International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

Check for updates

Optimization of Hole quality parameters using TOPSIS method in drilling of GFRP composite

Potta Chaitanya *, Thallapalli vamshi krishna, Arikari ganesh, Agirishetty bharat and Degala Rohith paul

Vignan institute of technology and science, Hyderabad, India.

International Journal of Science and Research Archive, 2023, 09(02), 030–038

Publication history: Received on 18 May 2023; revised on 24 June 2023; accepted on 27 June 2023

Article DOI: https://doi.org/10.30574/ijsra.2023.9.2.0505

Abstract

The attractive mechanical properties and light weight to strength ratio Glass Fiber Reinforced Plastic (GFRP) composites are preferred in automobile and aerospace industries. Drilling process is one of the basic and important manufacturing processes. Drilling of GFRP and its issues with hole quality are fiber crack, roughness of surface, dimensional error and delamination. In this work, the effect of three different drill (Slot type, twist type and brad type) and process parameters (machining speed and feed rate) on hole quality error is analyzed. Hole quality parameters, chosen are roundness error, roughness of the machined area, delamination factor and diameter deviation. Simultaneous optimization of multiple objectives is difficult task. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is used for optimization process parameters and minimize the hole quality error during drilling of GFRP composite. The result revealed that spur type drill with higher range of spindle speed was provided less error in the drilled holes. Also, TOPSIS procedure has minimum computational time because of its less computational steps and highly preferrable for various decision-making problems in manufacturing industry. Hole quality error is directly influencing the assembly accuracy and its minimization is important one.

Keywords: GFRP; Drilling; Drills; TOPSIS; Hole quality

1. Introduction

Automobile and aerospace industries are focused lightweight materials with higher strength ratio. GFRP composites are one of the choices because of its significance properties. Various methods are available to fabricate GFRP composite. Hand lay-up is widely preferred due to its easiest procedure [1]. Drilling on GFRP is used for assembling the subcomponents. The anisotropic in nature as well as composite material homogeneity there is a chance of drilled surface of GFRP may damage [2]. Drilling with better tolerance control, surface finish and less circularity error are the requirement of automobile and aerospace industries. Delamination is an important issue in drilling which influence the structural integrity of the material. Peel-up and pullout delamination are the two types of delamination error. In drilled hole, at the entrance of hole peel-up delamination occurs and push-out delamination occurs at the exit [3]. Process parameter is also strongly influencing the quality of drilled hole. Some of the hole quality parameters are roundness error, roughness of the machined area and diameter deviation. [4, 5]

Generally, optimization process is carried out for prediction of optimum set of process parameters and enhances the machining efficiency. It is classified into single objective optimization and multi objective optimization process parameter. Generally, optimization process needs coding, software and equations. Now a days, MCDM methods are used for optimization purpose to select best combination from given number of combination [6-10]. This method is used for simultaneous optimization method. Many MCDM techniques are available in which TOPSIS is unique method for solving muti criteria decision-making method. The significant advantages are easy computational steps, not involving any coding and software's. [11-15].

* Corresponding author: Potta Chaitanya

2. Literature Review

Jalumedi Babu et al. [16] made review process about delamination error and its various estimation methods. Measuring technique was played a significant role for estimation of delamination error. They result revealed that pointed about contribution of damage area was influenced the delamination error. Akhil et al. [17] optimized process parameters using Grey Relational Analysis (GRA) method parameters in drilling of FRP composites. Input parameters were considered feed rate, drill tool diameter and spindle speed. TaguchiL27 orthogonal array was used for performing experiments. ANOVA concept was used to find the process parameter significance. Grilo et al. [18] investigated that delamination error using three dissimilar drill geometries (spur, twist and candlestick) and process parameters (spindle speed and feed rate). The result revealed that spur drill was provided less error. Mudhukrishan et al. [19] conducted drilling process on GFRP composite using different process parameters and tool materials. Surface quality and dimensional error were the response analyzed. The result indicated that solid carbide drill with higher spindle speed was provided better machining performance. Ashrafi et al. [20] investigated about different process parameters on hole quality errors while drilling of FRP composites. Fiber pullout, roundness error and surface roughness were considered as response. The result showed that appropriate process parameters were significantly influenced the hole quality errors. Palanikumar et al. [21] developed a mathematical model in drilling process for minimization of delamination error and surface roughness. Spindle speed, feed rate and drill diameters were considered to develop a mathematical model. The result pointed out drill diameter and followed by process parameters were significantly influenced the response parameters. The developed mathematical model was adequate and ANOVA was used to find the significance parameters. Wang and kirwa [22] used three different drills twist drill, pilot hole and step drill for minimization of hole quality error when drilling of CFRP composites. The result revealed that thrust force during drilling process was controlled by step drill.

Shunmugesh and Panneerselvam [23] performed drilling process on FRP composite. TOPSIS method and Taguchi method were used to optimize the process parameters. The result showed that TOPISIS method was better agreement with Taguchi based optimized results. Surand Erkhan [24] conducted drilling on carbon based FRP composites using step geometry drill. L_{18} orthogonal matrix was selected for performing the trials. Drill point angle, speed and feed rate effects on surface quality and delamination error ere analyzed. Also, the results were optimized using TOPISIS method. AHP method was used to calculate the relative importance of response parameters. Tran [25] investigated about drilling on carbon based FRP composite and process parameters optimization using grey based TOPSIS technique. Entropy process was also used for finding the relative importance of output parameter. The response parameters were uncut fiber, surface quality of drilled surface and delamination error. The both advantage of grey concept and TOPSIS technique optimum combination of process parameters were predicted.

From the previous work, it is understood that drilling on GFRP and further hole quality errors (deviation in diameter, roundness error, roughness of the machined area and delamination error) are important in assembly accuracy. Multi objective and its simultaneous optimization need software and high mathematical steps. But, TOPSIS procedure consists of simple procedure and easy mathematical computational steps. Hence, in this paper an attempt has been made for optimization of hole quality parameters using TOPSIS method during drilling of GFRP composite.

2.1. Experimental Setup

GFRP composite is prepared using hand lay-up technique with woven roven glass fiber. The staking order of zero degree and 16 layers were considered. Laminate preparation fiber volume fraction is maintained as 58.63%. Also, resin (Epoxy-LY566) and hardener (5200) are used for preparation of laminate. Approximately 5 mm is maintained for prepared laminate. Figure 1 shows the hand lay- up technique. Vertical Machining Centre (VMC)is used for performing the drilling process. Figure 2 shows the VMC Setup. Three different drills (Slot type, twist type and brad type) with different spindle speed and feed rate are used. Drill material (High Speed Steel) and diameter (8mm) are used. Previous studies and preliminary experiments are used to select the process parameters. Table 1 presents the levels of process parameter selected. Figure 3 shows the machined sample.

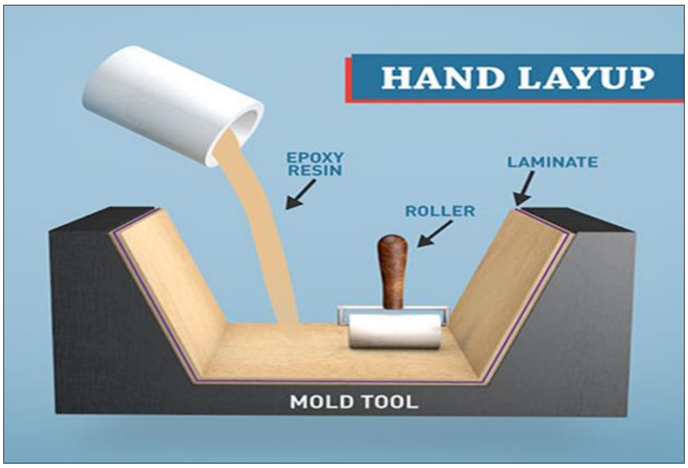

Figure 1 Hand lay up technique

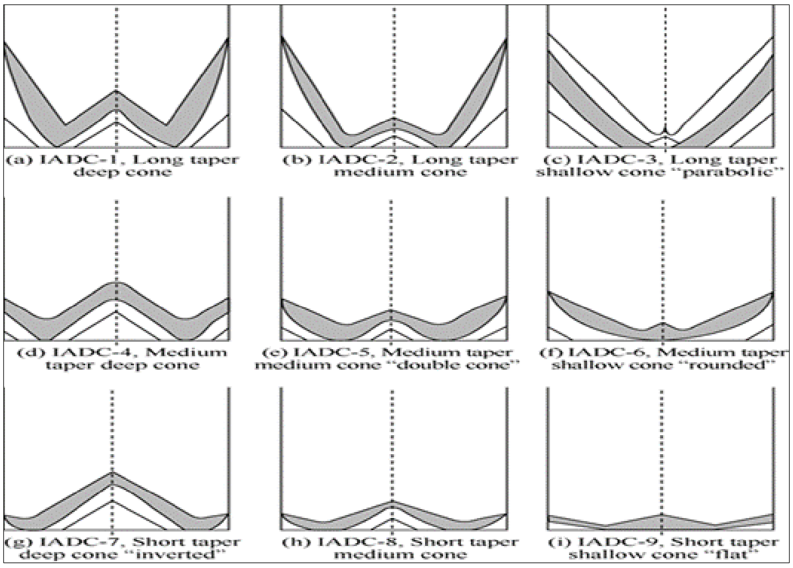

Figure 2 Drill profile

Table 1 Process parameters and their levels

Parameters	**Levels**		
	Level 1	**Level 2**	**Level 3**
Drill types	Twist	Slot	Spur
Spindle speed (rpm)	1000	1500	2000
Feed rate (mm/rev)	0.10	0.15	0.20

Microscope is used for drilling induced delamination factor. The difference of maximum diameter of the delamination (D_{max}) and the diameter of the hole (D) is used for estimating the delamination factor.

$$Delamination\ factor\ Fd = \frac{D_{max}}{D} \ ....(1)$$

Where, F_d = delamination factor, D_{max} = maximum damaged zone diameter, D = hole diameter. Figure 4 shows the microscopic image for delamination measurement.

Figure 3 Machined sample

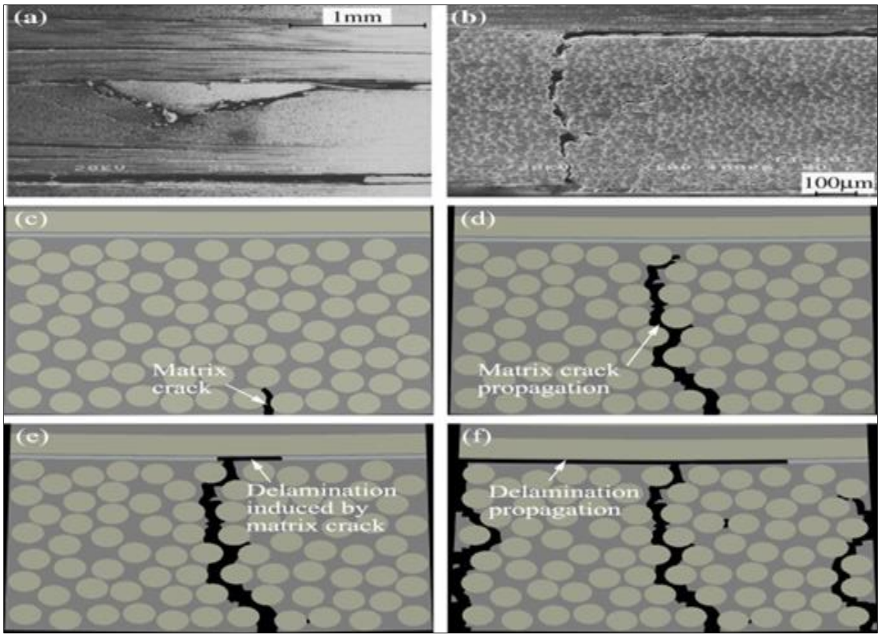

Figure 4 Microscopic images for delamination

Talysurf surface roughness testing machine is used for surface roughness measurement of drilled surface. Average value is considered for analysis which is measured three to five places of drilled surface. Coordinate Measuring Machine (CMM) is used for measuring roundness error which can be defined as distance between the minimum circumscribing circles to the maximum inscribing circle diameter. Also, diameter error is measured using CMM. The difference between actual size and drilled size is termed as diameter error. Table 2 shows the experimental results.

Table 2 Experimental results

Sl.No	Drill type	Spindle speed (rpm)	Feed rate (mm/rev)	Diameter deviation (mm)	Roundness error (mm)	Surface roughness (microns)	Delamination Factor
1	Twist drill	1000	0.1	0.27	0.048	4.05	1.463
2	Twist drill	1500	0.15	0.25	0.047	3.28	1.475
3	Twist drill	2000	0.2	0.038	0.072	3.15	1.375
4	Slot drill	1000	0.15	0.026	0.12	1.56	1.275
5	Slot drill	1500	0.2	0.014	0.092	1.56	1.265
6	Slot drill	2000	0.1	0.039	0.069	1.35	1.219
7	Spur drill	1000	0.2	0.033	0.067	2.9	1.475
8	Spur drill	1500	0.1	0.021	0.064	2.08	1.275
9	Spur drill	2000	0.15	0.029	0.054	1.15	1.354

3. Material and method

Multi Criteria Decision Making (MCDM)methods are used to find the optimum set of alternatives. Various MCDM techniques are available among TOPSIS is a unique and standard method. It is widely used in decision-making areas. The basic concept of TOPSIS is to consider the positive ideal solution nearest and negative ideal solution from farthest. The various steps involved in TOPSIS are given follows as [11-15]

3.1. Step 1: Consider the objective functions

The minimization or maximization of objective function is to be identified.

3.2. Step 2: Decision matrix formation (D_{ij})

Decision matrix is formed based on the output parameters and objective function. It is denoted as D. Table 3 presents the decision matrix value.

3.3. Step 3: Normalized decision matrix formation (N_{ij})

The output parameters are different units and normalization is used to bring into equivalent score. Table 3 presents the normalized matrix.

$$N_{ij} = x_{ij}/\sqrt{\Sigma x_{ij}^2} \quad \text{.................. (1)}$$

Table 3 Decision matrix and weighted matrix

Sl.No	Decision matrix (D)				Normalized matrix.			
1	0.27	0.048	4.05	1.463	0.717	0.217	0.532	0.359
2	0.25	0.047	3.28	1.475	0.664	0.212	0.431	0.362
3	0.038	0.072	3.15	1.375	0.100	0.325	0.414	0.337
4	0.026	0.12	1.56	1.275	0.069	0.543	0.205	0.313
5	0.014	0.092	1.56	1.265	0.037	0.416	0.205	0.310
6	0.039	0.069	1.35	1.219	0.103	0.312	0.177	0.299
7	0.033	0.067	2.9	1.475	0.087	0.303	0.381	0.362
8	0.021	0.064	2.08	1.275	0.055	0.289	0.273	0.313
9	0.029	0.054	1.15	1.354	0.077	0.244	0.151	0.332

Table 4 Weighted matrix, separation measure, relative closeness and rank

Sl.No	Weighted normalized matrix				Separation measure (S+)	Separation measure (S-)	Relative closeness	Rank
1	0.179	0.054	0.133	0.089	0.089897	0.001188	0.006037	9
2	0.166	0.053	0.107	0.090	0.090635	0.028663	0.142526	8
3	0.025	0.081	0.103	0.084	0.08449	0.159237	0.685109	7
4	0.017	0.135	0.051	0.078	0.078345	0.199032	0.707935	6
5	0.009	0.104	0.051	0.077	0.077731	0.195393	0.7938	4
6	0.025	0.078	0.044	0.074	0.074904	0.179439	0.860925	2
7	0.021	0.075	0.095	0.090	0.090635	0.163227	0.717275	5
8	0.013	0.072	0.068	0.078	0.078345	0.178899	0.834267	3
9	0.019	0.061	0.037	0.083	0.083199	0.186582	0.929148	1

3.4. Step 4: Weighted normalized decision matrix (W_{ij})

It is determined by considering relative importance of each output parameters with decision matrix. In this work, equal weightage of response parameters is considered. Table 4 represents the weighted matrix.

$$W_{ij} = RI_{ij} \text{ X } N_{ij} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

3.5. Step 5: Positive ideal solution and negative ideal solutions

It is calculated by equation (3) and (4)

$$A+ = \{(\max vij \mid j\epsilon J), (\min vij \mid j\epsilon J')\} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$A- = \{(\min vij \mid j\epsilon J),(\max vij \mid j\epsilon J')\} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$J = 1,2,3,\ldots.,n$$

Where J is represented with benefit measures

$$J' = 1,2,3,\ldots.,n$$

Where J' is represented with the cost measures

3.6. Step 6: Separation measure calculation

The separation of different alternatives from the positive ideal solution (5) and negative idea solution (6) are calculated by

$$Si^* = \sqrt{\Sigma} (vij-vj^*)^2 \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$Si^- = \sqrt{\Sigma} (vij-vj)^2 \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

3.7. Step 7: Relative closeness value estimation

The relative closeness is estimated by equation (7)

$$RC = Si-/(Si^*+Si-) \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The higher the Relative closeness (RC) value represents the optimum combination of alternatives.

Table 4 shows the separation measure and relative closeness value.

Step 8: Relative closeness value and its rank

4. Results and discussions

In this paper, GFRP composite is drilled using three different drills. Experimental is designed based on Taguchi L_9 orthogonal array. TOPSIS is utilized to investigate the experimental results and relative closeness index is calculated to predict the optimum combination of process parameters. Delamination error, deviation in diameter, roughness of the machined area and roundness error are considered as hole quality parameters. Diameter deviation is the difference of actual diameter and measured diameter value. Hole quality parameters analyzed Machinability and functional life are predicted using surface roughness measurement. Hole accuracy can be increased by less roundness error or circularity error. Delamination factor influences hole quality and assembly tolerances.

TOPSIS method is used to rank better alternatives among given number of alternatives. Relative closeness value is used to rank the best alternative. Higher the relative closeness indicates near the optimum values. The high value of relative closeness values among given alternative are 9-6-8-5-7-4-3-2-1. According to higher relative closeness value spur type drill, higher spindle speed of 2000 rpm and 0.15 mm/rev feed rate. Spindle speed influences the diameter deviation. At higher spindle speed, interfacial friction is reduced. Hence, less diameter error is noticed with higher spindle speed [19]. Spindle speed and feed rate are influenced the roundness error. In general, higher dynamic stability is produced with high value of spindle speed. Hence, reduced roundness error is noticed with high range of spindle speed [4]. Rotational stability is better at high range of spindle speed. Surface roughness of the machined area is influenced by spindle speed. Reduced surface roughness is noticed with higher spindle speed. Built up edge formation during drilling is the major issue with lower spindle speed [3]. Delamination error is influenced by spindle speed. Reduced delamination error with high range of spindle speed due to high temperature with higher spindle speed and followed by thermal softening [26]. Conventional twist drill has lower hardness compare with specialized drills. Specialized drills are producing less thrust force than conventional twist drill. This will be useful for producing less delamination error during drilling of FRP composites.

It is observed that among various MCDM methods, such as MOORA, VIKOR, GRA etc., TOPSIS procedure is easy to execute and simple calculations. This method consists of simple ratio analysis and minimum mathematical computations. Another important advantage is computational steps are not influenced by the considered of any assumed parameter (for example v in VIKOR and ξ in GRA methods) as it occurs in most of the multi objective optimization techniques. Hence, TOPSIS is mostly preferable for various decision-making problems [27-37].

5. Conclusion

The following conclusions are obtained from drilling of GFRP composite

- Drilling process is carried out on GFRP composite using three different drills namely twist, slot & spur types. Hole quality parameters (delamination error, surface roughness, diameter deviation and circularity error) are analyzed and optimized using TOPSIS method.
- Relative closeness value in TOPSIS method is used to analyze the results. According to high value of relative closeness, 2000 rpm of spindle speed, 0.15 mm/rev of feed rate with spur drill are the optimum combination of process parameters.
- Spur drill is noticed with less value of delamination error and other hole quality parameters. Higher spindle speed and lower feed rate are given less errors in drilled hole.
- TOPSIS procedure is used to solve multi objective optimization effectively. TOPSIS method has less calculation procedure, computational time and not required for any assumption.

Compliance with ethical standards

Acknowledgments

The authors would like to thank AICTE-MODROB scheme for providing funding support. Ref No: F.No: 9-226/IDC/MODROB/Policy-1/2019-20.

Disclosure of conflict of interest

If two or more authors have contributed in the manuscript, the conflict of interest statement must be inserted here.

References

[1] Karimi NZ, Heidary H, Minak G and Ahmadi M. Effect of the drilling process on the compression behavior of glass/epoxy laminates. Compos Struct. 2013; 98: 59-68.

[2] Singaravel, B., Radhika, M., Asif, M.M., Reddy, K.P.: Analysis of hole quality errors in drilling of GFRP composite. In IOP Conference Series: Materials Science and Engineering 1057, 012069 (2021)

[3] Singaravel, B., Saikrupa, C., Sandeep, M.: Analysis of Quality Parameters in Drilling of Titanium Alloy. International Journal of Vehicle Structures & Systems, 12, 210-213 (2020)

[4] Niranjan, T., Singaravel, B. and Raju, S.S., 2022. Optimization of hole quality parameters using TOPSIS method in drilling of GFRP composite. Materials Today: Proceedings, 62, pp.2109-2114.

[5] Niranjan, T., Singaravel, B. and Raju, S.S., 2022. Optimization of hole quality parameters using TOPSIS method in drilling of GFRP composite. Materials Today: Proceedings, 62, pp.2109-2114.

[6] Divya, C., Raju, L.S., Singaravel, B. and Niranjan, T., 2022. Performance investigation of micro hole textured cutting inserts on power consumption and its measuring methodology in turning process. Alexandria Engineering Journal, 61(4), pp.3125-3130.

[7] Singaravel, B., Marulaswami, C. and Selvaraj, T., 2016. Analysis of the effect of process parameters for circularity and cylindricity errors in turning process. In Applied Mechanics and Materials (Vol. 852, pp. 255-259). Trans Tech Publications Ltd.

[8] Shekar, K.C., Singaravel, B., Prasad, S. and Venkateshwarlu, N., 2019. Effect of fiber orientation on the flexural properties of glass fiber reinforced, epoxy-matrix composite. In Materials Science Forum (Vol. 969, pp. 502-507). Trans Tech Publications Ltd.

[9] Singaravel, B. and Selvaraj, T., 2015. Optimization of machining parameters in turning operation using combined TOPSIS and AHP method. Tehnički vjesnik, 22(6), pp.1475-1480.

[10] Balasubramaniyan, S. and Selvaraj, T., 2017. Application of integrated Taguchi and TOPSIS method for optimization of process parameters for dimensional accuracy in turning of EN25 steel. Journal of the Chinese Institute of Engineers, 40(4), pp.267-274.

[11] Singaravel, B., Shankar, D.P. and Prasanna, L., 2018. Application of MCDM method for the selection of optimum process parameters in turning process. Materials Today: Proceedings, 5(5), pp.13464-13471.

[12] Singarvel, B., Selvaraj, T. and Jeyapaul, R., 2014. Multi objective optimization in turning of EN25 steel using Taguchi based utility concept coupled with principal component analysis. Procedia Engineering, 97, pp.158-165.

[13] Singaravel, B. and Selvaraj, T., 2017. Multi criteria optimisation using analytic hierarchy process in turning operation. International Journal of Machining and Machinability of Materials, 19(3), pp.218-229.

[14] Singaravel, B. and Selvaraj, T., 2016. Application of Taguchi method for optimization of parameters in turning operation. Journal for Manufacturing Science and Production, 16(3), pp.183-187.

[15] Divya, C., Raju, L.S. and Singaravel, B., 2020. A review of TOPSIS method for multi criteria optimization in manufacturing environment. In Intelligent Techniques and Applications in Science and Technology: Proceedings of the First International Conference on Innovations in Modern Science and Technology 1 (pp. 719-727). Springer International Publishing.

[16] Babu J, Sunny T, Paul NA, Mohan KP, Philip J and Davim, JP. Assessment of delamination in composite materials: a review. P I MECH ENG B J, 2016; 230: 1990-2003

[17] Akhil, KT, Shunmugesh, K, Aravind, S and Pramod kumar M. Optimization of Drilling Characteristics using Grey Relational Analysis (GRA) in Glass Fiber Reinforced Polymer (GFRP). Mater Today: Proceed, 2017: 4: 1812-1819.

[18] Grilo, TJ, Paulo RMF, Silva, CRM and Davim, JP. Experimental delamination analyses of CFRPs using different drill geometries. Compos Part B-Eng, 2013; 45: 1344-1350.

[19] Mudhukrishnan, M, Hariharan, P, Palanikumar, K and Latha, B. Tool materials influence on surface roughness and oversize in machining glass fiber reinforced polypropylene (GFR-PP) composites. Mater Manuf Process, 2017; 32; 988-997.

[20] Alizadeh Ashrafi, S, Miller, P, Wandro, K and Kim, D. Characterization and effects of fiber pull-outs in hole quality of carbon fiber reinforced plastics composite. Materials, 2016; 9: 828.

[21] Palanikumar, K. Modeling and analysis of delamination factor and surface roughness in drilling GFRP composites. Mater Manuf Process, 2010; 25: 1059-1067.

[22] Wang, GD and Kirwa, MS. Comparisons of the use of twist, pilot-hole and step-drill on influence of carbon fiber-reinforced polymer drilling hole quality. J Compos Mater, 2018; 52:1465-1480.

[23] Shunmugesh, K and Panneerselvam, K. optimization of Machining Process Parameters in drilling of cFrP using Multi-objective taguchi technique, toPSIS and rSA techniques. Polym Polym Compos, 2017; 25:185-192.

[24] Erkan, Ö., Sur, G. and Nas, E., 2020. Investigation of surface morphology of drilled CFRP plates and optimization of cutting parameters. Surface Review and Letters, 27(09), p.1950209.

[25] Tran, Q.P., Nguyen, V.N. and Huang, S.C., 2020. Drilling process on CFRP: multi-criteria decision-making with entropy weight using grey-TOPSIS method. Applied Sciences, 10(20), p.7207.

[26] Niranjan, T., Singaravel, B. and Raju, S.S., 2022. Delamination error of fibre Reinforced Polymer composite with different drill tool in drilling-A review. Materials Today: Proceedings.

[27] Divya, C., Raju, L.S., Singaravel, B. and Niranjan, T., 2022. Performance investigation of micro hole textured cutting inserts on power consumption and its measuring methodology in turning process. Alexandria Engineering Journal, 61(4), pp.3125-3130.

[28] Singaravel, B., Marulaswami, C. and Selvaraj, T., 2016. Analysis of the effect of process parameters for circularity and cylindricity errors in turning process. In Applied Mechanics and Materials (Vol. 852, pp. 255-259). Trans Tech Publications Ltd.

[29] Shekar, K.C., Singaravel, B., Prasad, S. and Venkateshwarlu, N., 2019. Effect of fiber orientation on the flexural properties of glass fiber reinforced, epoxy-matrix composite. In Materials Science Forum (Vol. 969, pp. 502-507). Trans Tech Publications Ltd.

[30] Singaravel, B. and Selvaraj, T., 2015. Optimization of machining parameters in turning operation using combined TOPSIS and AHP method. Tehnički vjesnik, 22(6), pp.1475-1480.

[31] Balasubramaniyan, S. and Selvaraj, T., 2017. Application of integrated Taguchi and TOPSIS method for optimization of process parameters for dimensional accuracy in turning of EN25 steel. Journal of the Chinese Institute of Engineers, 40(4), pp.267-274.

[32] Singaravel, B., Shankar, D.P. and Prasanna, L., 2018. Application of MCDM method for the selection of optimum process parameters in turning process. Materials Today: Proceedings, 5(5), pp.13464-13471.

[33] Singarvel, B., Selvaraj, T. and Jeyapaul, R., 2014. Multi objective optimization in turning of EN25 steel using Taguchi based utility concept coupled with principal component analysis. Procedia Engineering, 97, pp.158-165.

[34] Singaravel, B. and Selvaraj, T., 2017. Multi criteria optimisation using analytic hierarchy process in turning operation. International Journal of Machining and Machinability of Materials, 19(3), pp.218-229.

[35] Singaravel, B. and Selvaraj, T., 2016. Application of Taguchi method for optimization of parameters in turning operation. Journal for Manufacturing Science and Production, 16(3), pp.183-187.

[36] Divya, C., Raju, L.S. and Singaravel, B., 2020. A review of TOPSIS method for multi criteria optimization in manufacturing environment. In Intelligent Techniques and Applications in Science and Technology: Proceedings of the First International Conference on Innovations in Modern Science and Technology 1 (pp. 719-727). Springer International Publishing.

[37] Singaravel, B., Deva Prasad, S., Chandra Shekar, K., Mangapathi Rao, K. and Gowtham Reddy, G., 2019. Optimization of process parameters using hybrid Taguchi and VIKOR method in electrical discharge machining process. In Advanced Engineering Optimization Through Intelligent Techniques: Select Proceedings of AEOTIT 2018 (pp. 527-536). Singapore: Springer Singapore.