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Optimization of dead metal zone to reduce cutting forces in micro milling of Inconel 718 using RSM

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A B S T R A C T

This study focuses on the mechanism of DMZ (dead metal zone) creation, as well as the impact of cutting edge geometries (sharp, chamfered, double chamfered, and blunt edges), cutting speed, and coefficient of friction on DMZ formation while milling Inconel 718 material (FEM). A non-contact type sensor called a laser doppler vibrometer (LDV) is used to monitor the vibration of rotating surfaces. In current research work, the LDV is used to measure the mill cutter vibration in micro-milling of Inconel 718 in terms of acoustic optic emission signals. A FFT (fast fourier transformer) is used for signals processing in to frequency domain. Design of experiments as per Taguchi, experiments were performed on the alloy at three levels of spindle speeds, depth of cuts, feed rates. Experimental results on the amplitude o vibration of tool along X and Y directions, surface roughness were measured and analysed using response surface methodology. Analysis obtained from the variance was used to recognize the significant parameters which effect the vibration of tool and roughness of surface. RSM was implemented and optimized process parameters for the minimum vibration amplitude and surface roughness.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials Innovation and Sustainable Manufacturing.

1. Introduction:

In the present days, many equipment's are used to measure the vibrations produced in various mechanical related machines, in which laser doppler vibrometer (LDV) is the most commonly used in measuring the vibration with high accuracy. In the current research work the LDV is used to analysis machining parameters of end milling operation using tungsten carbide inserts on Inconel 718. The main objective of the experimental analysis work is employed to review the machining parameters like feed rate, depth of cut, cutting speed and vibration amplitude. The experiments were conducted **by** CNC **milling machine** and calculate the surface roughness. Two directions(along x- axis, y-axis) of vibration amplitude were measured using laser droppler vibrometer along with the optimization analysis of the machining characteristics. The effective determination of a few key process control elements and combinations of such parameters by the optimization of various processing parameters on a CNC milling machine establishes a close relationship with the desired output of the machine. In order to improve machineability, choosing the best cutting conditions is a significant stage in the machining process (see Table 1).

Many researchers have done past studies on different alloy's vibration rate using Laser Doppler vibrometer (LDV) and response surface methodology. Sanvikcoromant [1] has stated that CNC milling process is the most frequent used method for MRR (metal removal rate) is high and production of complex shapes and structures which could not be performed by other processes.Savas V et. al [2] have conducted an experimental investigation to determine the impact of the tangential turn-milling technique on the surface roughness of the cutting parameters, including cutter speed, workpiece speed, axial feed rate, cutting tool helix angle, and depth of cut, when machining MS58 brass specimens. Sahoo, P.[3] investigated the surface profile's roughness characteristics after turning AISI 1040 steel on a CNC machine. Using the response surface approach and genetic algorithm, the surface roughness was optimized. Sabahudin et.al.[4] compared to the high speed turn-milling method's impact on the surface roughness of conventional turning. They came to the conclusion that high speed turning is preferable to conventional turning. Ramesh, S.[5] developed a surface methodology to reduce surface roughness when milling

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Table 1
CNC milling machine (BFW Chandra plus) Specifications.

Parameter	Specifications
Clamping area	316 × 1060 mm
Maximum load on the table	300Kg
Table top – spindle face distance	74 – 455 mm
No.of axis	3
Longitudinal operation (X-axis)	750 mm
Transverse operation (Y-axis)	340 mm
Vertical operation (Z-axis)	370 mm
Feed rate	1–5000 mm/min
Spindle speed range	60–6000 rpm
Maximum tool diameter	80 mm
Pneumatic supply	6 bar

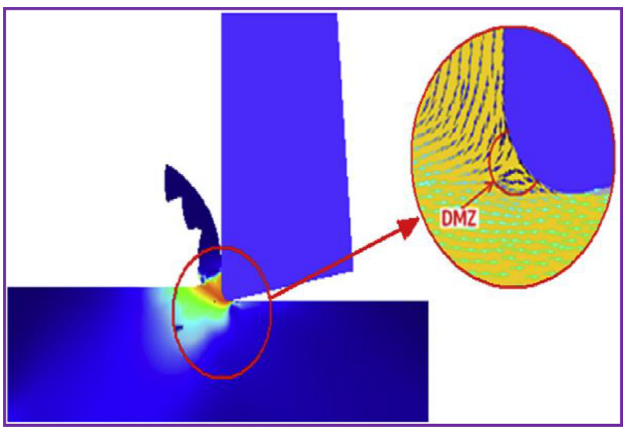

Fig. 1. Formation of dead metal zone in machining.

titanium alloy using Taguchi's orthogonal array and analysis of variance (ANOVA), and determined cutting parameters like feed, cutting speed, and depth of cut under various cutting conditions using tools coated with CVD (TiN– TiCN–Al2O3–TiN). In their research, W.H. Yang and Y.S. Tarng [6] they found out that the main cutting parameters will affect the cutting performance in turning operation of the S45C steel bars using tugsten carbide cutting tools, which was detected by taguchimethod.Sener.K et al.[7] examined the consequencesof machining parameters on the tool wear and milling forcethroughout milling of bothopen-cell SiC foam metal matrix composite (MMC) and Al 7075 utilizing a varnishedcarbide cutting tool and finally concluded that cutting tool wear was straight way over done by the cutting depth in the milling of MMC,and the feed rate was the most dominant factor on the tool wear in the milling of Al7075 [13,15].

Metal in the primary deformation zone gets compressed and flows plastically along the shear plane. As shown in the Fig. 1, some metal flows over the tool face in the form of chip and some metal flows in to the work-piece under the tool. Some metal gets trapped in front of the cutting edge called as dead metal cap or dead metal zone (DMZ) which greatly effects the cutting forces and machining performance.

Objectives of this study To Estimate Cutting Force (Fc) & Thrust Force (F_T) considering the DMZ Geometry. To optimize the process parameters (Spindle speed and feed) and Tool parameters (nose radius and rake angle) to minimize DMZ geometry in the micro milling of hardened AISI D2 steel [9].

2. Materials and methodolodgy

In this research work tests wereperformed on Inconel 718 alloy-with a differentchemical compostion depending on the research

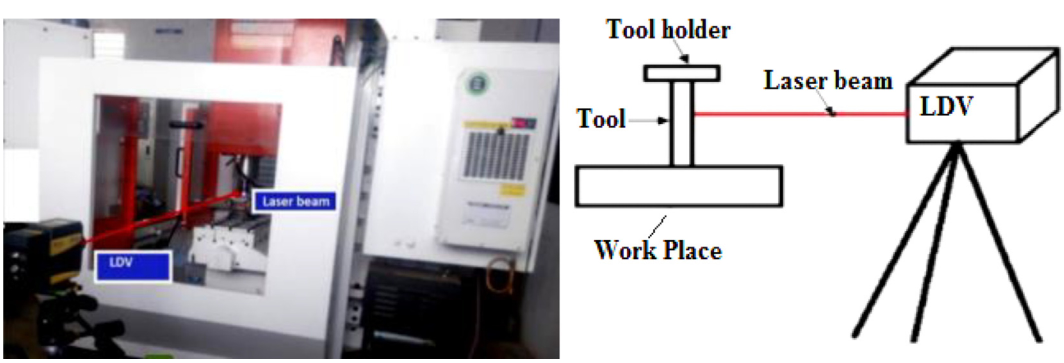

Fig. 2. Experimental setup with block diagarm.

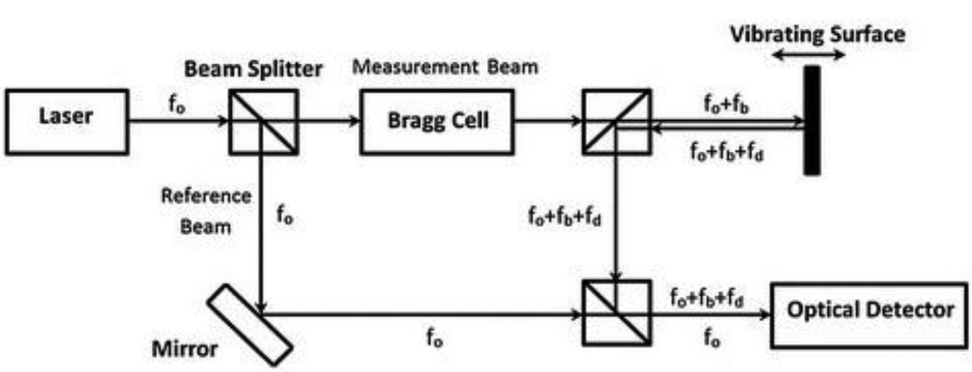

Fig. 3. Layout of laser doppler vibrometer.[8].

Table 2
ANOVA response on the surface roughness.

Source	Sum of squares	df	Mean square	F value	P value Prob > F
Model	0.24	5	0.043	4.34	0.0017
A:SS	0.13	1	0.14	19.57	0.0003
B:F	0.042	1	0.041	1.14	0.0325
C:DOC	1.668E-003	1	1.668E-003	1.80	0.6464
AB	0.047	1	0.047	0.52	0.0231
AC	2.134E-004	1	2.134E-004	1.42	0.8695
BC	0.022	1	0.022	1.63	0.1077
Residual	0.14	21	7.697E-003	–	–
Correlation total	0.41	25	–	–	–

requirement.Titanium can be used for turning, milling and drilling. It can give good surface integrity and high dimensional accuracy, being the machining an essential production process. How ever the machining process of titanium alloy is not easy.

Mill Cutter are made withtungsten carbide and it was used to perform an operation of micro milling on the titanium alloy. The miller cutter has a shank diameter of 4 mm and a tip diameter of 1 mm. Response surface methodology was used for optimizeparameters of cutter such as roughness of surface and vibration of milling cutter. RSM is a good alternative to the traditional approach to finding the surface variability and cutting variable response to tool life.

2.1. CNC milling machine specifications

CNC milling machine(BFW Chandra plus) was used in the experimentation process of the titanium alloy.

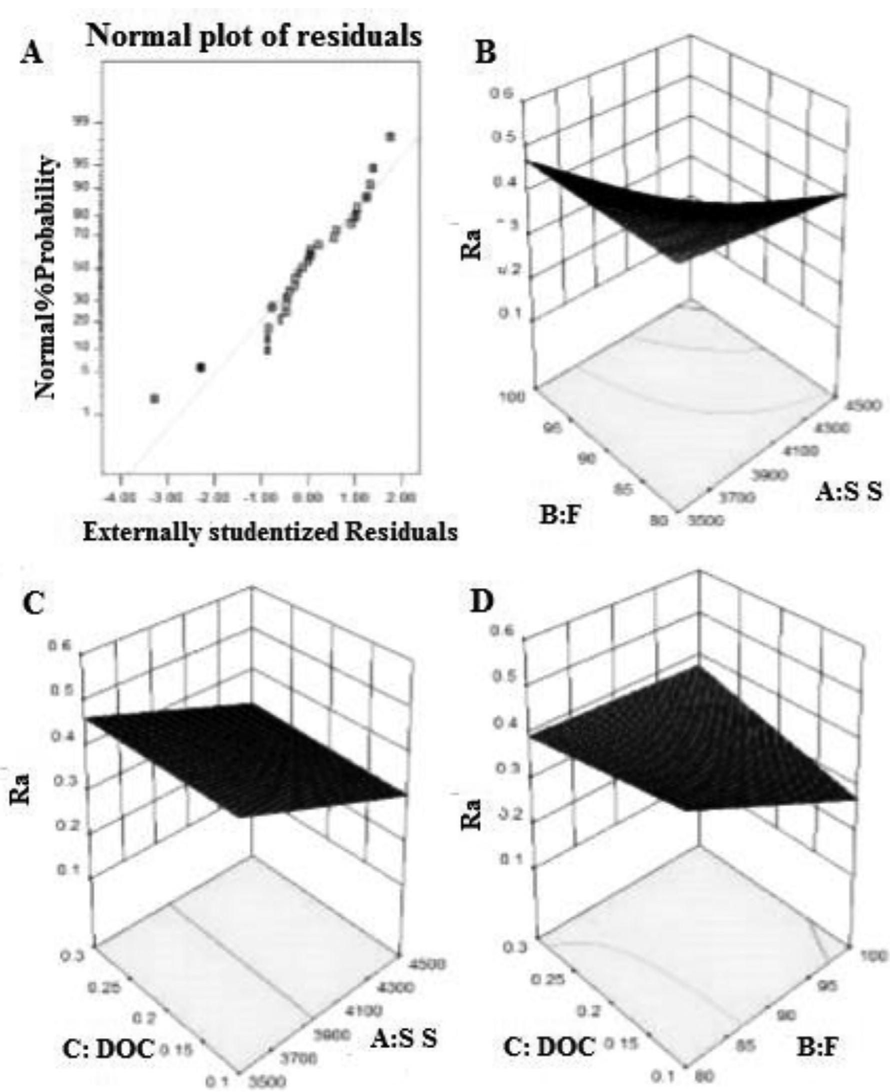

Fig. 4. Effect of surface roughness; (A) Normal probabilities of residuals for Ra, (B) Effect of feed and spindle speed on Ra, (C) Effect of cut depth and spindle speed on Ra, (D) Effect of cut depth and feed rate on Ra.

2.2. Laser doppler vibrometer:

Laser Doppler Vibrometer (LDV) is a velocity and displacement measurement techniuque.It is used in the analysis for diffrent types of vibrating systems.A typical modern vibrometer consists of the sensor head unit with a controller.The below Fig. 2 represents the experimental setup of the proposed LDV system. The result of the LDV is commonly a continuous analog voltage that is propotional to the destination velocity component onward to the path of the laser beam (see Fig. 3).

3. Results and discussion

Investigational outcomes on the roughness of surface, vibration of the cutter along the X and Y direction are represented in the Table 2. ANOVA is generally used to get the significant interaction of the cutting parameters on the surface roughness.The indiviual cutting parameters and the interaction of the cutting parameters which are having the p value less than 0.050 indicate that the model terms are significant. As per the output obtained, the spindle speed and the feed rate are significant with p values as 0.0004 and 0.0326. They is no significant effect on the depth of cut on the surface roughness.

Quadratic models for the surface roughness and the ampltiude of vibration velocity along × and y direction are given by the below stated equations

Ra = -2.16188 + 9.29928E-004*SPINDLE SPEED
$+ 0.036621 * F - 4.08031 * DOC - 1.24750E-$

005*SPINDLE SPEED*F + 8.43333E-005*SPINDLE SPEED*DOC
$+0.042658*$

F*DOC.

Vx = -0.65066 −3.93333E-005*SPINDLE SPEED
$- 8.46833E - 003 * F + 7.06439 * DOC$

+5.15000E-006*SPINDLE SPEED*F-8.45167E
$-004 * SPINDLESPEED * DOC-$

0.045233*F*DOC

Vy = + 1.37671 −2.45350E −004 * S −0.013878 * F
$-0.61975 * DOC + 2.4750-006*$

SPINDLE SPEED * F −1.48333E −005 * SPINDLE SPEED *DOC
$+ 8.97500E-$

003*F*DOC

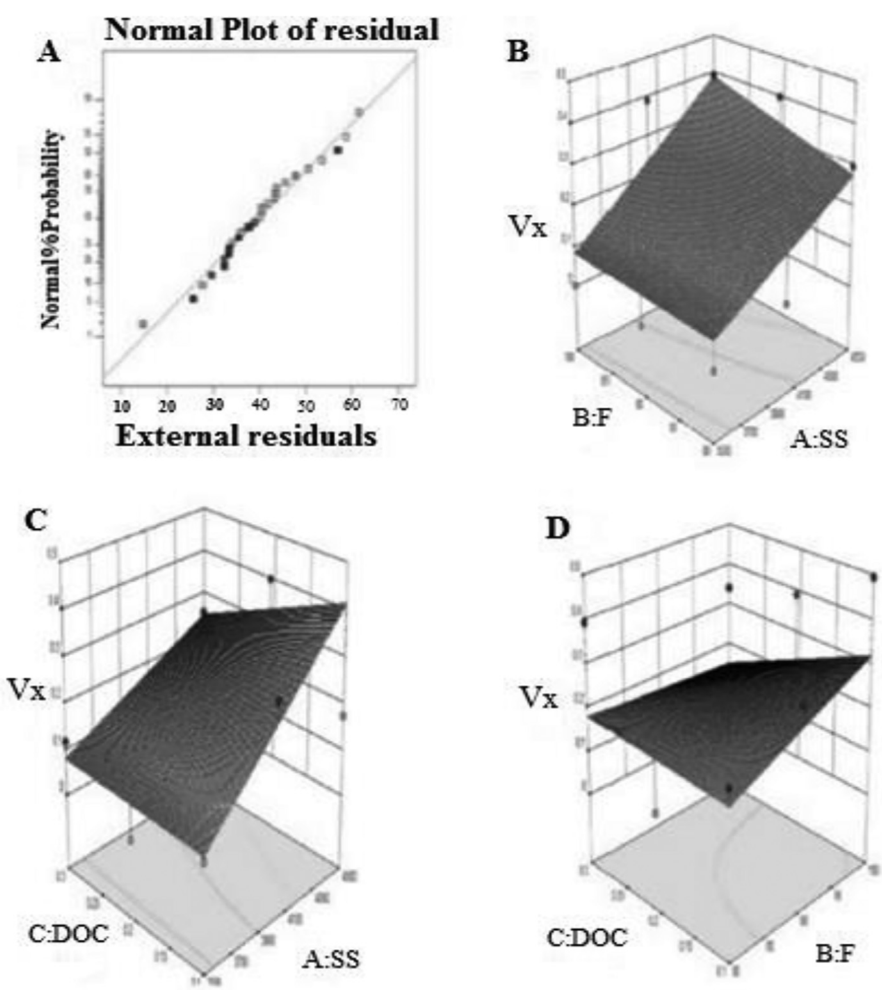

Fig. 5. Effect of vibration in X-direction; (A) Normal probabilities of residuals for Vx, (B) Effect of feed and spindle speed on Vx, (C) Effect of cut depth and spindle speed on Vx, (D) Effect of cut depth and feed rate on Vx.

3.1. Process parameters

Various parameters such as the feed rate,depth of cut and cutting speedare used in the experimentation by using taguchi method to find out performance for the specimen [10,11]. These parameters predict the strength, finishing, tolorence of the specimen before applying the speimen in various applications.result of various parameters such as feed rate, cutting speed, and depth of cut on the surface roughness of the Inconel 718 alloyis represented in the Fig. 4.The magnitude for the first experimentaion is shown also in the Fig. 4 below

3.2. Parameters effect on the amplitude of the cutter vibration along X-direction

Fig. 5 below illustrates the effects of the depth of cut, feed rate, and cutting speed on the amplitude vibration of the cutter in the x-direction of the Inconel 718 alloy. The graph shows a straight line

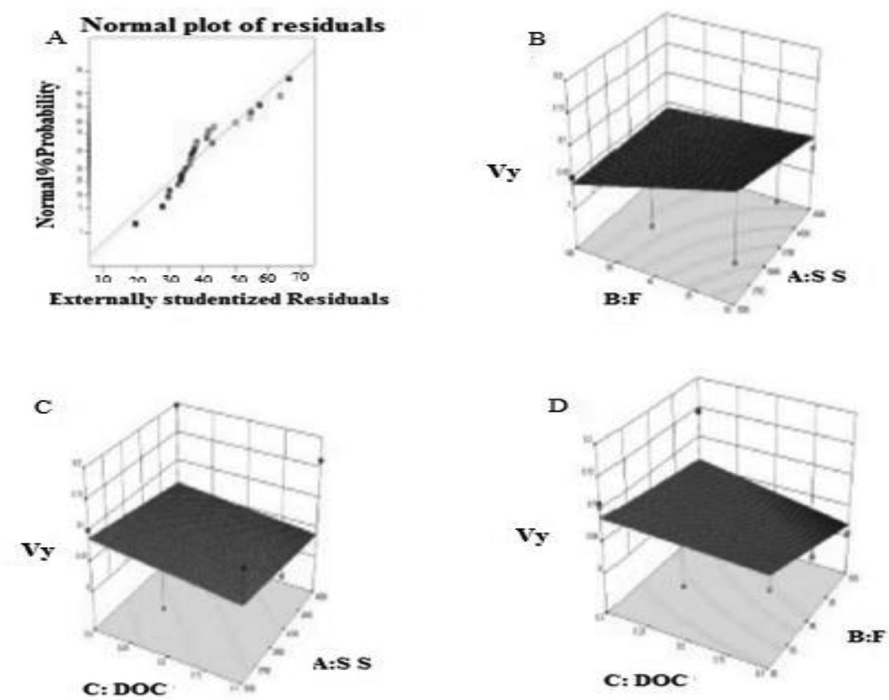

Fig. 6. Effect of vibration in Y-direction; (A) Normal probabilities of residuals for Vy, (B) Effect of feed and spindle speed on Vy, (C) Effect of cut depth and spindle speed on Vy, (D) Effect of cut depth and feed rate on Vy.

Table 3
ANOVA for vibration amplitude in X-direction.

Source	Sum of squares	df	Mean square	F value	P value Prob > F
Model	0.28	5	0.064	4.34	0.0058
A:SS	0.28	1	0.29	19.57	0.0004
B:F	0.0171	1	0.017	1.14	0.2972
C:DOC	0.028	1	0.027	1.80	0.1940
AB	7.957E-003	1	7.957E-003	0.52	0.4740
AC	0.022	1	0.021	1.42	0.2451
BC	0.018	1	0.019	1.63	0.2146
Residual	0.32	21	0.015	–	–
Correlation total	0.68	25	–	–	–

Table 4
ANOVA for vibration amplitude in Y-direction.

Source	Sum of squares	df	Mean square	F value	P value Prob > F
Model	0.0.17	6	2.885E-003	0.66	0.0453
A:SS	2.941E-003	1	2.941E-003	0.67	0.4231
B:F	8.580E-003	1	8.580E-003	1.95	0.0178
C:DOC	2.980E-003	1	2.980E-003	0.68	0.4201
AB	1.838E-003	1	1.838E-003	0.42	0.5254
AC	6.601E-006	1	6.601E-006	1.501E-003	0.9695
BC	9.666E-004	1	9.665E-003	0.22	0.6443
Residual	0.088	20	4.398E-004	–	–
Correlation total	0.11	26	–	–	–

of decreasing residuals, which is a representation of normal distribution errors. The impact of cutting parameter contact on cutting vibration is depicted in Fig. 5. The interaction between spindle speed and cut depth on cutter vibration amplitude is depicted in Fig. 5. The interaction between the spindle speed of 3000 rpm and the depth of cut of 0.1 µm is shown to result in a lower vibration amplitude. Less vibration amplitude is observed there. interaction with a 3000 spindle speed in rpm and the feed of 80 µm.

The spindle speed is impressively effective on the frequency of vibration along the x-axis direction, according to Table 3 above. The cutting parameters with a p value less than 0.05 are significant in the ANOVA, which was conducted at an 85% level of confidence.

3.3. Effect of parameters on cutter vibration along Y-direction

Consequences on the cutting speed, feed rate, and depth of cut on the amplitude vibration of cutter in Y-direction is same as effect of these parameters along Y-direction of the Inconel 718 alloy is shown in the Fig. 6above.The chart represents the major drop of residuals down the Y-axis indicated straight line and it indicates the normal errors distribution. The Figureno.6indicates the result of contact of cutting parameters on the vibration of cutting. The Figure no. 6 shows the result of interaction of the depth of cut and spindle speed on the amplitude of the cutter vibration. The vibration amplitude is found.to be less at the interaction of the spindle speed of 3000 rpm and depth of cut of 0.15 µm.The vibration amplitude is organized to be less at interaction ofthe spindle speed of 3000 rpm and the feed of 85 µm.

The Table 4 above indicates that the spindle acceleration is undoubtedly adequate on the amplitude of vibartion a006Cong the y-axis direction. The ANOVA was conducted at a confidence level of 87%, and the arameters of cutting which have p value less than 0.045 are considerable [15].

4. Conclusion

present study, non– contact type LDV was used to measure the vibration of titanium alloy using the milling cutter though micro milling process, As per taguchi DOE L27 experiments were conducted on the Inconel 718 alloy and ANOVA was used to analyze the experimental results.

The experimental setup with LDV is simple and takes less time interval to measure the vibration of the cutter, In the ANOVA for surface roughness, the spindle speed and feed were found to be considerable, In the ANOVA for cutter vibration in X and Y direction, both the feed rate and spindle speed found to be considerable and reasonable. The planned multi objective technique showed a cutting speed of 3500 rpm, feed rate of 99.798 µm/revolutions and the depth of cut which was 0.1545 mm is the perfect consolidation of the milling parameters for minimum roughness of surface and amplitude vibration of the cutter.

The estimated values of cutting and thrust forces are in good agreement with the experimental results.

CRediT authorship contribution statement

Bachina Harish Babu: Conceptualization, Methodology, Writing – original draft. **Sujith Bobba:** Validation, Data curation. **T.C.H. Anil Kumar:** Supervision. **NB. Prakash Tiruveedula:** Visualization. **Talluri Srinivasarao:** .

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bachina Harish babu reports was provided by VNR Vignana Jyothi Institute of Engineering and Technology.

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