiments. In Experiment 1, Bed temperature is 60 degrees Celsius, Nozzle temperature is 200 degree Celsius and Printing speed 15 mm/s [41-43] . In the Experiment 2, Bed temperature is 70 degree Celsius, Nozzle temperature is 200 degree Celsius and Printing speed is 20 mm/s . . Experiment 3, Bed temperature is 80 degree Celsius, Nozzle temperature is 200 degree Celsius and Printing speed is 25 mm/s . Experiment 4, Bed temperature is 70 degree Celsius, Nozzle temperature is 210 degree Celsius and Printing speed is 15 mm/s . . Experiment 5, Bed temperature is 80 degree Celsius, Nozzle temperature is 210 degree Celsius and Printing speed is 20 mm/s . Experiment 6, Bed temperature is 60 degree Celsius, Nozzle temperature is 210 degree Celsius and Printing speed is 25 mm/s . Experiment 7, Bed temperature is 80 degree Celsius, Nozzle temperature is 220 degree Celsius and Printing speed is 15 mm/s . Experiment 8, Bed temperature is 60 degree Celsius, Nozzle temperature is 220 degree Celsius and Printing speed is 20 mm/s . Experiment 9, Bed temperature is 70 degree Celsius, Nozzle temperature is 220 degree Celsius and Printing speed is 25 mm/s .**

**Table 2: Experimental design for 3 Parameters**

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment no | Bed Temp | Nozzle Temp | Printing speed |
| 1. | 60 | 200 | 15 |
| 2. | 70 | 200 | 20 |
| 3. | 80 | 200 | 25 |
| 4. | 70 | 210 | 15 |
| 5. | 80 | 210 | 20 |
| 6. | 60 | 210 | 25 |
| 7. | 80 | 220 | 15 |
| 8. | 60 | 220 | 20 |
| 9. | 70 | 220 | 25 |

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

**In this experiment Hardness strength sample and Compression strength sample . Both samples are following ASTM standard. In this** Compression sample, the ASTM standard is D695, and **in the** Hardness sample, the ASTM standard is **2240.** In this ASTM standard, the goal is to increase the accuracy of the design structure and stability.

# ****Result and discussion****

## Taguchi analysis

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Experiment no** | **Nozzle Temp** | **Printing speed** | **Bed Temp** | **Hardness** | **Compression** | **S/N ratio for Hardness** | **S/N ratio for Compression** |
| 1. | 200 | 15 | 60 | 86.8 | 98 | 38.7703945 | 39.82452151 |
| 2. | 200 | 20 | 70 | 87.9 | 99 | 38.8797775 | 39.91270389 |
| 3. | 200 | 25 | 80 | 88.5 | 100 | 38.9388654 | 40 |
| 4. | 210 | 15 | 70 | 85.9 | 97 | 38.6798633 | 39.73543469 |
| 5. | 210 | 20 | 80 | 84.2 | 96 | 38.5062418 | 39.64542466 |
| 6. | 210 | 25 | 60 | 83.3 | 95 | 38.4129 | 39.55447211 |
| 7. | 220 | 15 | 80 | 82.2 | 90 | 38.2974364 | 39.08485019 |
| 8. | 220 | 20 | 60 | 81.4 | 92 | 38.2124881 | 39.27575655 |
| 9. | 220 | 25 | 70 | 80.9 | 93 | 38.1589704 | 39.36965897 |

Table 3 presents the L9 experimental results for hardness, compression strength, signal-to-noise ratios [44-48], and FITS values using the Taguchi orthogonal array. At a nozzle temperature of 200 °C, the first three experiments showed higher hardness values and steadily improving compression strength. Experiment 1 (200 °C, 15 mm/s, 60 °C bed) produced a hardness of 86.8 D shore and compression strength of 98 MPa, with S/N ratios of 38.77 and 39.82. Increasing the speed and bed temperature to 20 mm/s and 70 °C in Experiment 2 improved hardness to 87.9 D shore and compression to 99 MPa, with higher S/N ratios of 38.87 and 39.91. At Experiment 3 (25 mm/s, 80 °C bed), hardness peaked at 88.5 D shore and compression reached 100 MPa, with S/N ratios of 38.93 and 40.0. These results indicate that at 200 °C nozzle temperature, increasing speed and bed temperature enhanced both hardness and compression performance.

Table 3: Experimental design using orthogonal array for Hardness and compression

When the nozzle temperature was raised to 210 °C, a decline in hardness and compression strength was observed. Experiment 4 (15 mm/s, 70 °C bed) showed hardness of 85.9 D shore and compression of 97 MPa, while Experiment 5 (20 mm/s, 80 °C bed) further decreased to 84.2 D shore and 96 MPa. At Experiment 6 (25 mm/s, 60 °C bed), hardness dropped to 83.3 D shore and compression to 95 MPa. The decline became more significant at 220 °C nozzle temperature, where Experiment 7 (15 mm/s, 80 °C bed) showed hardness of 82.2 D shore and compression of 90 MPa, while Experiment 8 (20 mm/s, 60 °C bed) recorded hardness of 81.4 D shore and compression of 92 MPa. The lowest values occurred at Experiment 9 (25 mm/s, 70 °C bed), where hardness was 80.9 D shore and compression strength 93 MPa. These results confirm that while 200 °C favors maximum hardness and compression, increasing nozzle temperature to 210–220 °C results in a progressive decline in mechanical properties, likely due to thermal softening and weaker interlayer bonding.

## Hardness and Compression signal to noise ratio

### Hardness

Table 4: Hardness for signal to noise ratio

|  |  |  |  |
| --- | --- | --- | --- |
| **Level** | **Nozzle Temp** | **Printing speed** | **Bed Temp** |
| 1 | 38.86 | 38.58 | 38.47 |
| 2 | 38.53 | 38.53 | 38.57 |
| 3 | 38.22 | 38.50 | 38.58 |
| Delta | 0.64 | 0.08 | 0.12 |
| Rank | 1 | 3 | 2 |

The Hardness signal to noise ratio is shown in Table 4 of this experiment. Level 1 indicates that the nozzle temperature is 38.86 degrees Celsius, the printing speed is 38.58 mm/s, and the bed temperature is 38.47 degrees Celsius. Level 2 indicates that the nozzle temperature is 38.53 degrees Celsius, the printing speed is 38.53 mm/s, and the bed temperature is 38.57 degrees Celsius. Level 3 reveals that the nozzle temperature is 38.22 degrees Celsius, the printing speed is 38.50 mm/s, and the bed temperature is 38.58 degrees Celsius.

In this experiment, figure 2 shows the Hardness main effect map for three parameters. The nozzle temperature delta is 0.64, indicating the highest rank, whereas the bed temperature delta is 0.12. The printing speed delta is the lowest, at 0.08.



Figure 2: SN ratio for Hardness

### Compression

The Compression signal to noise ratio is shown in Table 5 of this experiment. Level 1 indicates that the nozzle temperature is 39.91 degrees Celsius, the printing speed is 39.55 mm/s, and the bed temperature is 39.55 degrees Celsius. Level 2 indicates that the nozzle temperature is 39.65 degrees Celsius, the printing speed is 39.61 mm/s, and the bed temperature is 39.67 degrees Celsius. Level 3 reveals that the nozzle temperature is 39.24 degrees Celsius, the printing speed is 39.64 mm/s, and the bed temperature is 39.58 degrees Celsius.

Table 5: Compression response table for signal to noise ratio

|  |  |  |  |
| --- | --- | --- | --- |
| **Level** | **Nozzle Temp** | **Printing speed** | **Bed Temp** |
| 1 | 39.91 | 39.55 | 39.55 |
| 2 | 39.65 | 39.61 | 39.67 |
| 3 | 39.24 | 39.64 | 39.58 |
| Delta | 0.67 | 0.09 | 0.12 |
| Rank | 1 | 3 | 2 |

In this experiment, figure 3 shows the Compression main effect map for three parameters. The nozzle temperature delta is 0.67, indicating the highest rank, whereas the bed temperature delta is 0.12. The printing speed delta is the lowest, at 0.09.



Figure 3: SN ratio for Compression

## Analysis of Variance (ANOVA)

### Hardness

In this experiment, Table 6 shows the Hardness Analysis of Variance. In this table, Nozzle temperature, Printing speed, and Bed temperature are important factors, and Error is also an important factor. DF value for this four-source is 8, Seq. SS for this four-source is 64.16, Contribution for this four-source is 100.00%. Hardness model summary shows the coefficient of correlation is 95.98%, S is 1.135, R-sq (adj) is 83.92%, PRESS is 52.245, and R-Sq(pred) is 18.57%.

Table 6: Analysis of VarianceforHardness

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Seq SS** | **Contribution** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
| **Nozzle Temp** | 2 | 58.3267 | 90.91% | 58.3267 | 29.1633 | 22.61 | 0.042 |
| **Printing speed** | 2 | 0.8267 | 1.29% | 0.8267 | 0.4133 | 0.32 | 0.757 |
| **Bed Temp** | 2 | 2.4267 | 3.78% | 2.4267 | 1.2133 | 0.94 | 0.515 |
| **Error** | 2 | 2.58 | 4.02% | 2.58 | 1.29 |  |  |
| **Total** | 8 | 64.16 | 100.00% |  |  |  |  |

In this work, Figure 4 shows the Hardness Residual plots, the Normal probability plot displaying the standardized residual percentage level, and the Versus Fits displaying the standardized residual fitted value. The Histogram depicts the standardized residual frequency wave, while the versus order depicts the observation order for standardized residual. These are the residual graphs for hardness.



Figure 4: Hardness Residual plots

### Compression

In this experiment, table 7 shows the Analysis of Variance for compression. In this table, Nozzle temperature, Printing speed, bed temperature, and error are important factors. DF value for this four-source is 8, Seq. SS for this four-source is 90.222. Contribution for this four-source is 100.00%. Compression model summary shows the coefficient of correlation is 95.32%, S is 1.452, R-sq(adj) is 81.28%, PRESS is 85.5, and R-Sq(pred) is 5.23%.

In this work, Figure 5 depicts the Compression Residual plots, the Normal Probability plot displaying the standardized residual percentage level, and the Versus Fits exhibiting the standardized residual fitted value. The histogram represents the standardized residual frequency wave, whereas the order versus the standardized residual depicts the standardized residual's observation order. Here are the residual graphs for Compression.

Table 7: ANOVA for Compression

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | **DF** | **Seq SS** | **Contribution** | **Adj SS** | **Adj MS** | **F-Value** | **P-Value** |
| **Nozzle Temp** | 2 | 81.556 | 90.39% | 81.556 | 40.7778 | 19.32 | 0.049 |
| **Printing speed** | 2 | 1.556 | 1.72% | 1.556 | 0.7778 | 0.37 | 0.731 |
| **Bed Temp** | 2 | 2.889 | 3.20% | 2.889 | 1.4444 | 0.68 | 0.594 |
| **Error** | 2 | 4.222 | 4.68% | 4.222 | 2.1111 |  |  |
| **Total** | 8 | 90.222 | 100.00% |  |  |  |  |



Figure 5: Compression Residual Plots

## Regression model

### Hardness

Base hardness: 84.567 (constant value when all variables are at baseline/reference).Nozzle temperature: At 200°C, hardness increases significantly by +3.167.At 210°C, hardness decreases somewhat (-0.100).At 220°C, a significant reduction of −3.067. The best hardness is attained around 200°C, whereas 220°C has a detrimental effect. Printing Speed: 15 mm/s results in a little improvement (+0.400).Hardness is reduced somewhat at rates of 20 and 25 mm/s. Bed temperature of 60°C lowers hardness (-0.733), 70 °C and 80°C marginally increase hardness. Hardness improves the greatest at 200°C nozzle temperature, 15 mm/s speed, and bed temperatures more than 60°C. Higher nozzle temperatures (particularly 220°C) and a bed temperature of 60°C reduce hardness.

Regression Equation for Hardness

|  |  |  |
| --- | --- | --- |
| Hardness | = | 84.567 + 3.167 Nozzle Temp\_200 - 0.100 Nozzle Temp\_210 - 3.067 Nozzle Temp\_220 + 0.400 Printing speed\_15 - 0.067 Printing speed\_20 - 0.333 Printing speed\_25 - 0.733 Bed Temp\_60 + 0.333 Bed Temp\_70 + 0.400 Bed Temp\_80 |

### Compression

The base compression value is 95.556. The highest boost (+3.444) is achieved with a nozzle temperature of 200°C. 210 °C results in a slight increase (+0.444). 220 °C greatly lowers strength (-3.889). The best strength is achieved at 200°C; avoid 220°C.Printing at 15 mm/s somewhat lowers strength.20 mm/s and 25 mm/s enhance it little. Bed Temperature: 60°C reduces strength. 70°C provides the greatest rise (+0.778). 80 °C marginally lowers it. The greatest compression strength is achieved using a 200°C nozzle, a speed of 25 mm/s, and a bed temperature of 70°C. Again, the 220°C nozzle and 60°C bed temperature are deleterious.

|  |  |  |
| --- | --- | --- |
| Compression | = | 95.556 + 3.444 Nozzle Temp\_200 + 0.444 Nozzle Temp\_210 - 3.889 Nozzle Temp\_220 - 0.556 Printing speed\_15 + 0.111 Printing speed\_20 + 0.444 Printing speed\_25 - 0.556 Bed Temp\_60 + 0.778 Bed Temp\_70 - 0.222 Bed Temp\_80 |

## Contour plot for Hardness and Compression

The contour figure 6 shows that polycarbonate composite printed sample hardness rises with lower nozzle temperatures and higher bed temperatures. The deepest green zone, indicating the maximum hardness (>88), emerges at nozzle temperatures of 200°C and bed temperatures ranging from 75 to 80°C. The lightest green regions with the lowest hardness (<82) are seen at higher nozzle temperatures (215-220°C) and lower bed temperatures (60-65°C). This suggests that printing at a lower nozzle temperature and a higher bed temperature results in optimal hardness.



Figure 6: Contour plot for Hardness

Figure 7 shows the link between polycarbonate composite printed samples' compression strength and two important 3D printing parameters: nozzle temperature (x-axis) and bed temperature (y-axis). The colour gradient progresses from dark blue (lowest compression, <90) to dark green (maximum compression, >100).The highest compression values (>100, dark green) are obtained at a nozzle temperature of 200°C and bed temperatures of 75-80°C. As the nozzle temperature exceeds 210°C, compression strength declines progressively, reaching its lowest values (<90, dark blue) at 220°C, particularly at higher bed temperatures.



Figure 7: Contour plot for Compression

# Conclusion

This study investigated the effect of key FDM process parameters—nozzle temperature, bed temperature, and printing speed—on the mechanical performance of polycarbonate reinforced with 5% basalt fibre. Using an L9 Taguchi orthogonal array and ASTM D2240 and D695 standards for hardness and compression testing, the research revealed that nozzle temperature had the most significant impact on both properties. ANOVA analysis confirmed this with a contribution of over 90% for both hardness and compression strength, and statistically significant p-values. The optimal mechanical performance was achieved at a nozzle temperature of 200°C, bed temperature of 75–80°C, and printing speed between 20–25 mm/s, resulting in a maximum hardness of 88.5 Shore D and compression strength of 100 MPa. The regression models fit the experimental data for both Hardness and compression samples well (R² > 95%), but the small sample size limited the predictive values. Contour plots clearly supported these findings by demonstrating that lower nozzle temperatures and higher bed temperatures consistently delivered superior outcomes. Overall, this work presents a realistic process window for improving the structural characteristics of 3D-printed PC+BF composites while emphasizing the importance of temperature factors in FDM-based composite fabrication. Future study might involve investigating larger fibre loadings and real-time process monitoring.

# References

1. Anand et al., (2024). A comprehensive analysis of small-scale building integrated photovoltaic system for residential buildings: Techno-economic benefits and greenhouse gas mitigation potential. Journal of Building Engineering, 82, 108232.
2. Huang, M., Liu, H., Xiang, Q., & Zhang, Y. (2025). Surface modification of basalt fiber using to reinforce polycarbonate composites and its mechanical performance. *Polymer Composites*, *46*(7), 6059-6069.
3. Grosious et al., (2024, June). Utilizing 3D printing in marine industries: innovations for enhanced ship and boat production. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 132-143). SPIE.
4. Andrzejewski, J., Danielak, A., Piasecki, A., Islam, A., & Szostak, M. (2023). Biocarbon-based sustainable reinforcing system for technical polymers. The structure-properties correlation between polycarbonate (PC) and polybutylene terephthalate (PBT)-based blends containing acrylonitrile-butadiene-styrene (ABS). *Sustainable Materials and Technologies*, *36*, e00612.
5. Grosious et al., (2024, June). Advancements in automotive production: exploring the role of 3D printing and selective laser sintering. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 403-415). SPIE.
6. Zapornikov, V. A., Osipchik, V. S., Red'kina, A. A., Zakharov, D. B., Mishurova, M. V., & Kravchenko, T. P. (2015). Investigation of the structural and strength characteristics of modified polycarbonate. *International Polymer Science and Technology*, *42*(7), 15-20.
7. Jiang, Q., Xu, P., Feng, J., & Sun, M. (2020). Application of covalent organic porous polymers-functionalized basalt fibers for in-tube solid-phase microextraction. *Molecules*, *25*(24), 5788.
8. Grosious et al., (2024, June). Impact of additive manufacturing on sports safety prevention and performance enhancement: a review. In International Conference on Medical Imaging, Electronic Imaging, Information Technologies, and Sensors (MIEITS 2024) (Vol. 13188, pp. 46-56). SPIE.
9. R. Anand, and S. Santhosh Kumar. Optimization of process parameters in TIG welding of AISI 4140 stainless steel using Taguchi technique. Materials today: proceedings 37 (2021): 1550-1553.
10. Balaji, S., Bharathiraja, G., Kaliappan, S., Veeman, D., & Mammo, W. D. (2021). Experimental investigation on mechanical properties of TiAlN thin films deposited by RF magnetron sputtering. Journal of Nanomaterials, 2021(1), 5943486.
11. Seeniappan and Neha Garg. Checking and supervisory system for calculation of industrial constraints using embedded system. 2023 4th International Conference on Smart Electronics and Communication (ICOSEC). IEEE, 2023.
12. C. Angalaparameswari et al. Effective Utilization of Bast Fiber in High Density Polyethylene Nanocomposite Enriched by Alumina Nanoparticle: Mechanical Performance Evaluation. Journal of The Institution of Engineers (India): Series D, pp.1-5.
13. D. Dillikannan et al. 2024. An Approach of Nano-SiC-Filled Epoxy Nanocomposite Tensile and Flexural Strength Enriched by the Addition of Sisal Fiber. Journal of The Institution of Engineers (India): Series D, pp.1-5.
14. Selvi, S., et al. Optimization of solar panel orientation for maximum energy efficiency. 2023 4th International Conference on Smart Electronics and Communication (ICOSEC). IEEE, 2023.
15. Sai, Samavedam Aditya, et al. Transfer learning based fault detection for suspension system using vibrational analysis and radar plots. Machines 11.8 (2023): 778.
16. S. Baskar 2022, July. Thermal management of solar thermoelectric power generation. In AIP conference proceedings (Vol. 2473, No. 1). AIP Publishing.
17. P. Sakthivel et al. Synthesis and Thermal Adsorption Characteristics of Silver-Based Hybrid Nanocomposites for Automotive Friction Material Application. Adsorption Science & Technology, 2023.
18. Chennai Viswanathan, Prasshanth, et al., Deep learning for enhanced fault diagnosis of monoblock centrifugal pumps: Spectrogram-based analysis. Machines 11.9 (2023): 874.
19. C. Devanathan et al. 2024. Significance of Hemp Fiber on Mechanical and Thermal Performance of Polypropylene Nanocomposite Developed by Compression Mould Technique. Journal of The Institution of Engineers (India): Series D, pp.1-5.
20. C. B. Priya et al. "Bio-degradable waste banana and neem fiber reinforced epoxy hybrid composites: characteristics study." Journal of Mechanical Science and Technology 38, no. 4 (2024): 1891-1896. <https://doi.org/10.1007/s12206-024-0322-7>
21. M. Aruna et al. "Alkali-Processed Flax Natural Made High-Density Polyethylene Waste Recycled Composites: Performance Evaluation." Journal of The Institution of Engineers (India): Series D (2024): 1-5. <https://doi.org/10.1007/s40033-024-00739-z>
22. Pethuraj Manickaraj, and V. Sakthi Murugan. "Featuring with Nano Alumina Made Hybrid Epoxy/Carbon Fiber Nanocomposite: Performance Evaluation." Journal of The Institution of Engineers (India): Series D (2024): 1-5. <https://doi.org/10.1007/s40033-024-00754-0>
23. De Poures, Melvin Victor et al. "Sodium Hydroxide Processed Natural Sisal Fiber Made Polypropylene Composite: Characteristics Evaluation." Journal of The Institution of Engineers (India): Series D (2024): 1-5. <https://doi.org/10.1007/s40033-024-00761-1>
24. Vaishali, Kokila R., et al., Guided container selection for data streaming through neural learning in cloud. International Journal of System Assurance Engineering and Management (2021): 1-7.
25. Yogeshwaran, S., et al., Experimental investigation on mechanical properties of epoxy/graphene/fish scale and fermented spinach hybrid bio composite by hand lay-up technique. Materials Today: Proceedings 37 (2021): 1578-1583.
26. Khimsuriya, Yogeshkumar D., et al., Artificially roughened solar air heating technology–A comprehensive review. Applied Thermal Engineering 214 (2022): 118817.
27. Kumar, M. Senthil, et al., Experimental investigations on mechanical and microstructural properties of Al2O3/SiC reinforced hybrid metal matrix composite. IOP Conference Series: Materials Science and Engineering. Vol. 402. No. 1. IOP Publishing, 2018.
28. Josphineleela, R., and Upendra Mohan Bhatt. Intelligent Virtual Laboratory Development and Implementation using the RASA Framework. 2023 7th International Conference on Computing Methodologies and Communication (ICCMC). IEEE, 2023.
29. Suman, Turpati, et al., IoT based Social Device Network with Cloud Computing Architecture. 2023 Second International Conference on Electronics and Renewable Systems (ICEARS). IEEE, 2023.
30. S. Kaliappan. Mechanical Assessment of Carbon–Luffa Hybrid Composites for Automotive Applications. No. 2023-01-5070. SAE Technical Paper, 2023.
31. Muralidaran, V. Manivel, et al., Grape stalk cellulose toughened plain weaved bamboo fiber-reinforced epoxy composite: load bearing and time-dependent behavior. Biomass Conversion and Biorefinery 14.13 (2024): 14317-14.
32. K. Logesh et al. "Performance investigation of silicon nitride (SiNx) layer doped with twin thin films of gallium and zinc oxide for solar cell." Optical and Quantum Electronics 56, no. 7 (2024): 1-13.<https://doi.org/10.1007/s11082-024-07100-4>
33. R. Karthik et al. "Characteristics performance evaluation of AZ91-fly ash composite developed by vacuum associated stir processing." International Journal of Cast Metals Research (2024): 1-8.<https://doi.org/10.1080/13640461.2024.2364129>
34. Kaliappan, S., and Akshay Rajput. Sentiment Analysis of News Headlines Based on Sentiment Lexicon and Deep Learning. 2023 4th International Conference on Smart Electronics and Communication (ICOSEC). IEEE, 2023.
35. L. Kamaraj et al. 2024. Fabrication and Behavior Study of Natural Fiber Utilized Low-Density Polyethylene Nanocomposite via Injection Mold. Journal of The Institution of Engineers (India): Series D, pp.1-5.
36. Paranthaman et al., Influence of SiC particles on mechanical and microstructural properties of modified interlock friction stir weld lap joint for automotive grade aluminium alloy. Silicon 14.4 (2022): 1617-1627.
37. Sureshkumar, P., et al., Electrochemical corrosion and tribological behaviour of AA6063/Si3N4/Cu (NO3) 2 composite processed using single-pass ECAPA route with 120 die angle. Journal of Materials Research and Technology 16 (2022): 715-733.
38. M. Senthil Kumar. Influence of silicon carbide on tribological behaviour of AA2024/Al2O3/SiC/Gr hybrid metal matrix squeeze cast composite using Taguchi technique. Materials Research Express 6.12 (2020): 1265f9.
39. P. Sakthivel et al. Mechanical and thermal properties of a waste fly ash-bonded Al-10 Mg alloy composite improved by bioceramic silicon nanoparticles. Biomass Conversion and Biorefinery, pp.1-12.
40. A. Baraniraj et al. 2023. Silicon Carbide Particle Enriched Magnesium Alloy (AZ91) Composite: Physical, Microstructural and Mechanical Studies. Silicon, 15(15), pp.6367-6374.
41. M. V. Kumar et al. 2024. Development of Low-Density Polyethylene Nanocomposite with CNT Fibre Via Injection Moulding: Performance Study. Journal of The Institution of Engineers (India): Series D, pp.1-5.
42. P. Chandramohan et al. Processing and Characteristics Evaluation of Polyester Resin Nanocomposite Synthesized with Natural Fiber. Journal of The Institution of Engineers (India): Series D, pp.1-5.
43. V. Vijayan et al. 2016. Performance Evaluation of Multipurpose Solar Heating System. Mechanics & Mechanical Engineering, 20(4).
44. I. J. Isaac Premkumar et al. Combustion analysis of biodiesel blends with different piston geometries. Journal of Thermal Analysis and Calorimetry, 142(4), pp.1457-1467.
45. M. Vivekanandan et al. 2021. Experimental and CFD investigation of helical coil heat exchanger with flower baffle. Materials Today: Proceedings, 37, pp.2174-2182.
46. V. Vijayan et al. CFD modeling and analysis of a two-phase vapor separator. Journal of Thermal Analysis and Calorimetry, 145(5), pp.2719-2726.
47. Yogeshwaran, S., et al. Mechanical properties of leaf ashes reinforced aluminum alloy metal matrix composites. International Journal of Applied Engineering Research 10.13 (2015): 11048-11052.
48. M. Senthil Kumar, and Mukesh Chaudhari. Optimization of squeeze casting process parameters to investigate the mechanical properties of AA6061/Al2O3/SiC hybrid metal matrix composites by taguchi and anova approach. Advanced Engineering Optimization Through Intelligent Techniques: Select Proceedings of AEOTIT 2018. Singapore: Springer Singapore, 2019. 393-406