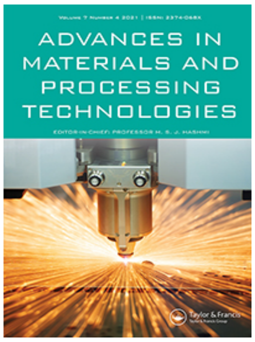

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Influence of cutting parameters on laser assisted machining of C103 Nb alloy

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ABSTRACT

C103 Nb alloy shows the good consistent microstructure that leads to better controlled properties of the material such as high strength, stress resistance, fabricability, and high temperature resistance. C103 Nb alloy shows the unique properties for challenging the aerospace, orbital rocket nozzles or chambers, and jet engine applications but they are costly and difficult to machine through traditional technique like single point cutting operation. Laser assisted heating plays a significant role in machining process due to easy and to develop very high intense heat energy in a precise region The generated energy leads to soften sample and smooth machining surfaces with crack free and superior quality. The present work deals with the influence of cutting parameters (laser power (LP) and depth of cut (DoC)) on the responses (surface roughness and cutting force (CF)) of C103 Nb alloy through laser assisted machining process at constant feed rate (0.02 mm/rev) and constant cutting speed (500 rpm). Based on the experimental results, LP shown the significance influence on surface roughness, CFs and decreases with increase of LP and increases with increase of DoC.

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KEYWORDS
C103 Nb alloy; laser assisted machining; cutting force; surface roughness; laser power

1. Introduction

Day to day rapid advancements in industrial, thermodynamics, aerospace and photonics applications, the brittle and very hard materials are playing vital role in their technical applications (mainly in the harsh environmental operations) [1] due to their superior properties such as strength, chemical inertness, and wide energy band gap. Hard and brittle materials show hard to machine due to their superior strength and brittleness that leads to problems like restrict the surface integrity and high tool wear (TW) [2]. To overcome these issues, the elevated temperature environmental operating conditions and thermal assisted machining processes (TAM) are the auspicious approaches to enhance the machinability [3]. TAM process has several widely used heat sources such as plasma, gas torch, laser beam, electric furnace, and induction heating. Among these heating sources, laser assisted heating is playing a significant role due to ease and focused into

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a small spot to develop very high intense heat energy in a precise region and can be easily mounted on operating machines [4].

C-103 Nb alloy is the combination of Niobium (Nb), Hafnium (Hf), Titanium (Ti), and other alloying components. It shows the good consistent microstructure that leads to better controlled properties of the material such as high strength, stress resistance, fabricability, and high temperature resistance. It is also showing the unique properties for challenging the aerospace, orbital rocket nozzles or chambers, and jet engine applications.

Sun et al. [5], investigated the influence of laser power (LP), cutting speed (CS), feed rate (FR) on cutting force (CF). It was noticed that the CF was dependent relative on temperature of Ti-6Al-4 V workpiece during laser assisted machining (LAM) process. It was noticed that the feed force led to a considerable fall in CF due to optimal temperature at shear zone. Gao et al. [6], investigated the CF during the BTi-6431S LAM process and observed that the BTi-6431S machinability was lower when compared to the Ti-6Al-4 V. The CF reduced with an enhancing in LP as well as reduction in the speed; the average decrease was 16.9%. The CF change in BTi-6431S chips was mainly due to the adiabatic shear bands, which is evidence in poor TW. The LAM process of Al_2O_3 particulates added aluminium metal matrix composites (AMMCs) investigated by Wang et al. [7], in comparison with CM. The feed force and radial force were reduced to closely 50% but the main CF was reduced by 10%. This was mainly due to AMMCs became softer and easily pressed on machined surfaces upon laser heating, which led to considerable decrease in CF. Kuppan et al. [8], investigated CF, Ra and TW performance on Tool Steel (SKD11) with coated ceramic TiN inserts through LAM process and compared to CM. It is observed that the CF reduced by 40%. It is also noticed that the CF decreased with enhancement of speed due to increase of temperature. Brecher et al. [9], studied LAM process on an Inconel 718, cemented carbide tool with coated TiAlN; the investigational tests were performed on LAM 5-axis machining. It was suggested that a huge decrement in CF and the thrust force reduced by 60%, while passive force as well as the main CF reduced by 40%. The laser combines a coherent, monochromatic, and converging radiation beam (electromagnetic). It is made up of three components: 'the resonator, the source of lasing energy, and the beam delivery mechanism'. However, the lasing medium can be classified as solid (Nd: YAG), liquid (dye), or gas (CO_2, He, Ne, etc.). The lasing medium used for machining difficult-to-cut materials, such as CO_2 lasers, Nd-YAG lasers, and Excimer lasers.

Oh et al. [10], investigated the CF and specific cutting energy in laser-assisted trochoidal milling (LATM) of Ti-6Al-4 V. The efficiency of the LATM was studied as well as checked for various machining conditions. Dargusch et al. [11], investigated the influence of various coated carbide cutting tools (CCCTs) on CM and LAM process of titanium alloys. Several CCCT were examined and provided typical limitations and highlighted the necessity of improved and new cutting tools for LAM application. Kalantari et al. [12], studied the surface integrity properties (grain refinement, Ra, microhardness, and CFs) in Ti-6Al-4 V alloy machining through CM and LAM processes at various process parameters. Zhai et al. [13], investigated the quality of machined surface (SQ) and surface heat-affected zone of workpiece (Ti-6Al-4 V alloy) through laser assisted micro cutting. They investigated the influence of CS, LP, and depth of cut (DoC) on TW, residual stress and SQ. N. Bharat et al. [14], reviewed the machinability of hard to cut materials and it was concluded that the best suited machining is LAM for hard to cut materials. N. Bharat et al. [15], carried out the study to analyse the effect of hybrid machining on difficult to cut materials. It was observed that the combination of thermal energy source with CNC driven system enhances the machinability of the required material. Zhipeng Pan et al. [16], investigated experimental characteristics on LAM based milling of Inconel 718 and proposed 3D model on FEM and temperature distribution predictions. It is also investigated laser scanning speed and LP on depth of melting zone and width. Yixuan Feng et al. [17], studied the experimental investigations on Ti_6Al_4V and Si_3N_4 ceramics through LAM based milling and validated with proposed analytical predictive models for cutting for and temperature distribution.

Most of the researchers exploring the feasibility of LAM with various hard materials and few issues are still existing with ineffective laser heating methods, process control is poor without temperature command, and inadequate machinability advantages. LAM process is characterised in terms of diverse operational and heating statuses. Experimentation should be handled in different environments conditions to reach the experimental data to the industry. Our research demos an observational survey of the machinability of C103 Nb alloy by the LAM procedure. The intent of this activity is to verify the consequences of laser heat aid through comparative inquiry and to obtain pragmatic data. The effect of the machining multivariate, such as LP, DoC on the responses like quality of machined surface (Ra) and CF were analysed on C103 Nb alloy through LAM process at constant FR (0.02 mm/rev) and CS (500 rpm). The reason for keeping these two parameters constant because in trial experiment these two values have given optimum result.

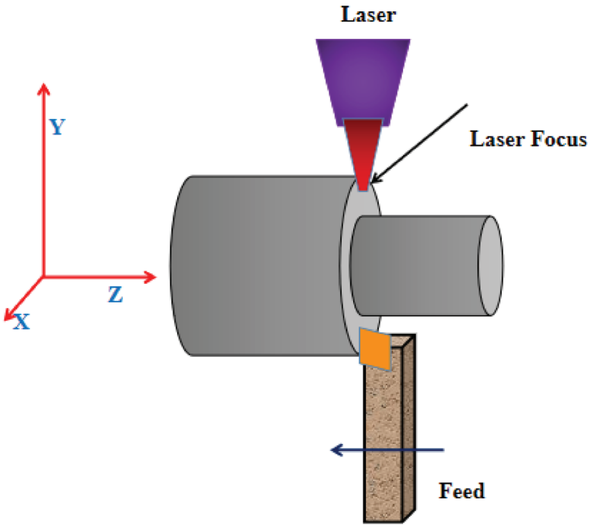
2. Materials and methods

C103 Nb alloy material was chosen as workpiece material for the experimentation and Table 1 represents its elemental weight (wt%) composition. C-103 Nb alloy has an excellent properties like high-strength, creep resistance, precipitation hardening, stress resistance, and exceptional strength in high-temperature applications [18]. It was acquired from Midhani Ltd, Hyderabad. The sample dimensions for the investigation are length 300 , ϕ50 , and 25 mm of machining length (each test). Dry machining conditions were adopted for all the examinations.

Experimental investigations were executed by a LAM assisted universal CNC machine (Laser: Nd: YAG and Model: YFL-600-SM, Maximum power: 600 W). Head of the laser was arranged at the tool holder of 90° angle and the representation of LAM process and machining setup are shown in Figure 1. The distance between the laser head tip to surface of the sample was maintained constant (15 mm) [14] and Tungsten Carbide (TiC) insert was selected as cutting tool (TNMG 16 04 04-MF 1125 grade, thickness: 4.7625 mm, clearance angle: 0°, cutting edge length: 16.498 mm and corner radius: 0.397 mm)

Table 1. C103 Nb alloy elemental composition [18].

Element	Ti	Hf	Zr	W	Ta	O	N	C	H	Nb
Weight %	1.2	8.5	>0.7	>0.5	>0.5	>0.025	>0.01	>0.015	>0.0015	Balance



(a): LAM Process

(b): LAT machining setup.

Figure 1. (a) LAM process. LAT machining setup.

Ra was examined through 'Taylor Hobson Surtronic S-100 series surface roughness tester' and A dynamometer of 'Kistler 9257' has been used to evaluate CFs. The experimental design on C103 Nb alloy were planned based on input machining parameters such as FR, CS, LP, and DoC. The FR and CS kept as constant (0.02 mm/rev and

500 rpm) and DoC and LP are the variables (0.25, 0.5, 0.75 mm and 300, 400, 500 W) to investigate the influence of CF and Ra on C103 Nb alloy.

3. Results and discussions

The influence of various factors has been considered such as LP, DoC in series of experiments to investigate CF and Ra and the obtained results were tabulated in Table 2. In these tests, FR and CS were maintained constant. L9 orthogonal array has been incorporated for analysis purpose. The LP was varied from 300 to 500 W at a constant depth of 0.25 mm and the corresponding CF and Ra results were measured. From the experimental results, it is noticed that the LP had the most effecting parameter and increase of LP was shown the decrease of machining forces and Ra. The diameter of the LP falling on the material depends on the intensity required for machining. If more intensity is required then very small diameter beam is required. It is mainly due to the effect of thermal softening enhancement that leads to higher drops in CF (shear flow stress). This happens because as the laser ray falls on the material the material tends to become soft and that reduces the CF during machining.

In the current investigation, with an increase of LP from 300 to 500 W, the percentage of reduction in CF is 22.95% at 0.25 mm DoC. Similarly, Ra also decreases with increase of LP due to thermal softening, material becomes soft, and the material removal is easily attained that leads to surface smooth and the percentage of Ra reduction is 23.92% at the same DoC. The significant effect of DoC on the CF and Ra was also noticed, and the increase of DoC shown the enhancement in CF and Ra due to higher shear stresses that leads to the larger volume of material removal, results in higher CF and Ra (due to the effect of thermal expansion which leads to the thermal softening of the workpiece material) [18].

Figure 2a-c shows the influence of LP on the CF and Ra at a constant DoC (0.25 mm, 0.50 mm, 0.75 mm) for the wide tool of 300 μm located at 200 μm from the centre of laser beam. and it was observed that the LP had a continuous effect on the CF and the higher the LP, the higher the decrease in CF when compared to traditional machining process due to material softening that assist the material removal at minimal CFs. The percentage of drop in LAM process was 22.95% in CF and 23.92% in Ra at 0.25 mm of DoC (Figure 2a), 28.94% in CF and 19.89% in Ra at 0.50 mm of DoC (Figure 2b), 19.73% in

Table 2. Experimental design and results.

DoC (mm)	LP (W)	Force (N)	Deviation	Ra (μm)	Deviation
0.25	300	61	3.05	1.63	0.0815
0.25	400	54	2.7	1.47	0.0735
0.25	500	47	2.35	1.24	0.062
0.5	300	76	3.8	1.81	0.0905
0.5	400	69	3.45	1.53	0.0765
0.5	500	54	2.7	1.45	0.0725
0.75	300	90.2	4.51	2.21	0.1105
0.75	400	84.6	4.23	1.93	0.0965
0.75	500	72.4	3.62	1.56	0.078

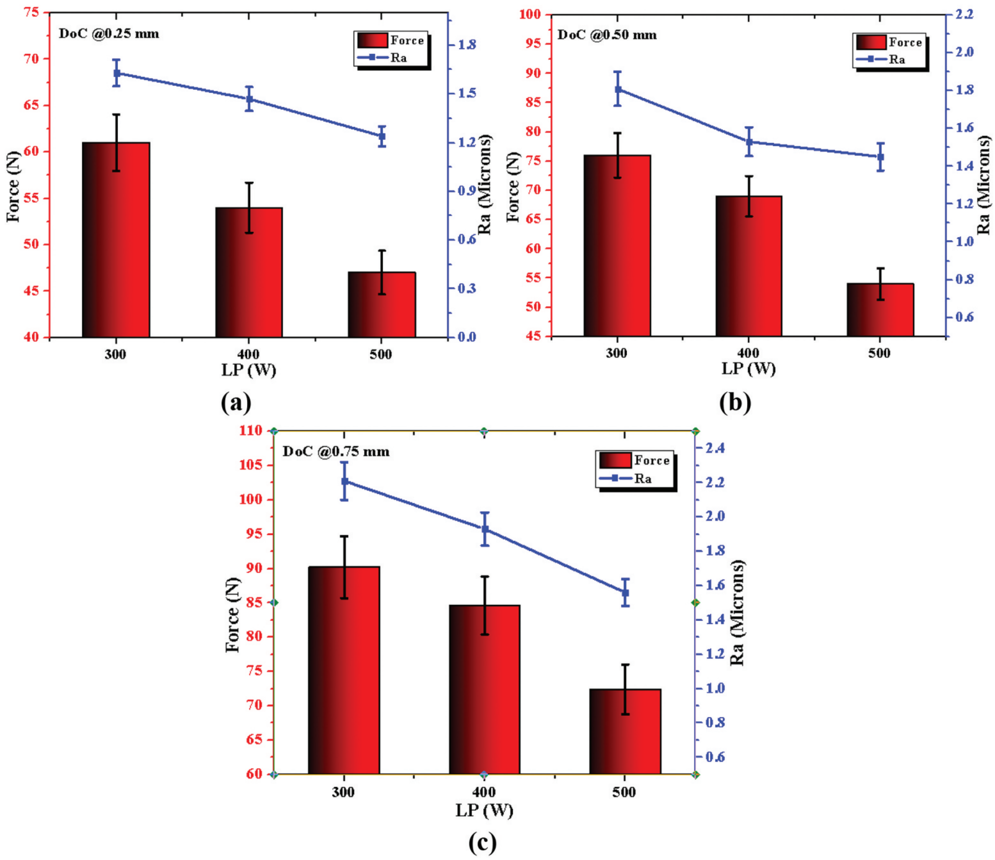


Figure 2. Effect of LP on CF and Ra at (a) 0.25 mm DoC. (b) 0.50 mm DoC. (c) 0.75 mm DoC.

CF and 29.4% in Ra at 0.75 mm of DoC (Figure 2c) respectively. It was mainly because of laser being applied on the location of the cutting, the surface of material gets heated and becomes soft and than the material removal is easily attained, which significantly reduces machining forces. Hence, the surface smooth also increases with LP.

Figure 3a-c shows the influence of DoC on CF and Ra at a constant LP (300 , 400 , and 500 W). Figure 3 indicates that CF increases with an increase in the DoC due to higher DoC that leads to the larger volume of material removal and higher shear stresses, which results in the significant improvement in CF, as like traditional machining process. From the results, the percentage of hike in CF was 47.88% at 300 W of LP (Figure 3a), 56.67% at 400 W of LP (Figure 3b), and 54.04% at 500 W of LP (Figure 3c) respectively. A accomplishable discussion for the corresponding CF with 300 to 500 W of LP is that the influence of thermal softening, which shows the higher in case of 500 W is being offset by the tool thermal expansion as compared to 300 W of LP. Hence, the thermal softening can be posses that the higher drop in CF, is a temperature rise function (i.e, thermal softening) as well as mixed thermal expansion of workpiece material and cutting tool.

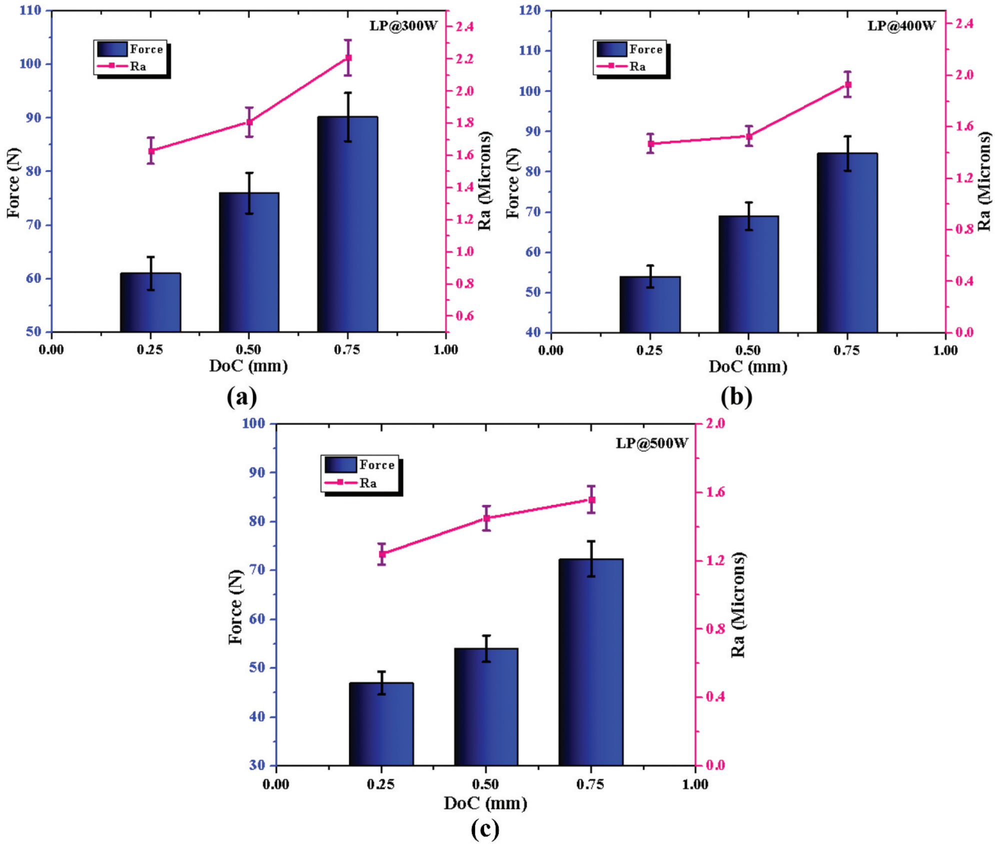


Figure 3. Influence of DoC on CF and Ra at (a) 300 W LP, (b) 400 W LP, and (c) 500 W LP.

The DoC positively influenced Ra and Ra increased with increase in DoC. The percentage enhancement in Ra was 35.57% at 300 W LP (Figure 3a), 31.29% at 400 W LP (Figure 3b), and 25.81% at 500 W LP (Figure 3c) respectively. These enhancements were mainly because of higher values of DoC creates more thrust force, which enhances the Ra due to a higher chip deformation that creates more forces against to contact surface, results in worse surface finish.

SEM photographs of LAM based machined surfaces at different LP are represented in Figure 4. The influence of LP on CF and Ra are confirmed with these photographs. Feed marks and metal debris are minimised (300–500 W) due to more thermal softening, that leads to reduce the CF and improved surface finish. The cavities also shows the supportive evidence of material side flow at higher LP [19].

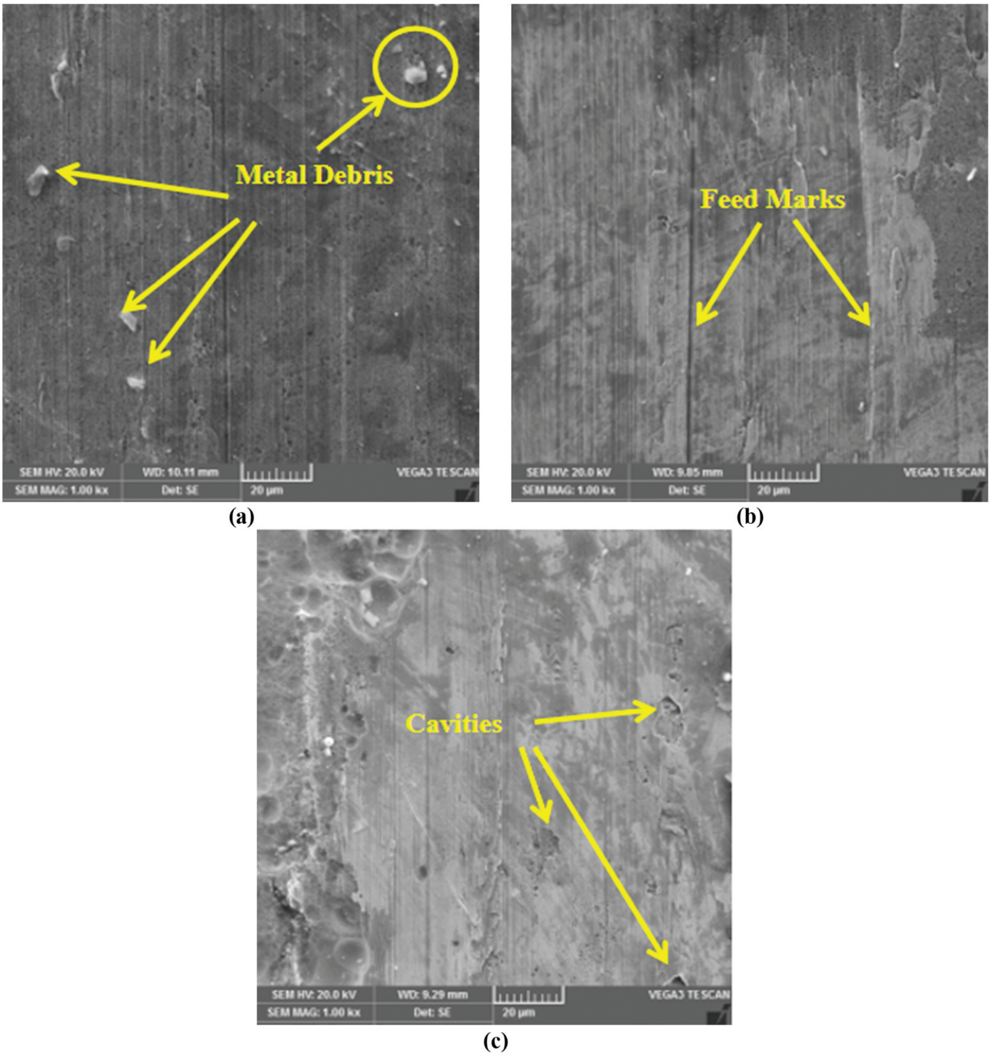


Figure 4. SEM photographs of machined surface at 0.25 mm DoC with the LP of (a) 300 W, (b) 400 W, and (c) 500 W.

4. Conclusions

This article investigated a series of experiments to analyse the influence of LP and DoC on Ra and CF. The addition of LP in the CNC enables the ease of the machinability of the superalloys. The following observations were drawn.

- CF has been increased with an increase of DoC due to the large amount of material removal volume. Ra increase with increase of DoC due to more thrust force, leads to a greater deformation of the chip and against to the work surface, resulting in rough surface.
- LP had the most effecting parameter, Ra and CF have been minimised with increase of LP (300 –500 W) due to thermal softening of the material. The percentage of

reduction in Ra and CF are 23.9% and 22.9%, at 0.25 mm DoC, 19.88% and 28.9% at 0.50 mm DoC, 29.4% and 19.7% at 0.75 mm DoC.
- It is concluded that laser assisted turning can be used for the machining different types of hard to cut material with enhanced surface quality and reduced CF.

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Compliance with ethical standards

Disclosure statement

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Ethical approval

The authors declare under the ethical responsibility that the submitted paper is original and has not been or is not being submitted to the peer review process to any other journal, and that all the authors have read the paper and agree with its submission to your Journal.

Author Contributions

Aravind Sankeerth K and Pagidi Madhukar designed the experimentation and wrote the manuscript. C. S. P. Rao and Veeresh Kumar GB offered great ideas to implement and improve the quality of the fabrication process. Gurabvaiah Punugupati provided constructive suggestions in the draft and revision of the manuscript.

Consent to participate

N/A

Consent for publication

Yes

Availability of data and materials

N/A

Research involving Human Participants and/or Animals

N/A

Informed consent

Yes

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