

Journal of Synergetic Research and Technology

<http://www.jsrt.in>

Research Article

OPTIMIZATION OF SPARK PLASMA SINTERING PARAMETERS OF INCONEL 825 COMPOSITES USING TOPSIS METHOD

S. Vinodh¹, P. Sivakumar^{1*} Santosh Kumar Tamang²

¹Aeronautical Engineering, Mahendra Engineering College, Namakkal, Tamil Nadu, India

²Department of Mechanical Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli, Arunachal Pradesh, India

Abstract

The processing technique utilized can improve the quality and properties of a material. This study investigates the impact of Spark Plasma Sintering (SPS) process parameters on the densification and microhardness properties of Inconel 825 superalloy composites. To reduce the number of tests, a L9 orthogonal array (OA) design is employed, and the experiments are evaluated using the Technique of Order Preference Similarity to the Ideal Solution approach. The experimental variables for spark plasma sintering include composite weight percentage, sintering temperature, and pressure. ANOVA was performed to identify the most influential factor on output performance. For optimal results, sintering at 1200°C and 40MPa is recommended. Based on the findings of ANOVA, the estimated F-values suggest that the composition of Inconel 825 compounds is the most significant factor influencing density and hardness, accounting for 98.53%.

Keywords: Sintering, ANOVA, Relative density, micro hardness, Pressure, Orthogonal array.

Published: 25-03-2026

***Corresponding author:** P. Sivakumar
Email: sivak1575@gmail.com

© 2026 The Author(s), TL Press

1. INTRODUCTION

Nickel-based alloys are used in a variety of industries, including aerospace and maritime applications. Nickel-based alloys have good chemical and mechanical qualities such as ductility, strength, toughness, and weldability. Sintering various materials with favorable qualities produces new materials that are used in a variety of engineering sectors. Furthermore, in order to improve mechanical performance, ceramics, particularly carbides, have been studied in recent years, and significant success has been achieved with various compounds, such as TiC, WC, or NbC. In recent years, research on the sintering of various materials has been done to increase thermal, mechanical, and chemical properties [1-3]. Ogunbiyi et al. (2020) used a sintering procedure to combine powders of super alloys. They improved the process variables and identified the most important elements affecting density and hardness. According to the study, sintering at 1200°C and 50MPa produces good density and toughness. Ogunbiyi et al. (2022) studied the microstructure, tribological, and corrosion properties of Inconel reinforced

with spark plasma sintered (SPS) graphene nanoplatelets. The inclusion of graphene nanoplatelets improves the friction coefficient. Pakseresht et al. (2016) used SPS to stack layered INCONEL 738 and NiCrAlY powder at 40 MPa under an 8 Pa vacuum environment. The sintered specimen was free of interfacial fractures and big pores. Yan et al. 2019 enhanced the mechanical characteristics of Inconel 718 alloy produced using the SPS technique. According to the study, the hardness and compressive characteristics improve significantly when manufactured using the SPS process. Rutkowski et al. 2023 used the SPS process to produce Inconel 625—(Ti,Zr)C0.85 composites and analyzed their properties. The rise in carbide reinforcement reduces heat diffusivity and specimen conductivity. Zhou et al. 2021 used laser cladding to create Inconel composites with nano tungsten carbide. WC/Inconel 625 has an improved microhardness rating of 590 HV. Graboś et al 2021 developed Inconel 625-niobium carbide composites for high-temperature applications. The analysis showed that the specimen's hardness improves uniformly.

This is an Open Access (OA) journal. All articles are published under the [Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License](https://creativecommons.org/licenses/by-nc-sa/4.0/), which permits others to remix, adapt, and build upon the work for non-commercial purposes, provided proper credit is given and any new works are distributed under the same license terms.

Murakam et al. (2021) used SPS to blend TiC0.5N0.5 , W, and Mo powders of particle sizes $<1 \mu\text{m}$. The analysis showed that the sintered specimen is very wear resistant. Zhang et al. (2009) created fine-grained INCONEL 625 superalloy via SPS and reported that the manufactured Inconel has exceptional strength and ductility. Oglezneva et al. (2021) used the SPS approach to create a homogenous binded sublayer of PV-NiCr16Al6Y and PV-Ni75Al23W composites. As a result, the following literatures demonstrate that the SPS method is utilized to generate diverse metal composites for a wide range of engineering applications. In this study, Inconel 825, with tungsten carbide (WC), cobalt (Co), and grapheme (Gr) powders are combined to investigate the influence of composition and sintering on relative density and microhardness. The composite composition, sintering temperature, and sintering pressure were all taken into account, and relative density and hardness were assessed using the L_9 Orthogonal Array (OA) experimental design, while performance was assessed using the Technique of Order Preference Similarity to the Ideal Solution (TOPSIS). Furthermore, an analysis of variance is performed to determine which factors have the greatest influence on output performance.

2. SPECIMEN PREPARATION

Specimens with 3 different compositions (90.85 wt% Inconel–7.5 wt% WC–0.5 wt% Co–1.15 wt% Gr, 50 wt% Inconel–5 wt% WC–35 wt% Co–10 wt% Gr, and 85 wt% Inconel–9 wt% WC–5 wt% Co–1 wt% Gr) were prepared at different sintering temperature and pressure. The Dr Sinter

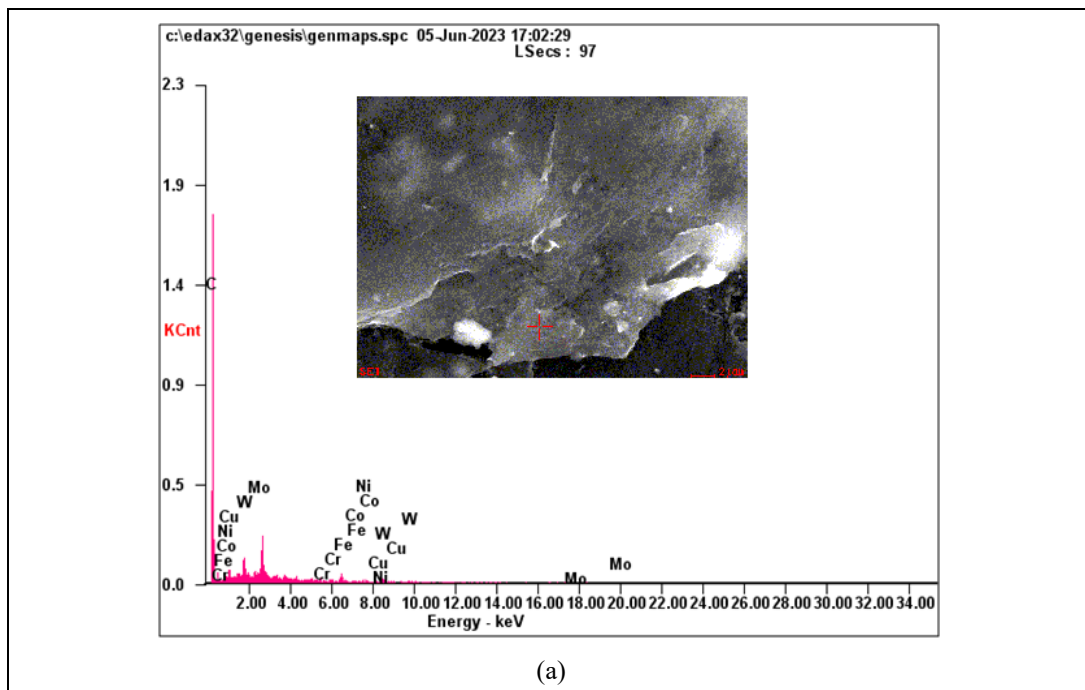
SPS machine shown in Figure 1 is used to sinter the specimens as shown in figure 2 [11-12].



Figure 1: Spark sintering process



Figure 2: Prepared sample



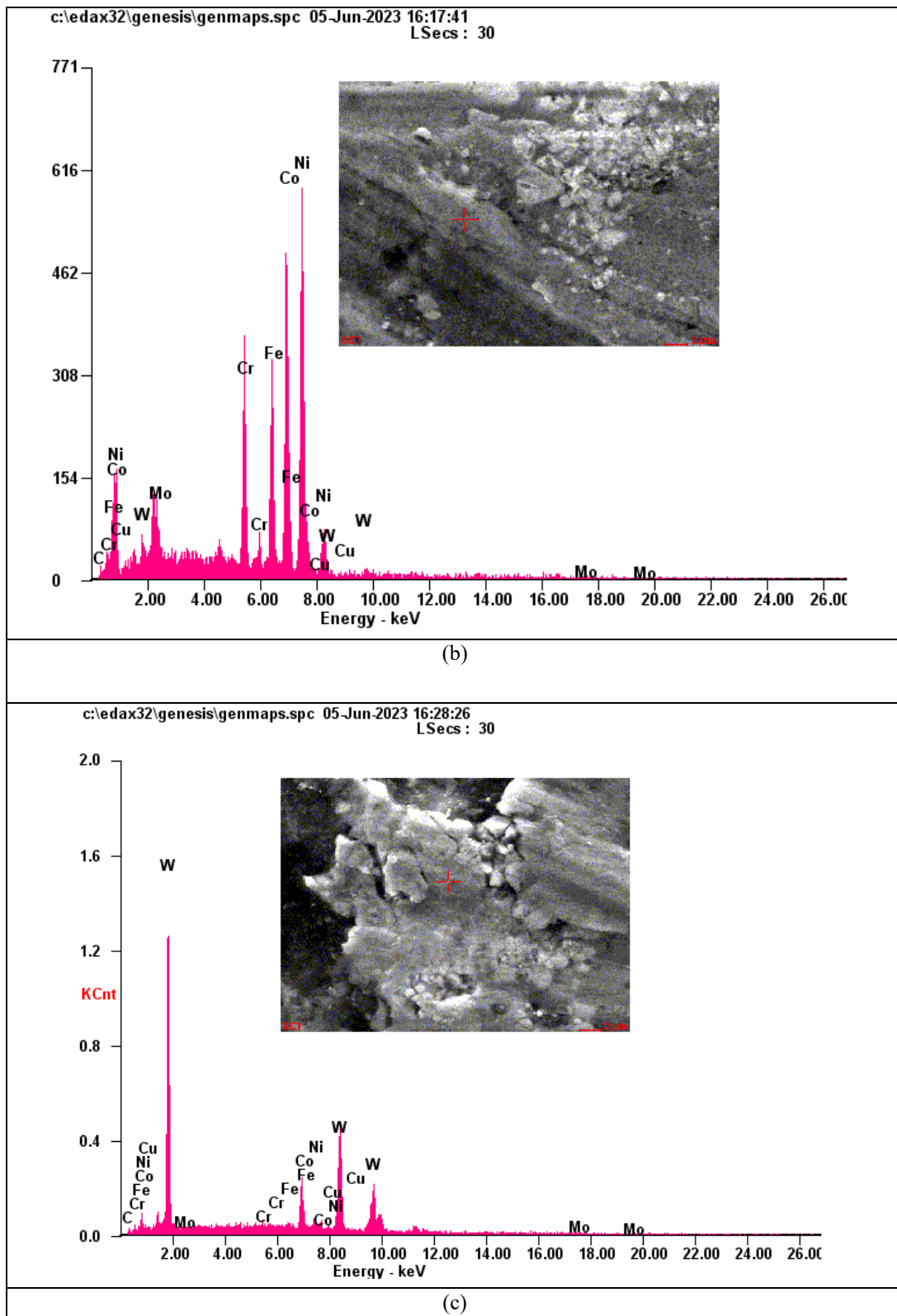


Figure 4: (a-c) Edax images of the all the specimens

Table 1 presents the parameters and levels considered for the spark sintering process. The total numbers of parameters are 3 and number of level is 3 and hence the degrees of freedom is $3(3-1)$ is 6. The orthogonal array (OA) selected should be more than 6, therefore L_9 OA is selected [13-14]. Table 2 presents the output performance is measured as

relative density of the specimen and micro-hardness. The parameters are optimized using TOPSIS and most significant process parameters are calculated using analysis of variance (ANOVA) [15-16].

Table 1: Sintering parameters

Sample with different composition	A	B	C
Sintering temperature (°C)	950	1000	1050
Pressure (MPa)	40	45	50

Table 2: L₉ OA and performance characteristics

Expt run	Sample with different composition	Sintering temperature (°C)	Pressure (MPa)	Relative density in %	Hardness (HV)
1	A	950	40	98	344
2	A	1150	45	96	341
3	A	1200	50	95	346
4	B	950	50	97	371
5	B	1150	40	98	377
6	B	1200	45	97	372
7	C	950	45	96	381
8	C	1150	50	97	379
9	C	1200	40	98	378

3. RESULTS AND DISCUSSION

TOPSIS is used to address the various problems and helps to make decision with different inputs. In the production sector, decision-making on problems depends on various factors, alternatives and their relations. Moreover, simultaneous effect of the factors on process plays a major role. Hence the application of the TOPSIS approach to such complicated problems has proved it as capable and simple to assess and pick the right set of factors from a available set of alternatives. This method utilizes the relative value of the estimation of the factors, in order to rise above various kinds of decision-making problems, TOPSIS can be successfully applied. TOPSIS is a multi-criteria optimization method applied to locate a finite set of the most suitable alternatives. The technique is based on the concept that the criterion picked must be the furthest away from the ideal positive outcome and the furthest away from the ideal negative result, with the top option being the one with the greatest relative closeness to the ideal answer.

TOPSIS processes can be summarized as follows.

TOPSIS's step-by-step procedure [14]:

1. Constructing of decision matrix consisting with m alternatives and n criteria,

$$\text{Decision Matrix} = \begin{bmatrix} \theta_{11} & \theta_{12} & \dots & \theta_{1n} \\ \theta_{21} & \theta_{22} & \dots & \theta_{2n} \\ \dots & \dots & \dots & \dots \\ \theta_{m1} & \theta_{m2} & \dots & \theta_{mn} \end{bmatrix}$$

---- (1)

2. Normalization of decision matrix is performed using equation 2, the normalized value σ_{ij} is calculated as

$$\sigma_{ij} = \frac{\theta_{ij}}{\sqrt{\sum_{j=1}^m \theta_{ij}^2}} \quad j=1,2,3,\dots,m, \quad i=1,2,3,\dots,n.$$

--- (2)

The weight for each criterion is calculated using the equation 3.

$$C_{ij} = X_i \sigma_{ij} \quad j=1,2,3,\dots,m, \quad i=1,2,3,\dots,n.$$

(3)

3. Obtain positive-ideal and negative-ideal outcome from the following relations

$$I^+ = (C_1^+, C_2^+, \dots, C_n^+) \text{ for max values}$$

(4)

$$I^- = (C_1^-, C_2^-, \dots, C_n^-) \text{ for min values}$$

(5)

4. Separation measures are evaluated using the following equations

$$d_j^+ = \sqrt{\sum_{i=1}^n (C_{ij} - C_i^+)^2} \quad j=1, 2, \dots, m.$$

(6)

$$d_j^- = \sqrt{\sum_{i=1}^n (C_{ij} - C_i^-)^2} \quad j=1, 2, \dots, m.$$

(7)

5. The relative closeness coefficient is found using the following equation

$$R_i = \frac{d_j^-}{d_j^+ + d_j^-}$$

(8)

6. The R_i values are arranged in the descending order for finding the most and the least preferred values.

Table 3: Normalized, weighted normalized data, separation measures and closeness coefficient values

Expt No	Normalized data		Weighted Normalized data		Separation measures		Closeness Coefficient
	Relative density in %	Hardness (HV)	Relative density in %	Hardness (HV)	d_j^+	d_j^-	R_i
1	0.3371	0.3135	0.0707	0.2478	0.0267	0.0031	0.1029
2	0.3303	0.3107	0.0692	0.2456	0.0288	0.0007	0.0244
3	0.3268	0.3153	0.0685	0.2492	0.0253	0.0036	0.1246
4	0.3337	0.3381	0.0699	0.2672	0.0072	0.0217	0.7495
5	0.3371	0.3436	0.0707	0.2716	0.0029	0.0260	0.9003
6	0.3337	0.3390	0.0699	0.2680	0.0065	0.0224	0.7743
7	0.3303	0.3472	0.0692	0.2744	0.0014	0.0288	0.9524
8	0.3337	0.3454	0.0699	0.2730	0.0016	0.0274	0.9445
9	0.3371	0.3445	0.0707	0.2723	0.0022	0.0267	0.9252

Table 4: Result of ANOVA

Symbol	Factors	DOF	SS	MS	F	% of contribution
A	Composition of Inconel 825 composite	2	1.2758	0.6379	1.4780	98.53
B	Sintering Temperature(°C)	2	0.0007	0.0004	0.0008	0.05
C	Pressure (MPa)	2	0.0130	0.0065	0.0150	1.00
F	Error	3	1.2949	0.4316		0.41
	Total	9	2.5844	0.2872		100.00

In this research the top alternative is found from 9 alternatives and based on the qualities, the decision matrix is found. By the TOPSIS techniques the Normalized decision matrix is evaluated. Weighted normalized decision matrix is evaluated from the normalized decision matrix, by using the weightage of 0.2096 and 0.7904 respectively for both the attributes. The positive ideal and negative ideal outcomes are established from weighted normalized decision matrix. Separation measures for every substitute are obtained using Equations 6 and 7. Then, the comparative nearness of a specific alternative were calculated using Equation 8. The maximum closeness coefficient is graded as number 1 among these values; it is obtained from the table 3 that the alternative 7 is best choice for relative density and hardness. The sintering temperature of 1200°C and 40MPa is best level to obtain the best output performance. Next best closeness coefficient is 0.9445 which is 8th experiment and the 9th experiment is the 3rd best alternative for the output responses. The relative density and hardness for the optimal parameter combination level is 99% and 381HV.

4. RESULTS OF ANOVA

The TOPSIS technique preference data are statistically evaluated using ANOVA to examine the influence of process variables on the output response. The F-test is used to examine the most significant parameter that influences performance characteristics. As per the outcome of ANOVA in Table 4, the estimated F-values show that the composition of Inconel 825 composition is the best important factor that

affects the density and the hardness with the contribution of 98.53%. The next influencing factor is pressure whose contribution is 1%.

5. CONCLUSIONS

- Four specimens with different weight percentage composition of Inconel 825, tungsten carbide (WC), cobalt (Co) and graphene powders are successfully sintered to study the effect of composition and sintering process on relative density and micro-hardness.
- The performance is evaluated using OA experimental design and (TOPSIS) method.
- The calculated weightage of relative density and micro-hardness is 0.2096 and 0.7904 respectively. The sintering temperature of 1200°C and 40MPa is the best level to obtain the best output performance. Next best closeness coefficient is 0.9445, the relative density and hardness for the optimal parameter combination level is 99% and 381HV.
- As per the ANOVA the assessed F-values illustrate that the composition of Inconel 825 composition is the best important factor that affects the density and the hardness with the impact of 98.53%. The subsequent influencing factor is pressuring whose contribution is 1%.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

REFERENCES

- Ogunbiyi, O., Jamiru, T., Sadiku, R., Adesina, O., Iolu Olajide, J., & Beneke, L. (2020). Optimization of spark plasma sintering parameters of inconel 738LC alloy using response surface methodology (RSM). *International Journal of Lightweight Materials and Manufacture*, 3(2), 177-188.
- Ogunbiyi, O., Jamiru, T., Sadiku, R., Adesina, O., Adesina, O. S., & Obadele, B. A. (2022). Spark plasma sintering of graphene-reinforced Inconel 738LC alloy: wear and corrosion performance. *Metals and Materials International*, 28, pages695–709 (2022)
- Pakseresht, A. H., Javadi, A. H., Bahrami, M., Khodabakhshi, F., & Simchi, A. (2016). Spark plasma sintering of a multilayer thermal barrier coating on Inconel 738 superalloy: Microstructural development and hot corrosion behavior. *Ceramics International*, 42(2), 2770-2779
- Yan, S., Wang, Y., Wang, Q., Zhang, C., Chen, D., & Cui, G. (2019). Enhancing mechanical properties of the spark plasma sintered inconel 718 alloy by controlling the nano-scale precipitations. *Materials*, 12(20), 3336.
- Rutkowski, P., Huebner, J., Graboś, A., Kata, D., Pasiut, K., Handke, B., & Nieroda, P. (2023). Thermal properties of spark plasma sintered Inconel 625 modified by titanium zirconium mixed carbide. *Journal of Thermal Analysis and Calorimetry*, 148, pages7633–7652 (2023).
- Zhou, S., Xu, T., Hu, C., Wu, H., Liu, H., & Ma, X. (2021). A comparative study of tungsten carbide and carbon nanotubes reinforced Inconel 625 composite coatings fabricated by laser cladding. *Optics & Laser Technology*, 140, 106967.
- Graboś, A., Huebner, J., Rutkowski, P., Zhang, S., Kuo, Y. L., Kata, D., & Hayashi, S. (2021). Microstructure and hardness of spark plasma sintered Inconel 625-NbC composites for high-temperature applications. *Materials*, 14(16), 4606.
- Murakami, T., Korenaga, A., & Ohana, T. (2021). Microstructure, mechanical properties, oxidation behaviors, and cutting performance of TiC0· 5N0. 5-X (X: W, Mo) cermet specimens prepared by spark plasma sintering. *Ceramics International*, 47(2), 1986-1999.
- Zhang, Z., Han, B. Q., Huang, J. Y., Han, Y. H., Zhou, Y., Kakegawa, K., & Lavernia, E. J. (2009). Mechanical behavior of cryomilled Ni superalloy by spark plasma sintering. *Metallurgical and Materials Transactions A*, 40, 2023-2029.
- Oglezneva, S. A., Kachenjuk, M. N., Smetkin, A. A., & Savich, V. V. (2021, August). Functional Gradient Heat-Resistant Materials Manufactured by Spark Plasma Sintering. In *Materials Science Forum* (Vol. 1037, pp. 464-472). Trans Tech Publications Ltd.
- Diouf, S. and A. Molinari, Densification mechanisms in spark plasma sintering: Effect of particle size and pressure. *Powder Technology*, 2012. 221: p. 220-227.
- Shongwe, M.B., et al., Effect of sintering temperature on the microstructure and mechanical properties of Fe–30%Ni alloys produced by spark plasma sintering. *Journal of Alloys and Compounds*, 2015. 649: p. 824-832.
- Maniraj, S., Thanigaivelan, R., Gunasekaran, K., & Saravanan, K. G. (2023). Optimization of Process Parameters in Electrochemical Micromachining of AMCs by Using Different Techniques of Weight Evaluation. *Advances in Materials Science and Engineering*, 2023.
- P. Venugopal, K.G. Saravanan, R. Thanigaivelan, Performance Analysis of EDM on Grey Cast Iron Using RSM and TOPSIS Method. *Applied Engineering Letters*, 8(1), 2023: 10-16. <https://doi.org/10.18485/aeletters.2023.8.1.2>
- Saravanan, K. G., Thanigaivelan, R., & Soundarrajan, M. (2021). Comparison of electrochemical micromachining performance using TOPSIS, VIKOR and GRA for magnetic field and UV rays heated electrolyte. *Bulletin of the Polish Academy of Sciences. Technical Sciences*, 69(5).
- Thanigaivelan, R., Arunachalam, R. M., Jerald, J., & Niranjana, T. (2011). Applications of Taguchi technique with fuzzy logic to optimise an electrochemical micromachining process. *International Journal of Experimental Design and Process Optimisation*, 2(4), 283-298.