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Research Article

Investigation and Optimization of WEDM Parameters for 15CDV6 Using RSM

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Abstract:

The aerospace, defence, automotive, nuclear, and electrical industries all make extensive use of 15CDV6 HSLA steel due to its great strength, durability, and ability to function in extreme conditions. The machining condition of a material have been reduced under the enhancement of the electrode wear rate, machining quality. This paper explains about the machining condition of the particular material by optimizing the parameters using RSM (Response Surface Methodology). It implies the quality, strength and productivity under the machining condition using EDM (Electro Discharge Machining) process for continuous cutting and the development of the specimens exhibits the selecting the proper parameters and improves the surface roughness for various condition. In this methodology the mathematical expression implies the importance of the parameters of a material under various conditions and associated with the optimal results. The significance of the improvement of the cutting process implies the high material removal under low surface condition. It implies the sustainability of the given input parameters and desired responses were checked in RSM analysis. It provokes the better mechanical properties of a 15CDV6 HLSA steel material and develops the machining area. It results 77.5% contribution in cutting of a material under Pulse-On Time, Pulse-Off Time, Gap and Input Current of the machining condition and sustain the out parameters in RSM procedure. This investigation implies and deep insights of a material under surface roughness and have been performed in ANOVA

1. Introduction

The new technological applications in manufacturing area in both thermal and mechanical era plays a significant challenges using the conventional methods, especially provides high accurate and more precise. WEDM is commonly used in cutting the materials which are in hard and strength. The material were cutted in intricate shapes and considering the parameters in various levels and enhanced the performance of the cutted material. The material 15CDV6 HLSA steel hard material were performed and considering the cutting parameters, maintained the gap between the electrode and workpiece should be constant. Using optimization techniques the best combination were identified and reported in results. The scrap of a work material is also essential in WEDM process. The electrode is kept as cathode and work piece as anode. The workpiece is immersed in dielectric fluid, with high temperature the material is removed in the fluid and maintained sufficient gap between the electrode and the workpiece as shown in figure 1.The parameters of a WEDM process are pulse on/off time, feed rate, wire tension, wire velocity to provide out performance. For electrode the materials were Brass, Copper, and Graphite were proposed by literature reviews. The fabrication of a 15CDV6 steel material by varying the heat treatment process such an austenizing and tempering, to identify the mechanical properties by maintaining the sufficient temperature [2]. The present study determines the performance of a process parameters in terms of material removal rate and surface roughness. Surface Response Methodology were considered to optimise the output responses.

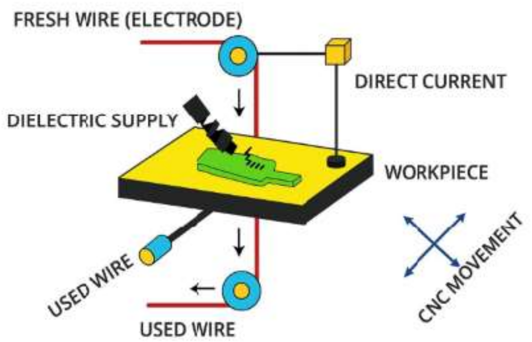


Figure 1. *Working Principle of Wire EDM*

2. Literature Review

Using the multi-objective optimization for minimize the material condition using EDM process, the rate of material removal and surface roughness were improves the performance the material under cutting process [1]. 15CDV6 material focused on the epoxy resins which improves the strength of the material and specimens were tested in optical microscope. The study explains about the penetration of adhesion properties for anti-corrosive coating were chemical bonding were strongly affected [3]. Alloys were used in various applications, especially in machining process EDM performs an important role in different approaches. In this paper the study of machining process were optimized using Taguchi analysis and the parameters were MRR and tool wear rate, ANOVA analysis were implemented[4]. Researcher explained about the WEDM process by parametric combination to enhance the performance of the process by comparing various algorithms such as ALO, TLBO, MFO, MPA, HHO, MPA to optimize the condition in machining process [5]. The applications of high speed machining process of 15CDV6 HSLA steel under flood lubrication and evolution of mathematical concepts by selecting the various parameters for the best approach responses [6]. The reinforcement of a 15CDV6 steels grain size under refining of mechanical properties were results on the recovery of the inoculation with titanium for refinement which improves the austenitic temperature of the given steel [7]. It explains about the mechanical properties of a nano materials and its structure in various electron microscopy techniques. The study of flaws, phases and mechanisms were optimised [8]. The variety of metals and alloys were played a significant part in increase the strength and behaviour of the alloys in elongation process under temperature effect [9]. Using the WEDM to make the intricate shapes for numerous applications. This paper exhibits about the surface characteristics of a machined surface by considering the process parameters such as voltage, wire speed and feed rate by full factorial design [10]. The effect of optimization in the EDM machining parameters of HSLA steel with multi-response method using Taguchi analysis [11].15CDV6 material were performed in aerospace applications. The mechanical and corrosion properties of material were optimized by considering the parameters and the structure of the grain size of the material, were analysed [12]. This paper explained about the machining process of an EDM on the premise of tool wear rate and material removal rate. The evaluation process were identified and the researchers were optimized the condition of the various materials which were used in aerospace applications [13]. Aluminium alloys were used in machining condition to test the input parameters effects the surface roughness and material removal rate using ANOVA analysis [14]. The properties of the nickel-titanium alloy used in bio-medical applications were tested using WEDM , the input variables were zinc coated brass material, pulse on/off time, servo voltage, wire feed and output responses are material removal rate, surface roughness. Servo voltage is highly influence on the process parameters [15]. In this study the author explained about the spark location while cutting continuously. The location of the spark region of the nickel based alloys were examined in various categories and reducing the machining condition [16]. The structure of a 15CDV6 steel material were observed in various applications especially in the manufacturing the different parts such as solid rocket booster provides excellent weld ability. To optimise the condition TOPSIS were used and highly influenced on the welding parameters [17]. The paper exhibits about the properties of a mechanical and magnetic variations of a metallic materials and is highly influenced on the various parametric conditions of a steel with better toughness [18]. The researcher studied about the surface morphology of a HLSA steel and analysed by WEDM process with microstructure of brass wire for machining condition. By considering the input parameters of a material using ANOVA, the process were developed instead of getting CT brass wire with respect of NCT brass wire were influenced in machining condition [19]. The process parameters were adopted for spring-seat based materials and defects were identified using surface response methodology, simulation process were adopted for manufacturing and cost for development of the material [20]. The investigation explains about the 15CDV6 steel for the development of the forming process to increase the strength of the cylindrical tubes with respect of weight ratio. It indicates the reduction of strain and percentage reduction were increased with the development of experiments and optimise the parameters [21]. It explains about the HSLA steel machined in WEDM process with effect of the process parameters using the Taguchi analysis and optimised by ANOVA [22].

3. Material and Methods

3.1 WEDM setup Description

Wire Electrical Discharge Machining, often known as Wire-EDM, is currently considered to be one of the most effective non-traditional machining technologies and the model used for experiments is Smart Cut 2530 CNC Wire-Cut EDM. It is difficult to discover all of these characteristics in one substance, though. Among these, 15CDV6 is notable for its exceptional strength, durability, heat resistance, and wear resistance and the 15CDV6 steel slab dimensions are 300mm x155mm x17mm. The EDS for the steel was examined to inspect the material particles that were possess strength and hardness as shown in fig (1). It explains to characterize of every particle in the material and the distribution of the various particles were projected in various machining conditions. The combination of these particles were projects the hardness and quantity of various elements.In the fig 2. Performs the nature of the major elements were silicon, chromium, manganese and remaining possess carbides and oxides. The material performs inclusions and precipitates to perform the composition of the steel material. The cathode is the wire, and the anode is the work piece. The work piece and the wire are both immersed in a dielectric fluid, which cools the area, removes melted particles, and aids in spark control. Between the workpiece and the wire, a voltage is applied.

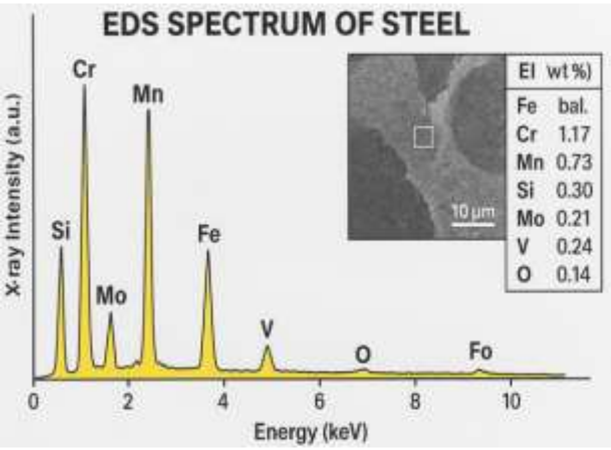


Figure 2. *Energy Dispersive Spectra for 15CDV6 HLSA steel*

The voltage is sufficiently high to ionize the fluid and produce a spark when the wire is near enough to the workpiece as shown in the fig 2(a). The workpiece and the wire are both immersed in a dielectric fluid, which cools the area, removes melted particles, and aids in spark control. Between the workpiece and the wire, a voltage is applied. The voltage is sufficiently high to ionize the fluid and produce a spark when the wire is near enough to the workpiece as shown in fig 2.This spark generates very high temperatures around 6000°C small miniature material from the cathode and workpiece are vaporized. With each spark eliminating a tiny bit of material, the wire precisely slashes through the workpiece as it continuously progresses along the intended path.

Figure 2 *(a) WEDM machine experimental setup*

Figure 2 *(b) Square blocks by WEDM*

3.2 Experimental Procedure

The dimension of the work piece is cut into 20mm x 10mm in rectangle shape were shown in fig 2(b). A thin wire made of Brass with 0.25 diameter (the electrode) and the work piece produce a sequence of quick electrical discharges (sparks) that remove material from the work piece in Wire-EDM. Using RSM analysis, L27 follows the experiment and the workpiece is cut in to 27 square blocks to reduce the errors in the experiment. By considering the input parameters are Pulse-on time, Pulse-off time, Input current and Gap between the work piece and the electrode were observed. Three levels and four parameters were considered in surface response methodology as shown in Table 1. Based on the experimental conditions two levels were considered for entire experiments (-1) and (+1). In the experimental steps, the levels and factors were considered in Box-Behnken technique, and to design the process modelling were taken in common points and the input factors were pulse-on time, pulse-off time, gap and input current between the electrode and the workpiece.

Table 1. *Input parameters and conditions*

Factors	**Input parameters**	**Limits**	
		-1	**+1**
1.	Pulse-on time	120	160
2.	Pulse- off time	45	55
3.	Input Current	1	3
4.	Gap	30	40

3.3 Surface Response Methodology

To find the input variations in the parameters one of the best method to optimise the given condition at the lower cost with respect to time, this method performs better results. RSM explains about the process parameters which were considered to obtain the correlation between the process parameters in the application oriented. To calculate the given responses and by comparing the four input parameters by developed in statistical analysis. This method is to optimise the given condition and analyse in ANOVA.The input parameters were considered on the pulse on time, pulse off time, gap and input current. These experiments were calculated with a maximum and minimum values of MRR and surface roughness. The variations of the given workpiece were tabulated in Table 2.

Table 2. *Experimental Observations for* ***MRR*** *and Surface Roughness*

Exp. Run	Pulse – On time (Pon) µs	Pulse-Off time (Poff) µs	Input Current A	Gap mm	Material removal rate (MRR) mm^3/min	Surface Roughness (Ra) µm
1	120	45	1	30	57.025	2.85
2	120	45	1	35	59.56	2.6
3	120	45	1	40	57.05	2.35
4	120	50	2	30	57.8	2.7
5	120	50	2	35	57.81	2.45
6	120	50	2	40	58.35	2.2
7	120	55	3	30	58.69	2.55
8	120	55	3	35	59.32	2.3
9	120	55	3	40	58.05	2.05
10	140	45	2	35	60	3.1
11	140	45	2	40	58.52	2.85
12	140	45	2	30	58.23	2.6
13	140	50	3	35	58.95	2.95
14	140	50	3	40	58.7	2.7
15	140	50	3	30	58.45	2.45
16	140	55	1	35	58.8	2.8
17	140	55	1	40	59.25	2.55
18	140	55	1	30	59.3	2.3
19	160	45	3	40	60.3	3.35
20	160	45	3	30	60.1	3.1
21	160	45	3	35	59.35	2.85
22	160	50	1	40	60.3	3.2
23	160	50	1	30	58.95	2.95
24	160	50	1	35	58.7	2.7
25	160	55	2	40	60.05	3.05
26	160	55	2	30	58.8	2.8
27	160	55	2	35	58.99	2.55

In RSM process, the four variables are pulse on time, pulse off time, input current and gap were considered and cutting dimensions according to the input parameters were given in the equation:

[redacted] --------(1)

Where 'X_i' implies actual value of the 'i_{th}' response

'x_i 'implies coded value

'X^o_i 'implies investigated value at center point

'ΔX_i' implies step size

The equation-(1) explains about the material removal rate and surface roughness to control the variables in the given responses and optimised the better output parameters. By considering these conditions the given responses were designed and coded. In this condition the variables are independent and more significant to analyse the minimum to maximum such as -1 to +1. Then the variables were deviated and the input condition using the Box-Behnken technique were analyzed and the effect of input parameters were optimised in WEDM machining process were in 27 runs, The final result were designed and coded with the correlation to the final output then the independent variables were more significant to perform the surface roughness. By considering the three-level factorial analysis the following equation as given below:

[redacted] ------(2)

Where 'X_1',' X_2', 'X_3','X_4'were the process responses as mentioned in the Table 1.

'Y' is the output variables

α_0 –α_9 were the coefficient of the design

The values were predicted by considering the three-factorial response between the four independent variables such as pulse on time, pulse off time, input current and gap to optimise the Surface roughness and MRR and to perform the correlation between the input parameters by analysing the RSM. The values were calculated and were shown in Table 3, 4. The variables if t-value and p-value were depend upon the input process parameters and the correlation were shown.

Table 3. *Response Surface Regression (RSR) for Surface Roughness*

Response	RSR	t-value	p-value
Constant	0.0250	308.37	0.000
pulse on	0.0125	-2.01	0.067
pulse off	0.0125	-0.52	0.612
Input current	0.0125	-1.68	0.118
Gap	0.0125	-2.98	0.012
pulse on*pulse on	0.0188	-1.98	0.071
pulse off*pulse off	0.0188	-1.45	0.173
Input current*Input current	0.0188	-1.16	0.268
Gap*Gap	0.0188	-1.00	0.337
pulse on*pulse off	0.0217	2.98	0.012
pulse on*Input current	0.0217	-0.01	0.990
pulse on*Gap	0.0217	1.67	0.120
pulse off*Input current	0.0217	-0.05	0.959
pulse off*Gap	0.0217	0.96	0.355

Table 4. *Response Surface Regression (RSR) for Material Removal Rate*

Response	RSR	t-value	p-value
Constant	0.0394	43.59	0.000
pulse on	0.0197	0.02	0.987
pulse off	0.0197	-0.80	0.441
Input current	0.0197	-0.24	0.813
Gap	0.0197	-2.42	0.032
pulse on*pulse on	0.0295	-1.17	0.265
pulse off*pulse off	0.0295	-2.54	0.026
Input current*Input current	0.0295	-0.99	0.340
Gap*Gap	0.0295	-1.12	0.286
pulse on*pulse off	0.0341	3.76	0.003
pulse on*Input current	0.0341	0.34	0.743
pulse on*Gap	0.0341	0.75	0.465
pulse off*Input current	0.0341	1.04	0.320
pulse off*Gap	0.0341	1.85	0.089
Input current*Gap	0.0341	2.97	0.012

Using the regression coefficient, the values of these variables were observed for developing the accuracy, this values elaborates the p-value is more important and statistically analyzed. To elaborate the Surface roughness and material removal rate for WEDM are given in the equation for with $\lambda = 0.5$

Ra1^0.5 = 8.23 – (0.0501* pulse on)+
0.015 (pulse off – (1.030 *Input current)) –
((0.120 *Gap)-
(0.000086* pulse on*pulse on))
– (0.00300*pulse off*pulse off)-
(0.0293* Input current*Input current))
- (0.00132 *Gap*Gap)+
(0.001284* pulse on*pulse off) +
(0.00057* pulse on*Input current)+
(0.000257 *pulse on*Gap) +
(0.00707 *pulse off*Input current) +
(0.00252 *pulse off*Gap)
+ (0.02025* Input current*Gap) (3)

mrr5^0.5 = 10.21 – (0.0201* pulse on) –
(0.0116 *pulse off) +
(0.192* Input current) –
(0.0409* Gap)-
(0.000093* pulse on*pulse on) –
(0.001088* pulse off*pulse off)

$$- (0.0218 * \text{Input current} * \text{Input current}) - (0.000751 * \text{Gap} * \text{Gap}) + (0.000645 * \text{pulse on} * \text{pulse off}) - (0.00001 * \text{pulse on} * \text{Input current}) + (0.000363 * \text{pulse on} * \text{Gap}) - (0.00023 * \text{pulse off} * \text{Input current}) + (0.000834 * \text{pulse off} * \text{Gap}) - (0.00322 * \text{Input current} * \text{Gap}) \quad (4)$$

3.4 Validation of a Model

Statistical methods were conducted to the experiments and these models, provides the additional models were performed. For these parameters the confirmation and developed model possess the characterisation of given responses have been represented as shown in Figures 3a-3b for Surface Roughness and MRR. All the values were plotted in the normal probability plot to control the responses then the values were in close to the straight-line.

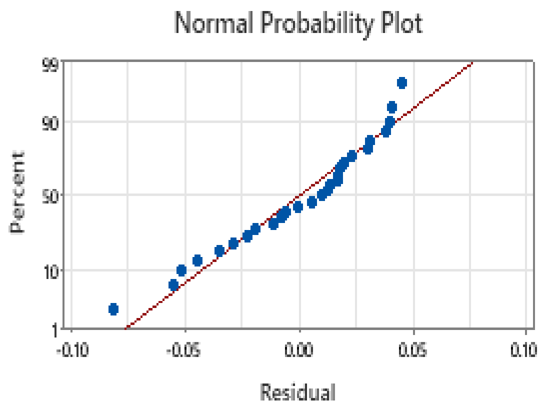


Figure 3 *(a) Normal probability plots for MRR*

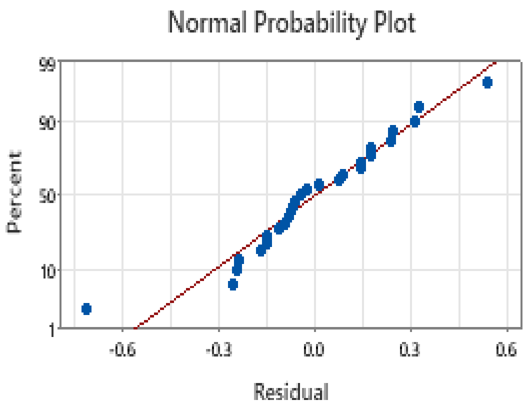
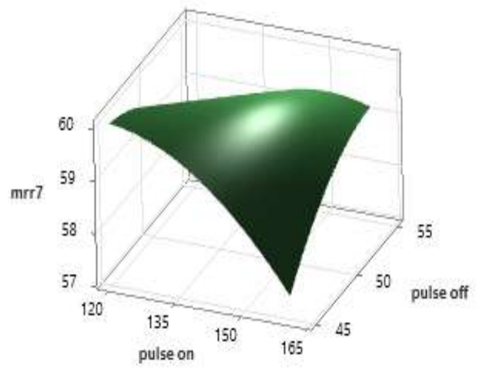


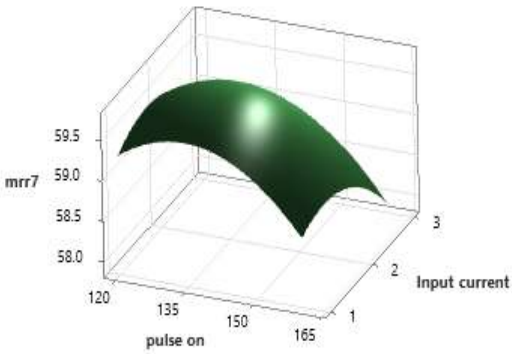
Figure 3 *(b) Normal probability plots for Ra*

3.5. 3D Response Surface

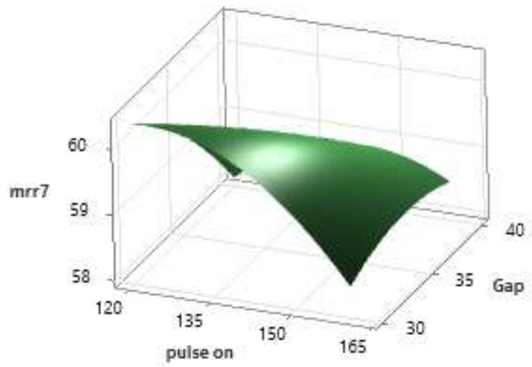
3.5.1 Material removal rate (MRR)



(a)



(b)



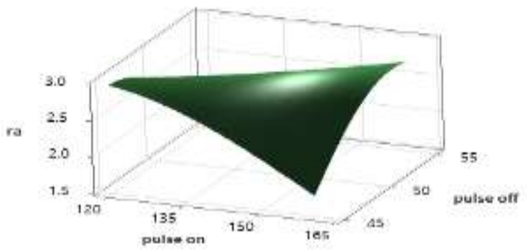
(c)

Figure 4 *Response Surface Graphs (a) Pon and Poff, (b) Pon and Current (c) Pon and Gap*

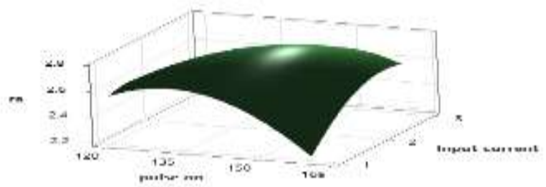
The Pon and Poff on material removal rate has been presented in the Fig 4(a). During the machining process the MRR increases in Pon time and moderate in Poff time. Therefore these two factors are minimize the MRR. In Fig 4(b) the Pon and input current slightly increases up to a certain point and falls. This implies that the range of the both parameters were optimized in machining. The MRR increases with increasing Pon time and gap, the curve increases to certain point and falls. It indicated that two parameters can achieved maximum MRR during machining process.

3.5.2 Surface Roughness (Ra)

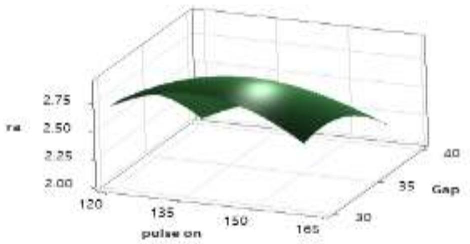
The relationship between pulse on time and pulse off time and surface roughness (Ra) is depicted in this 3D surface map. There comes a point at which increasing both factors causes the surface roughness to rise. It is necessary to tune these settings for improved surface finish since a rougher surface is often the result of higher pulse on and pulse off times. The impact of input current and pulse on time on surface roughness (Ra) is displayed in this three-dimensional surface graphic. Surface roughness likewise grows until it reaches a peak and then begins to gently decline as both parameters rise. This suggests that although rougher surfaces are produced by increasing energy input, the impact eventually stabilizes or diminishes. In order to achieve the correct surface finish in machining, careful management of these factors is necessary.



(a)



(b)



(c)

Figure: 5 *Response Surface Graphs (a) Pon and Poff, (b) Pon and Current (c) Pon and Gap*

The impact of gap voltage on surface roughness (Ra) and pulse on time is displayed in this three-dimensional surface graphic. Surface roughness first rises with pulse on time and gap, peaks, and then gradually falls. This implies that while very low or high values of these parameters may increase surface smoothness, intermediate levels often lead to increasing roughness. The desired surface quality requires optimization.

4. Conclusions

The researcher objective projects the machining condition of the WEDM which specifies the quality of the rectangle pieces were observed with material removal rate and surface roughness by varying the pulse on time, pulse off time, input current and gap. The material removal rate and surface roughness was optimised and reduce the direct contact between the electrode and the work piece. With the help of conductive substance the cut material through the degree of hardness and the methods of cutting should be observed. The cutting condition of the work pieces were observed and the conclusion were given below:

- The rectangle shape of the cutted material were observed with different parameters which increase the quality of the shape and characterize the cutted material.
- Material removal rate were greatly influenced on the area of the cutted part by varying the pulse on time 120,140,160mm.
- Using Box-Behnken design four factors of each input parameter were considered and observations were implemented by Surface Response Methodology (RSM) analysis.
- The surface plots explained about the nature of the curve process using input parameter and optimised to the peak level of the cutting process, therefore the observations were resulted.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict 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
- **Acknowledgement:** The authors would like to thanks manufacturing processes lab, department of Mechanical Engineering, S V University

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- **Author contributions:** The authors declare that they have equal right on this paper.

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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