



Contents lists available at ScienceDirect

## Materials Today: Proceedings

journal homepage: [www.elsevier.com/locate/matpr](http://www.elsevier.com/locate/matpr)

## Comparing green Machining and clean technology based Machining for tool wear reduction in Machining SAE 1045 steel

S. Rajesh<sup>a</sup>, R. Saravanan<sup>b</sup>, C.B. Sekar<sup>c</sup>, C. Gnanavel<sup>d</sup>, Avinash Malladi<sup>e</sup>, D.K. Nagarathi<sup>f,\*</sup>

<sup>a</sup> Department of Mechanical Engineering, Meenakshi College of Engineering, Chennai 600 078, Tamil Nadu, India

<sup>b</sup> Institute of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai 602105, Tamil Nadu, India

<sup>c</sup> Department of Mechanical Engineering, Tagore Engineering College, Chennai 600126, Tamil Nadu, India

<sup>d</sup> Department of Mechanical Engineering, School of Engineering, Vels Institute of Science, Technology and Studies (VISTAS), Vels University, Chennai 600117, Tamil Nadu, India

<sup>e</sup> Department of Mechatronics Engineering, Faculty of Science and Technology, ICFAI Tech, ICFAI Foundation for Higher Education, Hyderabad, Telangana State, India

<sup>f</sup> Department of Computer Science, Annamalai University, Chidambaram. & Office of Registrar, Tamil Nadu Teachers Education University, Chennai 600097, Tamil Nadu, India

### ARTICLE INFO

#### Article history:

Available online 5 May 2022

#### Keywords:

Machinability  
WCCO  
Nono-fluid  
Tool wear  
Acidum Boricum

### ABSTRACT

The shafts of machines and motors are manufactured in Lathe and precision shaft machining requires costly cooling methods like Minimum Quantity Liquid coolant, cryogenic cooling or high-cost artificial coolant. On other hand some soft requires CNC machining for meeting the requirements. The machinability performance can be measured with respect to tool wear. If tool wear increases it affects surface quality. Here used coconut oil or waste coconut oil (WCCO) with Nanoparticles of Acidum Boricum for machining the precision shaft and measured tool wear responses to measure and optimize the machining performance. The conventional green machining and proposed nanofluid machining with proposed nanofluid performance compared. Taguchi L16 experimental design employed with three factors varied at four levels. Cutting Vel. (40, 90, 140 and 190 m/min), Tool Feed (0.05, 0.10, 0.15 and 0.20 mm/rev) and The PVD coated insert used with Nose Radius (0.30, 0.60, 0.90 and 1.20 mm). The observation of both group of experiments statistically tested with independent samples test. The proposed method outperformed. Secondly the process parameters optimized with Taguchi analysis and further analyzed. Thirdly the mathematical model developed with ANOVA. This investigation focusses a passive technique of improving the flood cooling by use of biodegradable nanofluid as well as aimed to support the clean technology by identifying further use of WCCO.

Copyright © 2022 Elsevier Ltd. All rights reserved.

Selection and peer-review under responsibility of the scientific committee of the Second International Conference on Engineering Materials, Metallurgy and Manufacturing.

## 1. Introduction

Tool wear is very important measure of performance in orthogonal machining. Because the Finishing of shaft machining and material removal rate are depending on the tool wear. EN31 steel face milling was investigated with green machining, near dry machining (MQL), wet machining, air cooling with tungsten carbide tool inserts. The authors L18 mean based Taguchi method (ANOM) and analysis of variance also used for optimization, mathematical model developed. MQL reduced the flank 5.29% than flood cooling [1 2] investigated dry turning tool wear performance for machining AISI 52,100 steels. The experimental design and opti-

mize the process parameters with use of response surface methodology. The authors vary only process inputs like cutting velocity, nose radius of the tool insert used, feed rate [3]. Tool wear was reduced up to 0.052 mm and there by obtained minimum surface roughness of 2.967  $\mu\text{m}$ . the statistical model  $R^2$  for surface roughness was 0.9921 and 0.9876 for tool wear. As  $R^2 > 0.95$  indicated significant agreement between experimental results and model predictions [4 5–9] suggested the mechanical fitness through the fatigue life of the steel grade SAE 1045 for meeting the requires of dual rotating shaft [10–15] ensured the endurance of fatigue loading capability in both the uniform speed and variable speed also investigated. Variety of steel works were investigated by various researchers and comparatively the steel of SAE 1045 is found fit for shock loading type applications [16–22 23–25] ensured the tribological properties of SAE 1045. [26] preferred

\* Corresponding author.

E-mail address: [kaavya\\_naga@yahoo.com](mailto:kaavya_naga@yahoo.com) (D.K. Nagarathi).

the water-based alumina nanofluid for as heat transfer fluid applications. This research aimed to support clean technology by identifying the alternate use of waste (used) coconut that is the coconut oil after used for preparing banana chips in the ‘Kerala chips’ at Chennai. The tool wear reduction by use of oil with Nano Acidum Boricum particles suspension in the flood cooling method. This investigation is novel and did not considered so far for the similar application.

## 2. Materials and methods

### 2.1. Experimental setup

Tool wear minimization in SAE 1045 steel shaft manufacturing is prime objective of this study. This investigation utilized general purpose but semiautomated 8 speed heavy duty lathe (Fig. 1). The steel samples obtained from the industrial shaft manufacturers at Ambattur Chennai and prepared the specimens.

### 2.2. Work and tool material

The steel samples obtained from the industrial shaft manufacturers at Ambattur Chennai and prepared the specimens.

### 2.3. Nanofluid coolant

The used coconut oil pre-processed for cleanliness and free from foreign particles, filtered and impurities removed. The increase of quantity of Acidum Boricum concentration will increase the viscosity of the nanofluid. Ball mill employed here for 12 h to prepare nanofluid fraternisation base fluid (used coconut oil) and Nanoparticles of Acidum Boricum. The coolant supplied at the cutting zone was 3.5 L per minute. The flow rate set by trail experiments to finalize it at the condition of no fumes generated. So, no harm fumes generated while testing.

### 2.4. Testing

Sample length of 50 mm is machined in each work piece. The observations like machining time for sample length by using digital stop watch and weight loss of tool insert with help of Precision Balance with the accuracy of 0.01 mg. The rage of weight could be measured from 0.01 mg to 300,000 mg.

**Table 1**  
SAE1045 Steel shaft manufacturing input particulars with Eco-friendly Nanofluids.

Input Levels	Manufacturing Inputs		
	Cutting (Speed) Velocity	Feed Rate (mm/ rev)	Tool tip (nose) radius (mm)
1	40	0.05	0.3
2	90	0.1	0.6
3	140	0.15	0.9
4	190	0.2	1.2

### 2.5. Experimental design and optimization

Taguchi analyse is employed in this investigation. As this investigation involves 4 factors and used at 4 levels, the L16 orthogonal array (Table 2) used to conduct experiment. The range of input values adapted by considering the manufacturer catalogue and conducting trail experiments for meeting the shaft requirements by the end application (Table 1). The experiments conducted without supplying any coolant condition and supplying the Nanofluid as coolant condition. There were multiple trails (minimum 3 trails) conducted and tool wear observed and average of them considered as final observation. Tool wear was measured and presented group wise experiment wise comparatively in Table 2.

## 3. Results and discussion

The samples which machined without cooling environment is called as green machining or dry machining. Same experimental input conditions employed for both machining conditions. The observations of surface roughness of the samples from the dry machining and nanofluid based clean machining or wet machining were consolidated in the Table 2 and the same was used. T-test used for conducting the statistical test on observations for both machining practices. Table 3 illustrates differences in average of average observations difference. That is the mean of surface roughness observations for dry machining 0.7528 g and for proposed nanofluid wet machining 0.3536 g. Fig. 3 illustrates this graphically with error bar at 95% confidential level with  $\pm 1SD$ .

From the Table 4 the decision can be made are as follows: As significant value is less than 0.05 ( $0.027 < 0.05$ ) the proposed method significantly reduced tool wear. The mean difference 0.39925 g ( $t_{4,656} = 0.39925$  g) indicates that the proposed method reduced tool wear averagely by 0.39925 g. Fig. 2 shows the graphical comparison of means of tool wear of both methods. Results of



**Fig. 1.** Experimental Setup of HMT heavy duty lathe and Tool wear tester.

**Table 2**  
Observations of average Tool Wear in Machining Conditions.

Trail	Cutting (Speed) Velocity (m/min)	Feed Rate (mm/rev)	Tool tip (nose) radius (mm)	Tool Wear (g) observed on Machining Condition of	
				Clean/Dry Machining	Green Machining
1	40	0.05	0.3	0.35	0.06
2	40	0.10	0.6	0.39	0.08
3	40	0.15	0.9	0.43	0.13
4	40	0.20	1.2	0.5	0.18
5	90	0.05	0.6	0.49	0.21
6	90	0.10	0.3	0.56	0.24
7	90	0.15	1.2	0.62	0.29
8	90	0.20	0.9	0.68	0.33
9	140	0.05	0.9	0.85	0.34
10	140	0.10	1.2	0.9	0.39
11	140	0.15	0.3	0.94	0.44
12	140	0.20	0.6	0.99	0.5
13	190	0.05	1.2	1.03	0.53
14	190	0.10	0.9	1.1	0.58
15	190	0.15	0.6	1.07	0.64
16	190	0.20	0.3	1.14	0.71

**Table 3**  
T-Test – Methods Statistics.

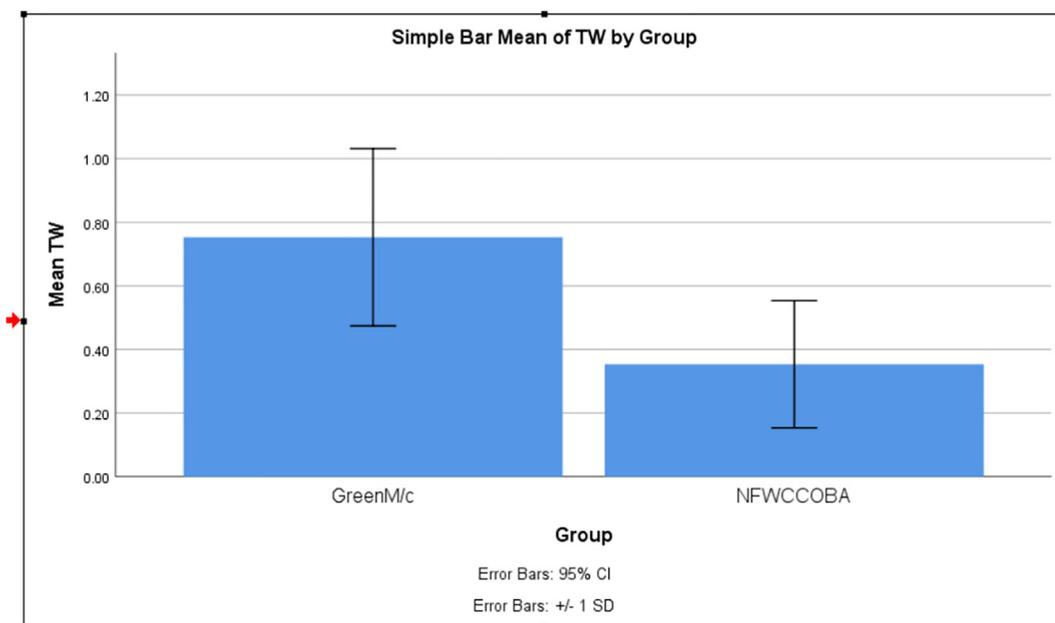
Group	Tool Wear (g) observed on Machining Condition of	
	Green/Dry Machining	Clean Machining
No of samples per method	16	16
Mean tool wear	0.7528	0.3536
Std. Deviation	0.27879	0.19983
Std. Error Mean	0.06970	0.04996

the Taguchi analysis furnished in the Table 5. If the value of signal to noise ratio high is favourable for achieving minimum tool wear. The delta value decides the Ranking of input variables. Rank 1 is more sensitive and rank 3 is less sensitive. Fig. 3 is graphical form of Table 5 its shows the signal to noise ration factor wise as well as

**Table 4**  
Results of Levene's Test for equality of variances.

Particulars	Description	Observations of Tool Wear (g) Equal Variances	
		assumed	not assumed
t-test for Equality of Means	Mean Difference	0.39925	0.39925
	Standard Error Difference	0.08575	0.08575
	Sig. (2-tailed)	0.000	0.000
Levene's Test for equality of variances	F	5.435	-
	Sig.	0.027	-
	df	30.000	27.194
95% Confidence Interval of the Difference	Lower	0.22412	0.22336
	Upper	0.57438	0.57514

**GGraph**



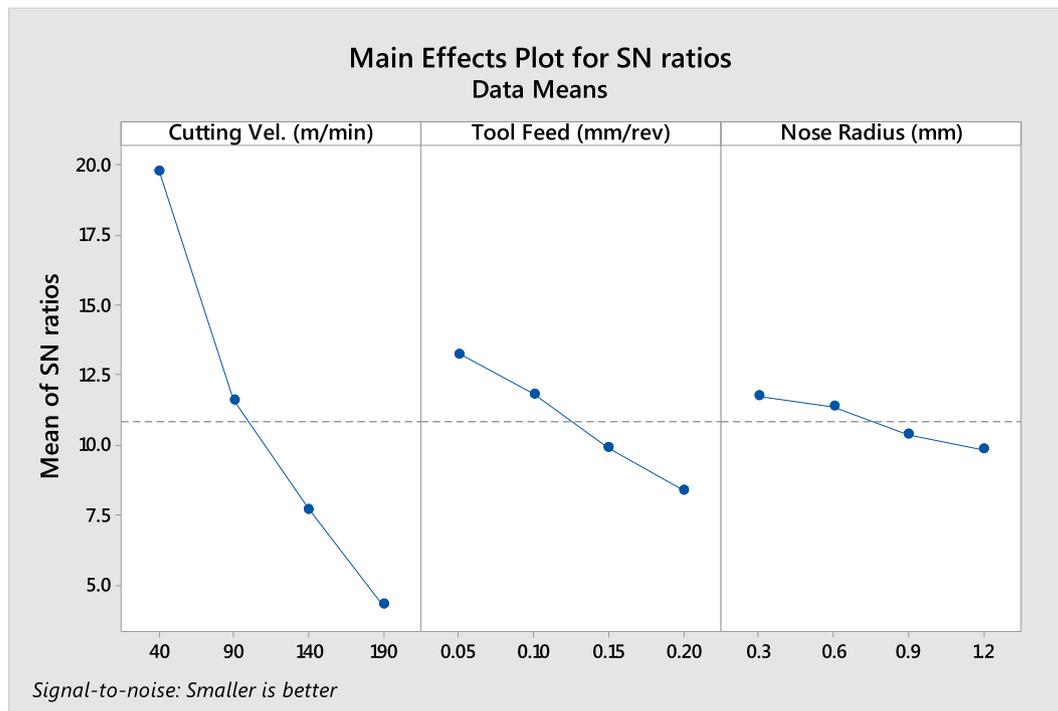
**Fig. 2.** G-Graph for comparative means of Tool wear observations.

**Table 5**  
Results of Taguchi Analysis for tool wear.

Level	Cutting (Speed) Velocity	Feed Rate (mm/rev)	Tool tip radius (mm)
1	19.748	13.219	11.735
2	11.583	11.811	11.348
3	7.675	9.870	10.363
4	4.274	8.380	9.835
Delta	15.473	4.839	1.900
Rank	1	2	3
Smaller is better			

level wise. Relationship between level variation for each factor for the response of tool wear. Table 6 confirms nose radius not influencing ( $p > 0.1$ ) in the tool wear response. This may be due to range selected was low but it is good for machining the steel work of grade SAE1045. Table 7 is Coefficient for mathematical model (equation (1)) for predicting the tool wear for unexperimented combinations of inputs. The Fig. 4 ensured that the observations are acceptable has neglected residuals.

In case of nose radius is  $p = 0.15$  and  $p > 0.1$ . So that factor did not influence on tool wear response. Table 7 is ANOVA results and



**Fig. 3.** Taguchi analysis results for the response of Tool wear in proposed Nano fluid based clean manufacturing.

**Table 6**  
Results for fitness of Factors.

Observation Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cutting (Speed) Velocity	3	0.551819	0.183940	1731.20	0.000
Feed rate	3	0.047869	0.015956	150.18	0.000
Tool tip radius	3	0.000819	0.000273	2.57	0.150
Error	6	0.000637	0.000106		
Total	15	0.061144			

**Table 7**  
Results for the fitness of Factor's Level.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.35312	0.00258	137.03	0.000	
Cutting (Speed) Velocity					
40	-0.24063	0.00446	-53.91	0.000	1.50
90	-0.08562	0.00446	-19.18	0.000	1.50
140	-0.06438	0.00446	14.42	0.000	1.50
Feed rate					
0.05	0.06813	0.00446	-15.26	0.000	1.50
0.10	0.03062	0.00446	-6.86	0.000	1.50
0.15	0.02187	0.00446	4.90	0.003	1.50
Tool tip radius					
0.3	0.00937	0.00446	-2.10	0.080	1.50
0.6	0.00437	0.00446	0.98	0.365	1.50
0.9	-0.00812	0.00446	-1.82	0.119	1.50

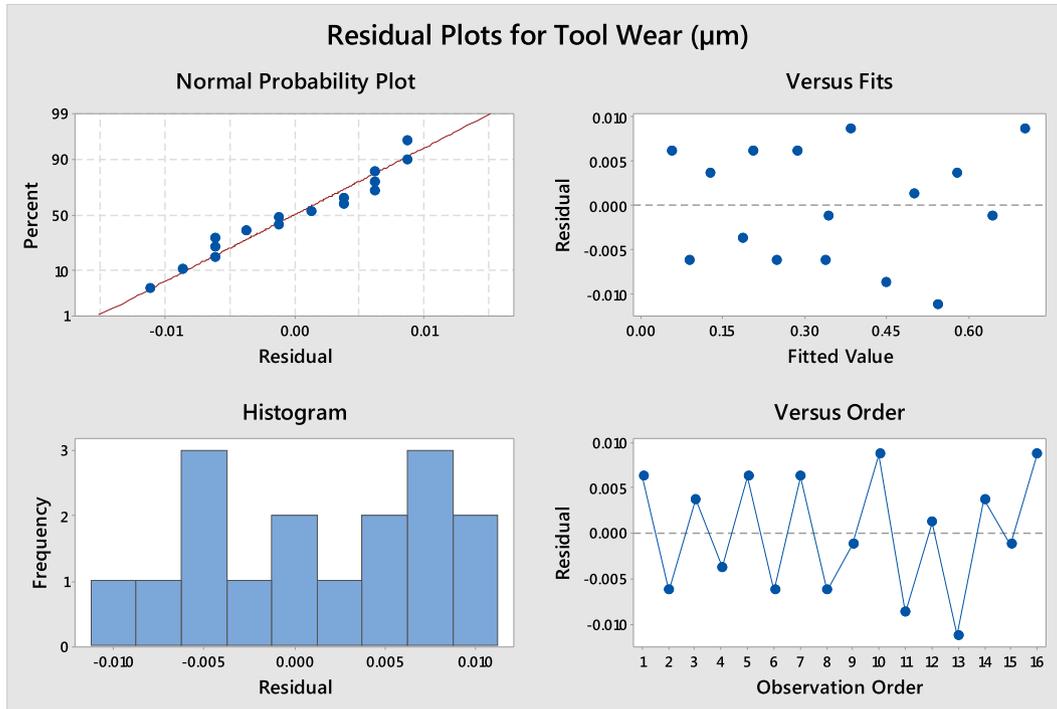


Fig. 4. Analysis of Variance results for of Tool wear in proposed Nano fluid based clean manufacturing.

Table 8 Results of Model validation.

Model Summary			
S	R <sup>2</sup>	R <sup>2</sup> (adj)	R <sup>2</sup> (pred)
0.0103078	99.89%	99.73%	99.25%

help to make decision on the factor’s level. In particularly the low nose radius (0.3 mm) influence a little but not significant as  $p = 0.080$ ;  $p < 0.05$ . In case of nose radius 0.6 mm and 0.9 mm were not significantly influences on tool wear. In the 16 experimental observations, none is found lack of fit.

Table 8 confirms that as R<sup>2</sup> value is greater than 95%. The prediction of mathematical model is good agreement with results by experimentation.

$$\begin{aligned}
 \text{ToolWear} = & 0.35312 - 0.24063 * [\text{Cutting}(\text{Speed})\text{Velocity}_{40}] \\
 & - 0.085626 * [\text{Cutting}(\text{Speed})\text{Velocity}_{90}] + 0.06438 \\
 & * [\text{Cutting}(\text{Speed})\text{Velocity}_{140}] + 0.26188 \\
 & * [\text{Cutting}(\text{Speed})\text{Velocity}_{190}] - 0.06813 * [\text{FeedRate}_{0.05}] \\
 & - 0.03062 * [\text{FeedRate}_{0.10}] + 0.02187 * [\text{FeedRate}_{0.15}] \\
 & + 0.07688 * [\text{FeedRate}_{0.20}] + 0.00937 \\
 & * [\text{Tooltip's Nose Radius}_{0.3}] + 0.004371 \\
 & * [\text{Tooltip's Nose Radius}_{0.6}] - 0.00812 \\
 & * [\text{Tooltip's Nose Radius}_{0.9}] - 0.00562 \\
 & * [\text{Tooltip's Nose Radius}_{1.2}]
 \end{aligned} \tag{1}$$

#### 4. Conclusion

The low cost nanofluid based machining was experimented and discussed. The result discloses that the proposed clean manufacturing method considerably reduced the Tool wear. The followings are silent points.

- The T test results reveals that the observations are statistically significant and value of P = 0.028 which is less than 0.05.
- The R<sup>2</sup> value is found 99.89% which indicates that good agreement between the predicted value with use of proposed mathematical model with experimented results.
- The proposed novel Nano fluid based wet machining reduced the tool wear from 0.7528 g to 0.3536 g. The optimal machining parameters are Hence enhanced of tool life is ensured.
- The low cutting velocity and low feed rate gave minimal tool wear. The nose radius does not influence significantly under the limitations of this study.
- The optimal process parameters identified are: machining speed 40 m/min, and feed rate 0.05 rate and tool tip radius 0.3 mm.

#### Declaration of Competing 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

- [1] S. Karthikeyan, B. Mohan, S. Kathiresan, G. Anbuhezhiyan, J. Mater. Res. Technol. 15 (2021) 2658–2672.
- [2] H. Wu, T. Bill, Z.J. Teng, S. Pramanik, K.-P. Hoyer, M. Schaper, P. Starke, Mater. Sci. Eng.: A, 794 (2020) 13959720, <https://doi.org/10.1016/j.msea.2020.139597>.
- [3] G.M. Dominguez Almaraz, J.A. Ruiz Vilchez, A. Domingue, Procedia Struct. Integrity 18 (2019) 594–599, <https://doi.org/10.1016/j.prostr.2019.08.204>.
- [4] V.V. Castro, L. Antonio, M. Fontoura, J. Dornelas, M.S. Benfica, J. Luiz, C.A. Pacheco Santos, Wear 368–369 (2016) 267–277, <https://doi.org/10.1016/j.wear.2016.09.026>.
- [5] R. Pugazhenthii, G. Anbuhezhiyan, R.K. Muthuraman, M. Vignesh, A. Ponshanmugakumar, Mater. Today: Proc. 46 (2021) 4344–4348.
- [6] J. Thiyagaraj, I. Rahamathullah, R. Bharathiraja, G. Anbuhezhiyan, A. Ponshanmugakumar, Mater. Today: Proc. 46 (2021) 3665–3669.
- [7] T. Sathish, N. Sabarirajan, R. Saravanan, J. Mater. Res. Technol. 14 (2021) 1494–1503.

- [8] J. Thiagaraj, I. Rahamathullah, G. Anbuhezhiyan, R. Bharathiraja, A. Ponshanmugakumar, *Mater. Today: Proc.* 46 (2021) 4047–4053.
- [9] R. Saravanan, R. Pugazhenthii, T. Gopalakrishnan, *Microscopy Res.* 10(4), 284–291.
- [10] N. Ramadoss, K. Pazhanivel, G. Anbuhezhiyan, *J. Mater. Res. Technol.* 9 (3) (2021) 6297–6304.
- [11] M. Karuppasamy, R. Saravanan, M. Chandrasekaran, V. Muthuraman, *Int. J. Mech. Eng. Technol.* 10 (2016) 120–127.
- [12] G. Anbuhezhiyan, B. Mohan, N. Senthil Kumar, R. Pugazhenthii, *Met. Mater. Int.* 27 (2021) 3058–3069.
- [13] G. Anbuhezhiyan, B. Mohan, R.V. Karthikeyan, *App. Mech. Mater.* 766–767 281–286.
- [14] M. Karuppasamy, R. Saravanan, M. Chandrasekaran, V. Muthuraman, *Mater. Today: Proc.* 21–1 (2020) 940–947, <https://doi.org/10.1016/j.matpr.2019.08.242>.
- [15] C. Gnanavel, R. Saravanan, M. Chandrasekaran, *Mater. Today: Proc.* 21 (2018) 865–869.
- [16] K. Velavan, B. Mohan, G. Anbuhezhiyan, N. Senthilkumar, *Silicon* 13 (2021) 3639–3647.
- [17] E.J. Siochi, *Nat. Nanotechnol.* 9 (2014) 745–747.
- [18] P. Cataldi, A. Athanassiou, *Appl. Sci.* 8 (2018) 1438, <https://doi.org/10.3390/app8091438>.
- [19] A.C. Ferrari, F. Bonaccorso, V. Fal'Ko, K.S. Novoselov, S. Roche, P. Bøggild, S. Borini, F.H. Koppens, V. Palermo, N. Pugno, *Nanoscale* 7 (2015) 4598–4810.
- [20] A.K. Geim, K.S. Novoselov, *Nat. Mater.* 6 (2007) 183–191.
- [21] M. Ayyandurai, B. Mohan, G. Anbuhezhiyan, *J. Mater. Res. Technol.* 15 (2021) 2170–2187.
- [22] H. Wu, L.T. Drzal, *Carbon* 50 (2012) 1135–1145.
- [23] G. Anbuhezhiyan, B. Mohan, R. Kathiresans Pugazhenthii, *Mater. Today Proc.* 27 (2020) 1530–1534.
- [24] C. Lin, D.D.L. Chung, Graphite nanoplatelet pastes vs. carbon black pastes as thermal interface materials, *Carbon* 47 (1) (2009) 295–305.
- [25] S. Prolongo, R. Moriche, A. Jiménez-Suárez, M. Sánchez, A. Ureña, *J. Adhes.* 90 (2014) 835–847.
- [26] M. Ramamurthy, M. Balasubramanian, N. Senthilkumar, G. Anbuhezhiyan, *Mater. Res. Express* 9 (2022) 026528.