Sustainable Compositions and 3D Printing Technologies for Characterizing and Optimizing Recycled PETG

Ved Prakash Mishra[1], *Nibras* Hayder[2], *G V V* Satyanarayana[3], *Uma* Reddy[4*], *Sorabh* Lakhanpal[5], *Ankit* Meheta[6], *Yelamasetti* Balram[7]

[1]Department of Civil Engineering, IES College of Technology, Bhopal, Madhya Pradesh, India.
[2]Hilla University College, Babylon, Iraq.
[3]Department of Civil, GRIET, Bachupally, Hyderabad, Telangana, India.
[4]Department of Artificial Intelligence and Machine Learning, New Horizon College of Engineering, Bangalore, India
[5]Lovely Professional University, Phagwara, India.
[6]Lloyd Institute of Engineering & Technology, Knowledge Park II, Greater Noida, Uttar Pradesh, India.
[7]Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, Telangana, India-500059

Abstract. The packing industry makes extensive use of terephthalate polyesters because of their chemical durability and optical qualities. Examples of these materials are polyethylene terephthalate (PET) and glycol-modified PET (PETG). They also supply building materials, medical technology, technical polymers, and the textile sector. PET is made of terephthalic acid as well as ethylene glycol, whereas 30% of the diol moles in PETG are replaced with CHDM during synthesis. Detailed structural analyses of polyethylene terephthalate glycol-modified (PETG) are presented in this study. In two directions, PETG square blocks were tested with a load of 12,200 N to determine their durability and mechanical response. This block experienced a total deformation of 0.2318 mm under vertical loading, with the outer layer experiencing 33.93 MPa, and the middle layer experiencing 23.148 MPa. According to its performance under vertical stress, PETG had a maximum fatigue life of approximately 572,540 cycles and a minimal safety factor of 0.035116. A deformation of 0.23192 mm was recorded under horizontal loading. The bottom layer had a stress of 46.317 MPa and the top layer had a stress of 20.174 MPa, with a better fatigue life of 616,880 cycles and a safety factor of 0.35979.

Keyword-: 3D printing, PETG, square blocks, simulation, optimization, manufacturing.

1 Introduction

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[*] Corresponding Author : nvumareddy@gmail.com

The need for the materials utilized also grows as printing technology advances. At first, 3D printing was intended to be limited to small-scale production and product prototype [1-4]. Modern industrial 3D printers are also being progressively integrated into manufacturing facilities, along with improved materials for 3D printing [5-7]. Products made with a 3D printer are manufactured using materials that can temporarily replace destroyed parts of the equipment until the original accessories are received, in the event of a machine failure throughout production. The method of reusing printed foils consisting of ethylene terephthalate (PETG) [8], or glycol-modified polymer, after consumption. The foils are made into regranulate PETG pellets and are composed of PETG and PS layers. With the addition of new PETG, three different kinds of PETG/r PETG blends were created in [9], demonstrating their homogeneity and raising the PETG degradation temperatures [10-12]. Comparative tensile strengths and a Young's modulus were shown through mechanical study. T Chen examined the process of degradation of poly (ethylene glycol-co-1,4-cyclohexanedimethanol terephthalate) (PETG) random copolymers with varying 1,4-cyclohexanedimethanol (CHDM) concentration in [13] as well as the impact of copolymer compositions on photo degradation behavior. With a rise in CHDM material, PETG copolymers' photo oxidation rate rose along with the degree of crosslinking that was achieved. The research presented in [14-17] details the creation of fluorescent poly (urea-formaldehyde) microcapsules that are integrated into various polymers and contain formulations of a solvatochromic cyanostilbene dye. The color of the fluorescence changes when an item composed of these composites is destroyed because the dye solution is liberated, diffuses into the matrix, and evaporates [18]. Using additive manufacturing technologies, surfing as a competitive activity may be enhanced. Designing, prototyping, and testing 3D printed surfboard fins with integrated sensors that connect with a configured surfboard prototype was the goal of the study in [19]. The objective was to build six equipped fins and 101 rectangular samples, modify a 3D printer to manufacture carbon fiber composites [20-23], and create molds and instruments for data gathering and mechanical analysis. Some of the following items have been produced: a touch probe, fin mould, mould for rectangle-shaped samples, router templates, and a Shimadzu EZ-S mechanically based analyzer adaptor [24-26]. The Shimadzu EZ-S during lockdowns demonstrated tenfold worse accuracy in determining flexural modulus than did the epidemic tool [12]. The impact of production factors on the mechanical characteristics of PETG components produced by the Fusion Deposition Modelling (FDM) method was evaluated in a research published in [27-30]. A 2^4 factorial design with established levels for each manufacturing industries variable was used in the study in [31], and the ASTM D638-10 standard was followed in the modelling and construction of the test specimens [32-334]. With the use of statistical software, the data were statistically examined using Analysis of Variance (ANOVA) [335]. Composite materials of conductive carbon nanotubes and poly (ethylene terephthalate glycol modified) [17] (SWCNT/PETG) were created by sonication-assisted in situ polymerization [36]. The thin films were characterized by dielectric spectroscopy and electron microscopy, respectively, which showed well-dispersed nanotubes along with amorphous films with a distinct insulator-to-conductor transition [37].

2 Methodology of 3d Printing Block Printing

Engineers may now more easily develop and produce prototypes and mock-ups more quickly than ever before like 3D printing. Editing is simple and can be done fast, which is best of all. It may be able to replace traditional manufacturing technologies with very accurate 3D printing. In the present work square block of 25 mm x 25 mm x 25 mm has been used to perform structural, fatigue and model analysis for different types of 3D printing materials such as PEGT. Fig.1 outlines the workflow for finite element analysis (FEA), which begins with CAD Modeling the creation of a geometric model of an object. This model is then assigned Material Properties describing its physical properties. Boundary load conditions are used to simulate real-world capacities and constraints. In the Finite Element Analysis (FEA) phase, these algorithms are used to partition the problem into manageable elements and to calculate stresses, strains, and strains. Finally, the interpretation of the results examines these results to assess the performance of the products under expected conditions. This process is technically necessary to ensure that the designs are feasible and meet safety standards prior to construction

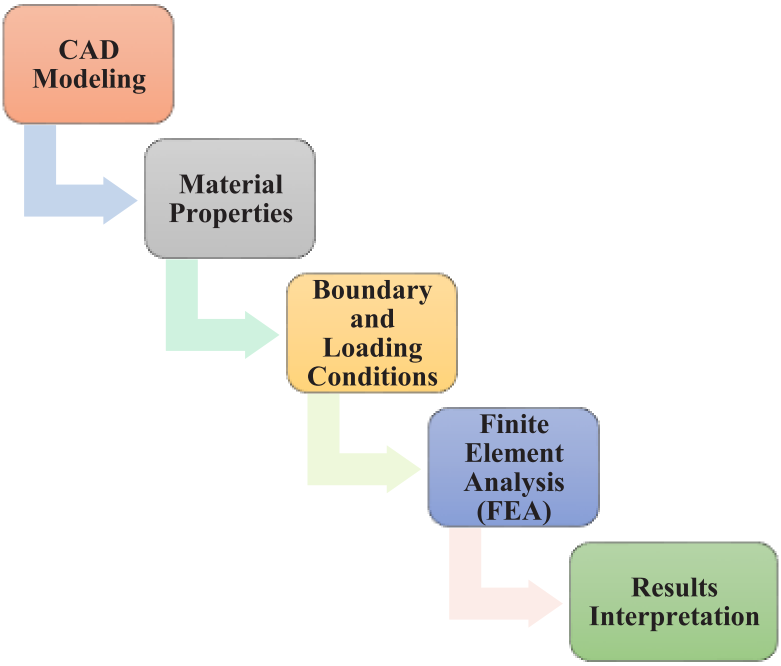

Fig. 1: Proposed methodology flow chart

In the present work finite element analysis have been conducted on Simple structure of square block with dimensional parameter 25 mm x 25 mm x 25 mm, this FEM analysis includes compression test using static structural analysis, fatigue analysis and model analysis. The total deformation and equivalent stress layer wise have been found by compression test, whereas the design life and safety factor of the material is determined by the fatigue analysis and the natural frequency of the square block has been found in the modal analysis.

3 Result and Discussion

In the present work finite element analysis have been conducted on Simple structure of square block with dimensional parameter 25 mm x 25 mm x 25 mm, this FEM analysis includes compression test using static structural analysis, fatigue analysis and model analysis. The total deformation and equivalent stress layer wise have been found by compression test, whereas the design life and safety factor of the material is determined by the fatigue analysis and the natural frequency of the square block has been found in the modal analysis. For the compressive test perform structural analysis by keep lower side fixed and apply a compressive load of 12200 N on top layer of the square block. Check fatigue life and safety factor by using fatigue tool and for the natural frequencies need to perform model analysis with six possible modes.

3.1 Structure analysis of square block for PETG at 12200 N applied in vertical direction

3.1.1 Total Deformation: -

After performing compression test structural analysis on square block for PETG at 12200 N applied in vertical direction, the total deformation of 0.2318 mm has been observed as shown in Table 1. After performing compression test structural analysis on square block for PETG at 12200 N applied in vertical direction, the equivalent stress ranging from 33.93 Mpa at outer layer to 23.148 Mpa of at middle layer of square block has been observed in Table 1.

3.1.2 Fatigue analysis: -

After performing fatigue analysis on square block for PETG at 12200 N applied in vertical direction, the maximum fatigue life of 5.7254E+5 total number of cycles before fatigue causes the component to fail at the corner of the square block has been observed as shown in Table 1. After performing fatigue analysis on square block for PETG at 12200 N applied in vertical direction, the minimum safety factor of 0.035116 regarding a fatigue breakdown during a specific design life at the corner of the square block has been observed as shown in Table 1. Values less than one that indicates failure prior to the end of the design life.

Table 1: Comparative analysis of square block for PETG at 12200 N applied in vertical direction

Parameter	Description	Minimum Value	Maximum Value
Total Deformation	Deformation under vertical load (mm)	0 mm	0.2318 mm
Fatigue Life	Cycles until failure under vertical load	0.005724 cycles	5.7254E+5 cycles
Safety Factor	Factor of safety against vertical fatigue failure	0.035116	0.24562

After performing fatigue analysis on square block for PETG at 12200 N applied in vertical direction, the maximum available life of 4081.6 cycle on Log-Log scaling with respect to a fatigue failure at a given design life has been observed.

3.2 Structure analysis of square block for PETG at 12200 N applied in horizontal direction

3.2.1 Total Deformation

After performing compression test structural analysis on square block for PETG at 12200 N applied in horizontal direction, the total deformation of 0.23192 mm has been observed as shown in Table 2. After performing compression test structural analysis on square block for PETG at 12200 N applied in horizontal direction, the equivalent stress ranging from 46.317 Mpa at bottom layer to 20.174 Mpa of at top layer of square block has been observed in Table 2.

3.2.2 Fatigue analysis

After performing fatigue analysis on square block for PETG at 12200 N applied in horizontal direction, the maximum fatigue life of 6.1688E+5 numbers of cycles until the part will fail due to fatigue at the corner of the square block has been observed as shown in Table 2.

Table 2: Comparative analysis of square block for PETG at 12200 N applied in horizontal direction

Parameter	Description	Minimum Value	Maximum Value
Total Deformation	Deformation under horizontal load (mm)	0 mm	0.23192 mm
Fatigue Life	Cycles until failure under horizontal load	0 cycles	6.1688E+5 cycles
Safety Factor	Factor of safety against horizontal fatigue failure	0.035979	0.25166

The maximum fatigue life as inferred from the analysis was found to be approx. 6.1688E+5. After performing fatigue analysis on square block for PETG at 12200 N applied in horizontal direction, the minimum safety factor of 0.035979 regarding fatigue failure at a provided design life at the corner of the square block has been observed as shown in Table 2 Values less than one that indicates failure prior to the end of the design life**.** After performing fatigue analysis on square block for PETG at 12200 N applied in horizontal direction, the minimum available life of 3962 cycle on Log-Log scaling regarding to a fatigue breakdown at a given design life has been observed.

4 Comparative Results

The mechanical performance of Polyethylene Terephthalate Glycol (PETG) below one of a loading situations is detailed through a series of measurements and comparisons, illustrated within the provided tables and figures. Table 3 gives the maximum equivalent stress results for PETG, with the material experiencing 33.93 MPa beneath vertical loading and barely higher pressure of 39.93 MPa below horizontal loading, as visually represented in Fig. 1. This shows a notable resilience of PETG, with a better pressure tolerance in the horizontal orientation.

Table 3: Comparative result of maximum equivalent stress for PETG

Materials	**PETG**
Maximum equivalent stress at load on vertical Layer [MPa]	33.93
Maximum equivalent stress at load on horizontal Layer [MPa]	39.93

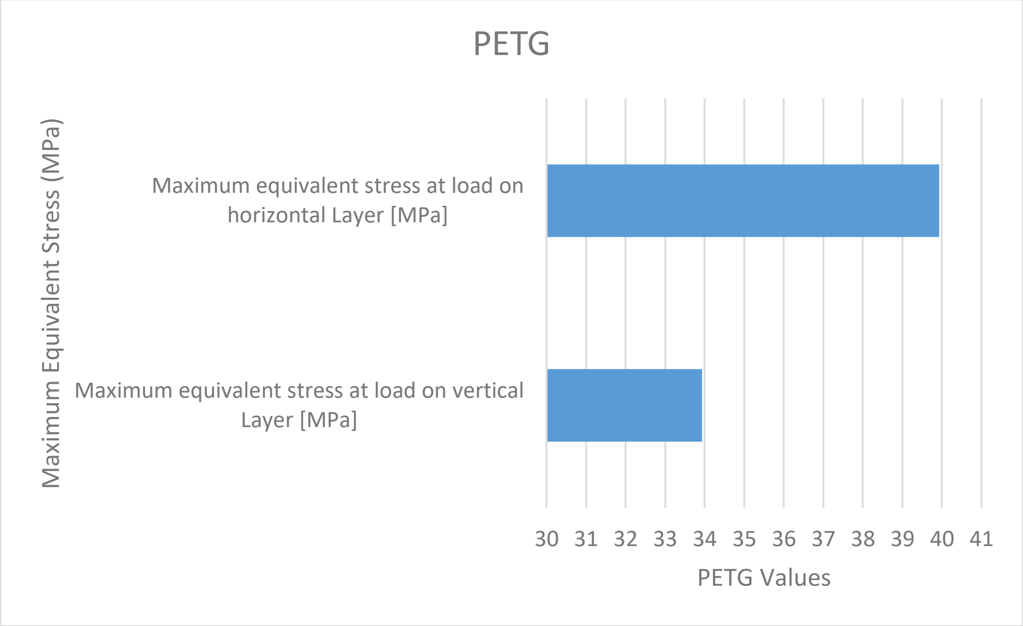

Fig. 1: Comparative result of maximum equivalent stress for PETG

Table 4 focuses on the fatigue existence of PETG, where it is proven to withstand 572,500 cycles underneath vertical load and 616,880 cycles whilst loaded horizontal. This indicates that PETG can sustain great cyclic loading before failure, with a slightly higher performance horizontally.

Table 4: Comparative result of Fatigue life for different materials

Materials	**PETG**
Fatigue life at load on vertical Layer	5.725E+5
Fatigue life at load on horizontal Layer	6.1688E+5

The graph presented in Fig. 2 indicates the fatigue life of the material PETG, which is Polyethylene Terephthalate Glycol, under two loading orientations: horizontal and vertical. Fatigue life is the number of cycles a material can withstand under repeated stress until failure. It may be noted that the fatigue life of PETG is much larger when the load is applied in a horizontal layer than that in a vertical layer. This means that the PETG is far more resilient and resistant to fatigue failures when exposed to stress in a horizontal orientation, which is quite significant in the quest for applications in which cyclic loading is a factor.

Table 5 displays the safety factors for PETG, which are particularly low at 0.035116 for vertical loads and 0.035979 for horizontal masses. These values imply a marginal protection margin beneath the given loading situations, pointing to potential vulnerabilities in PETG's use in packages where better safety factors are generally required. Together, those statistics offer a comprehensive evaluate of PETG’s mechanical residences, critical for information its applicability and barriers in diverse engineering contexts.

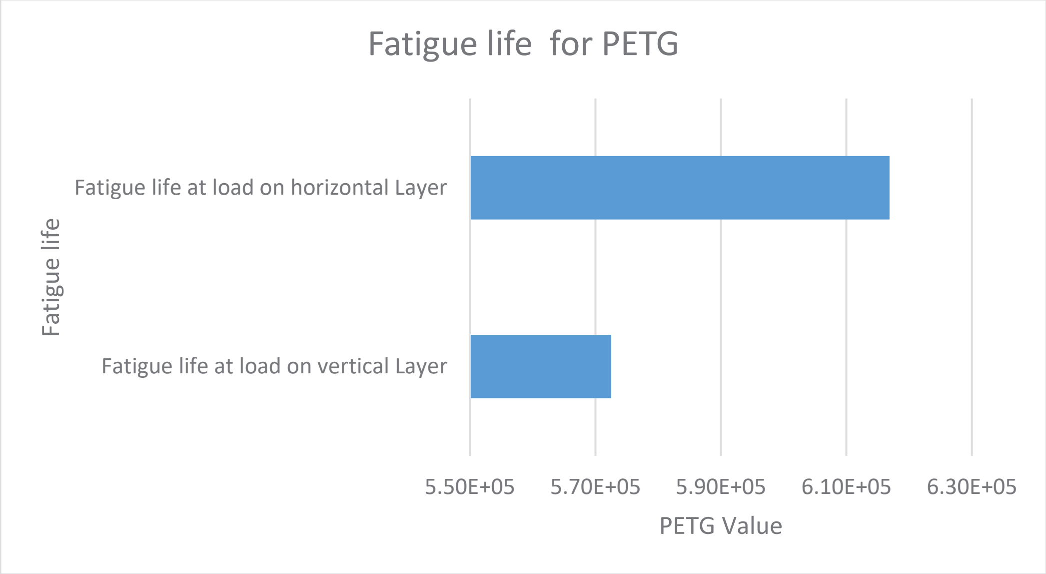

Fig. 2: Comparative result of Fatigue life for PETG

Table 5: Comparative result of safety factor for different materials

Materials	**PETG**
Safety factor at load on vertical Layer	0.035116
Safety factor at load on horizontal Layer	0.035979

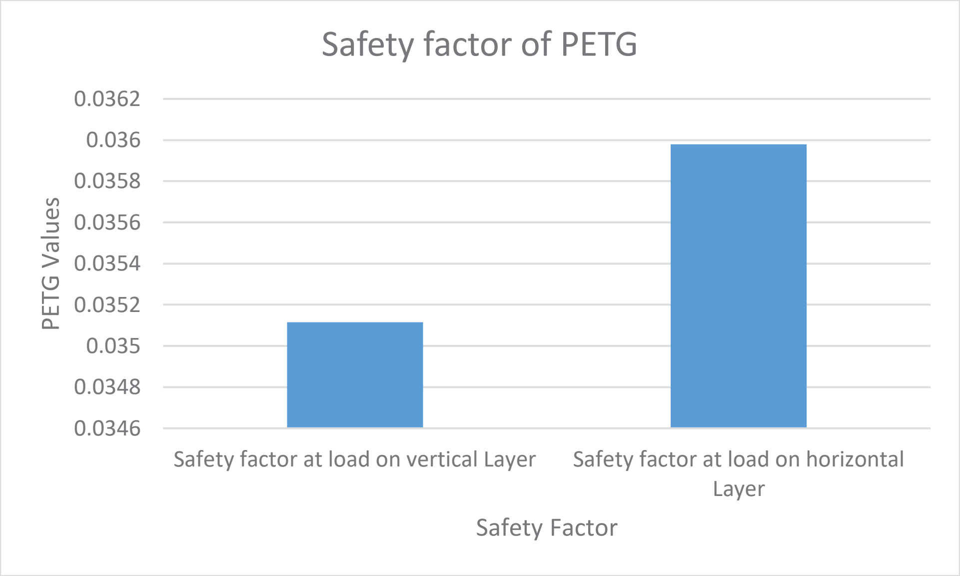

Fig. 3: Comparative result of safety factor for PETG

Fig. 3 shows the PETG Safety Factor in Vertical and Horizontal Layer Loading Orientations The safety factor of PETG under two loading orientations-vertical and horizontal layer loading-is shown in Fig. 12. Horizontally applied loads show a higher safety factor than vertically applied loads. The loading direction indicates that PETG is more effective under horizontal loads, but the insight is still critical about designing and using PETG for applications where direction of load is important in regards to performance.

5 Conclusion

In the present work finite element analysis have been conducted on Simple structure of square block with dimensional parameter 25 mm x 25 mm x 25 mm, this FEM analysis includes compression test using static structural analysis, fatigue analysis and model analysis.

- Testing a PETG square block vertically with 12,200 N resulted in a total deformation of 0.2318 mm. A similar load applied horizontally caused a slightly higher total deformation at 0.23192 mm.
- The block was repeatedly loaded (cyclic load) to simulate real-world operating conditions, where it was found to withstand a maximum of about 572,540 cycles before failing due to fatigue at one corner. The horizontal loading showed a slightly higher fatigue life, 616,880 before failure due to corner fatigue life.
- During the vertical compression test, the equivalent stress in the material varied between layers, with a maximum stress of 33.93 MPa in the outer layer and decreased to 23.148 MPa in the middle layer. This gradient of stress distribution this helps to understand how the material carries loads from the inside back to the end.
- The minimum safety found was 0.035116 for fatigue failure, especially at corners during the life of the system. This very low safety indicates a high risk of failure, whether design the material will require reinforcement or reappraisal to increase its reliability under anticipated load conditions.

References

1. Latko-Durałek, Paulina, Kamil Dydek, and Anna Boczkowska. "Thermal, rheological and mechanical properties of PETG/rPETG blends." Journal of Polymers and the Environment 27 (2019): 2600-2606.
2. Chen, Tingting, Jun Zhang, and Hongjun You. "Photodegradation behavior and mechanism of poly (ethylene glycol-co-1, 4-cyclohexanedimethanol terephthalate) (PETG) random copolymers: Correlation with copolymer composition." RSC advances 6, 104 (2016): 102778-102790.
3. Calvino, Céline, Emma Henriet, Livius F. Muff, Stephen Schrettl, and Christoph Weder. "Mechanochromic polymers based on microencapsulated solvatochromic dyes." Macromolecular rapid communications 41, 7 (2020): 1900654.
4. Krzyzanowski, Pawel. "Design and development of 3D printed fins integrated into an instrumented surfboard." (2022).
5. Santos, Jean Vitor Vassoler dos. "Análise da influência das variáveis de fabricação altura de camada, densidade de preenchimento, temperatura do bico extrusor e velocidade de impressão sobre as propriedades mecânicas de peças de PETG fabricadas através do processo de FDM." (2023).
6. Paszkiewicz, S., I. Pawelec, A. Szymczyk, and Z. Roslaniec. "Swcnts/Poly (Ethylene Terephthalate Glycol-Modified)(Petg) Nanocomposites: Preparation And Characterization Of Thin Conductive Films." International Journal of Materials Engineering and Technology 11, 2 (2014): 139.
7. Haase, Andreas, Pascal Hesse, Lars Brommer, Olaf Jacobs, Clarissa Abetz, Ulrich A. Handge, Adriana Boschetti-de-Fierro, and Volker Abetz. "Modification of Polycarbonate and Glycol Modified Poly (ethylene terephthalate) by Addition of Silica-

Nanoparticles Grafted with SAN Copolymer Using “Classical” and ARGET ATRP." Macromolecular Materials and Engineering 298, 3 (2013): 292-302.

8. Vidakis, Nectarios, Markos Petousis, Lazaros Tzounis, Sotirios A. Grammatikos, Emmanouil Porfyrakis, Athena Maniadi, and Nikolaos Mountakis. "Sustainable additive manufacturing: Mechanical response of polyethylene terephthalate glycol over multiple recycling processes." Materials 14, no. 5 (2021): 1162.
9. Bremer, Mats, Lukas Janoschek, Denis Kaschta, Nick Schneider, and Michael Wahl. "Influence of plastic recycling—a feasibility study for additive manufacturing using glycol modified polyethylene terephthalate (PETG)." SN Applied Sciences 4, no. 5 (2022): 156.
10. Hassan, Mohamed H., Abdalla M. Omar, Evangelos Daskalakis, Yanhao Hou, Boyang Huang, Ilya Strashnov, Bruce D. Grieve, and Paulo Bártolo. "The potential of polyethylene terephthalate glycol as biomaterial for bone tissue engineering." Polymers 12, no. 12 (2020): 3045.
11. Katschnig, Matthias, Juergen Wallner, Thomas Janics, Christoph Burgstaller, Wolfgang Zemann, and Clemens Holzer. "Biofunctional glycol-modified polyethylene terephthalate and thermoplastic polyurethane implants by extrusion-based additive manufacturing for medical 3D maxillofacial defect reconstruction." Polymers 12, no. 8 (2020): 1751.
12. Lenshin, Alexander S., Vera E. Frolova, Sergey S. Ivkov, and Evelina P. Domashevskaya. "Microstructural and hydrophilic properties of polyethylene terephthalate glycol polymer samples with different 3D printing patterns." Condensed Matter and Interphases 26, no. 1 (2024): 78-87.
13. Zapciu, A., C. Gh Amza, F. Baciu, and M. I. Vasile. "Heat treatment of 3D printed polyethylene terephthalate glycol in a supporting powder bed." In IOP Conference Series: Materials Science and Engineering, vol. 1182, no. 1, p. 012083. IOP Publishing, 2021.
14. Garwacki, Mikołaj, Igor Cudnik, Damian Dziadowiec, Piotr Szymczak, and Jacek Andrzejewski. "The Development of Sustainable Polyethylene Terephthalate Glycol-Based (PETG) Blends for Additive Manufacturing Processing—The Use of Multilayered Foil Waste as the Blend Component." Materials 17, no. 5 (2024): 1083.
15. Clarke, Tim, and Ali Hosseini. "Effects of print parameters on tensile characteristics of additively manufactured polyethylene terephthalate-glycol (PETG)." The International Journal of Advanced Manufacturing Technology 125, no. 11 (2023): 4953-4974.
16. Mahesh, Vinyas. "ANN based prediction of the absorption characteristics of additive manufactured glycol-modified polyethylene terephthalate nanocomposites reinforced with short-carbon fibers and nanoclay fillers." Polymer Composites 44, no. 12 (2023): 8223-8239.
17. Bernasconi, Roberto, Gabriele Natale, Marinella Levi, and Luca Magagnin. "Electroless plating of NiP and Cu on polylactic acid and polyethylene terephthalate glycol-modified for 3D printed flexible substrates." Journal of The Electrochemical Society 163, no. 9 (2016): D526.
18. Suji Prasad, S. J., M. Thangatamilan, M. Suresh, Hitesh Panchal, Christober Asir Rajan, C. Sagana, B. Gunapriya, Aditi Sharma, Tusharkumar Panchal, and Kishor Kumar Sadasivuni. "An efficient LoRa-based smart agriculture management and monitoring system using wireless sensor networks." International Journal of Ambient Energy 43, no. 1 (2022): 5447-5450.
19. Joseph, Sudha, Kavitha Joseph, Trevor C. Lindley, and David Dye. "The role of dwell hold on the dislocation mechanisms of fatigue in a near alpha titanium alloy." International Journal of Plasticity 131 (2020): 102743.

20. Prasad, C. Durga, S. Kollur, M. Nusrathulla, G. Satheesh Babu, M. B. Hanamantraygouda, B. N. Prashanth, and N. Nagabhushana. "Characterisation and wear behaviour of SiC reinforced FeNiCrMo composite coating by HVOF process." Transactions of the IMF 102, no. 1 (2024): 22-28.
21. Meenal, R., D. Binu, K. C. Ramya, Prawin Angel Michael, K. Vinoth Kumar, E. Rajasekaran, and B. Sangeetha. "Weather forecasting for renewable energy system: a review." Archives of Computational Methods in Engineering 29, no. 5 (2022): 2875-2891.
22. Akshatha, S., S. Sreenivasa, L. Parashuram, Fahad A. Alharthi, and Tadimety Madhu Chakrapani Rao. "Microwave assisted green synthesis of p-type Co3O4@ Mesoporous carbon spheres for simultaneous degradation of dyes and photocatalytic hydrogen evolution reaction." Materials Science in Semiconductor Processing 121 (2021): 105432.
23. Akshatha, S., S. Sreenivasa, L. Parashuram, V. Udaya Kumar, S. C. Sharma, H. Nagabhushana, Sandeep Kumar, and T. Maiyalagan. "Synergistic effect of hybrid Ce3+/Ce4+ doped Bi2O3 nano-sphere photocatalyst for enhanced photocatalytic degradation of alizarin red S dye and its NUV excited photoluminescence studies." Journal of Environmental Chemical Engineering 7, no. 3 (2019): 103053.
24. Ramkumar, M., C. Ganesh Babu, K. Vinoth Kumar, D. Hepsiba, A. Manjunathan, and R. Sarath Kumar. "ECG cardiac arrhythmias classification using DWT, ICA and MLP neural networks." In Journal of Physics: Conference Series, vol. 1831, no. 1, p. 012015. IOP Publishing, 2021.
25. Kumar, CB Pradeep, B. S. Prathibha, K. N. N. Prasad, M. S. Raghu, M. K. Prashanth, B. K. Jayanna, Fahad A. Alharthi, S. Chandrasekhar, H. D. Revanasiddappa, and K. Yogesh Kumar. "Click synthesis of 1, 2, 3-triazole based imidazoles: Antitubercular evaluation, molecular docking and HSA binding studies." Bioorganic & Medicinal Chemistry Letters 36 (2021): 127810.
26. Rajesh, A., K. Gopal, B. Rajesh Kumar, A. P. Sathiyagnanam, and D. Damodharan. "Effect of anisole addition to waste cooking oil methyl ester on combustion, emission and performance characteristics of a DI diesel engine without any modifications." Fuel 278 (2020): 118315.
27. Naik, Ramachandra, S. C. Prashantha, H. Nagabhushana, S. C. Sharma, H. P. Nagaswarupa, and K. M. Girish. "Effect of fuel on auto ignition route, photoluminescence and photometric studies of tunable red emitting Mg2SiO4: Cr3+ nanophosphors for solid state lighting applications." Journal of Alloys and Compounds 682 (2016): 815-824.
28. Naveen Kumar, Rangaswamy, J. Suresh Goud, Pudhari Srilatha, Pattasale T. Manjunatha, S. Prasanna Rani, Raman Kumar, and S. Suresha. "Cattaneo–Christov heat flux model for nanofluid flow over a curved stretching sheet: An application of Stefan blowing." Heat Transfer 51, no. 6 (2022): 4977-4991.
29. Vallabhuni, Rajeev Ratna, G. Yamini, T. Vinitha, and S. Sanath Reddy. "Performance analysis: D-Latch modules designed using 18nm FinFET Technology." In 2020 International Conference on Smart Electronics and Communication (ICOSEC), pp. 1169-1174. IEEE, 2020.
30. Dhanalaxmi, B., and G. Apparao Naidu. "A survey on design and analysis of robust IoT architecture." In 2017 International Conference on Innovative Mechanisms for Industry Applications (ICIMIA), pp. 375-378. IEEE, 2017.
31. Nikam, Pritam B., Jayendra Kumar, V. Sivanagaraju, and Achinta Baidya. "Dual-band reconfigurable EBG loaded circular patch MIMO antenna using defected ground structure (DGS) and PIN diode integrated branch-lines (BLs)." Measurement 195 (2022): 111127.

32. Vallabhuni, Rajeev Ratna, Jujavarapu Sravana, Chandra Shaker Pittala, Mikkili Divya, B. M. S. Rani, and Vallabhuni Vijay. "Universal shift register designed at low supply voltages in 20 nm FinFET using multiplexer." In Intelligent Sustainable Systems: Proceedings of ICISS 2021, pp. 203-212. Singapore: Springer Singapore, 2021.
33. Kishore, Somasundaram Chandra, Raji Atchudan, Thomas Nesakumar Jebakumar Immanuel Edison, Suguna Perumal, Muthulakshmi Alagan, Rajangam Vinodh, Mani Shanmugam, and Yong Rok Lee. "Solid waste-derived carbon fibers-trapped nickel oxide composite electrode for energy storage application." Energy & Fuels 34, no. 11 (2020): 14958-14967.
34. Malagavelli, Venu, Srinivas Angadi, J. S. R. Prasad, and Subodh Joshi. "Influence of metakaolin in concrete as partial replacement of cement." Int J Civil Eng Technol 9, no. 7 (2018): 105-111.
35. Ashok Babu, Puralasetty, Javanna Latheef Mazher Iqbal, S. Siva Priyanka, Machana Jithender Reddy, Gaddam Sunil Kumar, and Rajaram Ayyasamy. "Power control and optimization for power loss reduction using deep learning in microgrid systems." Electric Power Components and Systems 52, no. 2 (2024): 219-232.
36. Saritha, M., M. Lavanya, G. Ajitha, Mulinti Narendra Reddy, P. Annapurna, M. Sreevani, S. Swathi, S. Sushma, and Vallabhuni Vijay. "A VLSI design of clock gated technique based ADC lock-in amplifier." International Journal of System Assurance Engineering and Management 13, no. 5 (2022): 2743-2750.
37. Pittala, Chandra Shaker, Rajeev Ratna Vallabhuni, Vallabhuni Vijay, Usha Rani Anam, and Kancharapu Chaitanya. "Numerical analysis of various plasmonic MIM/MDM slot waveguide structures." International Journal of System Assurance Engineering and Management 13, no. 5 (2022): 2551-2558.