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Effect of Cutting Parameter on Surface Roughness in Laser-Assisted Turning of 9CrSi Hardened Steel

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***Abstract*— *The laser- assisted turning experiments for 9CrSi hardened steel (62 HRC) were set up by using the YAG laser source. A full factorial experiment was designed with 9 trials to analyze the influences of the laser power, cutting speed and feed rate on the surface roughness. The cutting tool used for this work is the TiAlN coated carbide insert. The results indicated that the laser power and the feed rate are the greatest effect parameters on the surface roughness and the cutting speed exhibits the lower influence on surface roughness in the laser-assisted turning 9CrSi hardened steel process. In this study, a mathematical function was also determined to present the influence of the laser power, cutting speed and feed rate on the surface roughness in the laser-assisted turning 9CrSi hardened steel process. The minimum surface roughness in laser-assisted turning process can be obtained by setting the laser power (A), feed rate (C) and the cutting speed (B) with high, low, and low levels respectively.*

***Keywords*— *9CrSi, hardened steel, laser-assisted turning, surface roughness, turning.*

I. INTRODUCTION

The alloy steel is widely used in many industries because it has many advantages. The alloy steel is usually hardened to get the high hardness state (50-70 HRC) [1-4]. In order to manufacture the finished product, many operations are required. After hardening, the products are usually machined by grinding process or EDM machining process. However, these machining methods have many disadvantages such as low material removal rate, low quality [5-6]. In recent years, the laser-assisted machining (LAM) process was studied by many researchers and applied to machine the hardened alloy steel. This method can enhance the machinability of the hardened alloy steel and stabilize the desired characteristics of the material, whilst ensuring the preservation of their desired properties.

Guenael Germain studied the effect of LAM on residual stress and fatigue in the machining process with two different materials and the optimum cutting parameters was determined [7-8]. P. Dumitrescu investigated that the applying the high power diode laser on the turning process hardened AISI D2 tool stell can reduce the tool wear and cutting force [9]. Laser-assisted machining (LAM) also applied on machining the High-nitrogen, nickel-free stainless steels. This study determined the effects of temperature and surface speed on the tool wear, cutting forces, surface roughness, and work piece integrity [10]. Another research investigated the effects of the cutting conditions on the cutting forces, specific cutting energy, surface roughness, and tool wear in the Laser-assisted machining of compacted graphite iron [11]. In Frank's research, the total thermal energy deposited in the workpiece is compared with the theoretical minimum required to heat the workpiece in order to determine what percentage of the deposited energy is actually used in the thermally assisted machining process [12]. Applying the laser-assisted turning process on machining super alloy Inconel 718 was researched by Attia et al (2010). This machining method can increase in material removal rate and improve the tool life and quality surface [13]. Hongtao Ding and Yung C. shin (2010) showed that the laser assisted effects on the surface integrity [14]. A. K. M. Nurul Amin (2012) studied the surface roughness and vibration in heat assisted milling of SKD11 steel [15]. The research determined the optimal parameters for the heat assisted milling SKD11 steel using the ball end tool. The laser-assisted machining Titanium alloy was also studied by R.A. Rahman (2012) and M.W. Norazlan (2013). Rahman analyzed the effect of the cutting speed and feed rate on the cutting forces and cutting temperatures [16], and Norazlan studied the effect of the heating temperature on the cutting forces and tool wear in the laser-assisted machining Titanium alloy [17]. In 2014, Xavierarockiaraj studied the effects of The LAM parameters on the machinability in the laser assisted turning of SKD 11 using TiN coated ceramic inserts ceramic inserts [18]. In addition, the laser-assisted machining process was also applied on cutting Inconel 718 alloy by Venkatesan [19]. Venkatesan's researches (2017) indicated that the machinability of Inconel was improved by using the laser-assisted machining process [20]. This study analyzed the effect of cutting parameters of laser-assisted machining of Inconel 718 on the cutting force and chip formation. The result showed that the application of laser can help to reduce the cutting forces and tool wear in the machining Inconel 718.

The present research focuses to analyze the effect of the laser power (P), cutting speed (v), and feed rate (s) on surface roughness in the laser-assisted turning 9CrSi steel. The full factorial experiment design has been used to analyze ANOVA. The response function of the surface roughness based on the estimated parameter is determined by the "least squares" method with the Matlab software.

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II. METHODOLOGY

A. Experimental set up

An experimental system using for analyzing the effect of the laser power, cutting speed and feed rate on the surface roughness in the laser-assisted turning process is set up and shown in fig. 1.

Fig. 1. Experimental design of the laser-assisted turning 9CrSi hardened steel.

TABLE I. Specification of ISI Sky I.

Elements	C	Si	Mn	S	P	Cr	Mo
%	0.92	1.40	0.62	0.024	0.018	1.28	0.11

TABLE II. Specification of ISI Sky I.

S. No.	Parameters	Values
1	Iso code	DCMT11T304VP15TF
2	Inscribed circle diameter	9.525 mm
3	insert thickness	3.97 mm
4	Grade	VP15TF
5	Include angle	55^0
6	Nose radius	0.4
7	Clearance angle	7^0

The workpiece used for the experiments is 9CrSi alloy steel with a diameter of 32 mm and the hardness of 61-63 HRC. TiAlN coated carbide inserts of Mitsubishi having DCMT11T304VP15TF Code were selected for this machining process. Table II shows the fundamental parameters of cutting insert used in the present study. The workpiece is fixed on the T6M16 turning machine.

In order to preheating the workpieces before machining, The YAG laser generator system of Lasincom Company with the normal power 350 W and wavelength of 1064 nm. The laser source was fixed on a shelf moving together with the holder tool in the machining process. The laser head delivers the laser beam always striking the centerline of the workpiece during cutting process. The laser head is set in front of the cutting tool 20 mm and made the angle of 60-750 to the tool. The machining zone is protected by the compressed Ar air stream at 4 bar.

B. Experimental design

Based on the calculation of the theoretical cutting mode selected and combined with the working conditions of the cutting tools and the equipment, the experimental parameters were chosen with the following 3 levels (table 3) for the input parameters: laser power P(W), cutting speed v(m/min), feed rate f(mm/rev).

TABLE III. Parameters affect surface roughness.

Parameters	Level		
	-1	0	+1
P (W)	270	300	330
v (m/min)	25	62,5	100
f (mm/rev)	0,06	0,12	0,18

In this research, a full factorial design was used with 8 main trials and one trial at center point, as shown in table 4. After turning, the surface roughness was measured by machine Hommel tester T1000 and the obtained results were shown in table IV.

TABLE IV. Matrix of experiment.

StdOrder	P(W)	V (m/min)	f(mm/rev)	Ra(µmM
1	270	25	0.06	0.715
2	330	25	0.06	0.408
3	270	100	0.06	0.816
4	330	100	0.06	0.462
5	270	25	0.18	0.984
6	330	25	0.18	0.569
7	270	100	0.18	1.118
8	330	100	0.18	0.651
9	300	62.5	0.12	0.681

III. RESULTS AND DISCUSSION

The analysis of variance for effects and interactions was done by minitab 16 software. The results are shown in the figure 2. The sequential sums of squares (Seq SS) and adjusted sums of squares (Adj SS) indicated that the experiment design is suitable. The analysis of variance also show the p-values contacted with each individual model term. The p-values indicated that just two two-way interactions P * V (p = 0.032) and P*f (p=0.014), and three main effects P (p = 0.002) and V (p=0,009) and f (p = 0.009) are significant.

Analysis of Variance for Ra (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.420841	0.420841	0.140280	44889.75	0.003
P(W)	1	0.297606	0.297606	0.297606	95233.96	0.002
V(m/min)	1	0.017205	0.017205	0.017205	5505.64	0.009
f(mm/rev)	1	0.106030	0.106030	0.106030	33929.64	0.003
2-Way Interactions	3	0.007795	0.007795	0.002598	831.51	0.025
P(W)*V(m/min)	1	0.001225	0.001225	0.001225	392.04	0.032
P(W)*f(mm/rev)	1	0.006105	0.006105	0.006105	1953.64	0.014
V(m/min)*f(mm/rev)	1	0.000465	0.000465	0.000465	148.84	0.052
Curvature	1	0.001050	0.001050	0.001050	336.11	0.035
Residual Error	1	0.000003	0.000003	0.000003		
Total	8	0.429690				

Fig. 2. The results of analysis ANOVA.

The effect magnitude and the importance of the survey parameters are determined by using a Pareto chart of the effects on Minitab software. The chart shows the absolute value of the effects and a reference line on the chart, shown in the figure 3. The results indicated that the power of assisted laser (W), cutting speed, feed rate and interaction P*f are the greatest effect parameters on the surface roughness.

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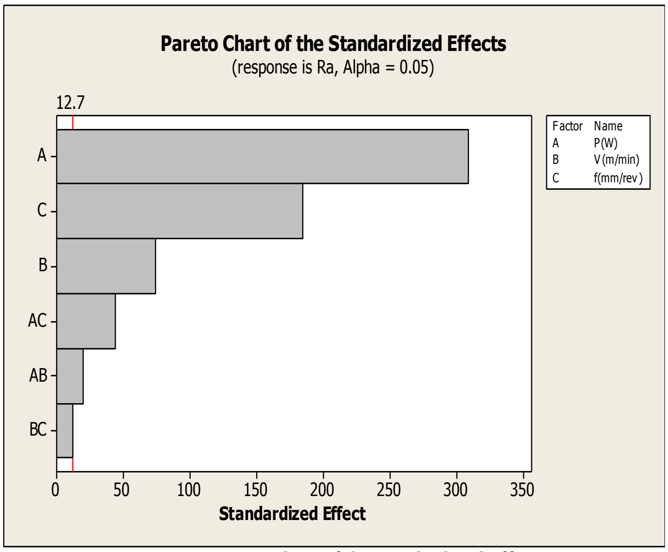

Fig. 3. Pareto chart of the standardized effects.

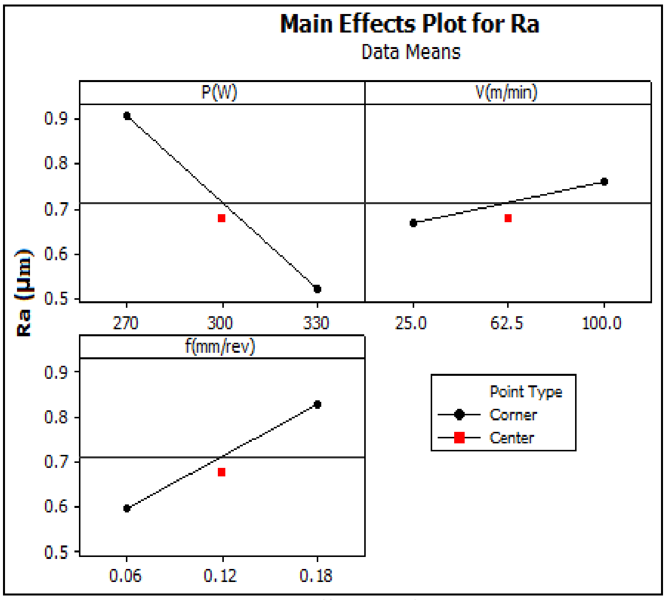

Fig. 4. Main effects plot for Ra.

The figure 4 shows the main effect of survey factors on the surface roughness. The result indicated that the power is the most significant parameter. The surface roughness decreases when the assisted laser power increases from 270W to 330W. And the effect of the cutting speed and feed rate are lower than the effect of laser power. The figure 5 shows the interaction effect of input parameter on the surface roughness. The results showed that the interactions between the input parameters are small.

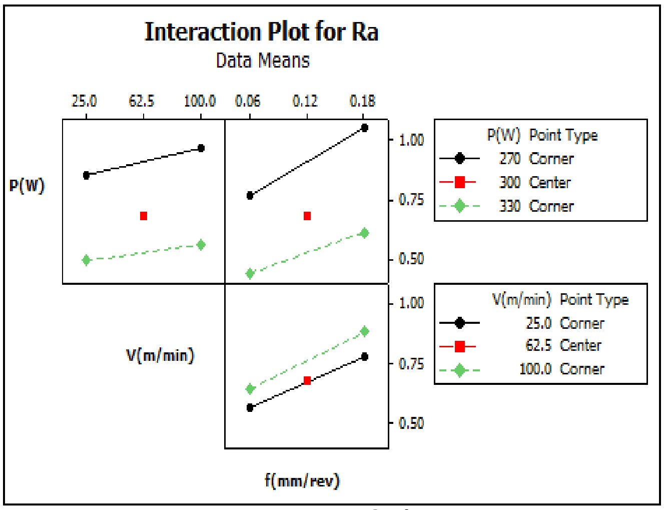

Fig. 5. Interaction plot for Ra.

The results of ANOVA analysis also indicated that the curvature model showing the effects of survey factors on the surface roughness is significant, so the effect of parameters on the roughness can be presented by the curvature model. An exponential function was selected in order to show effect of the input parameter on the surface roughness when turning with the assisted laser power, (shown in equation (1)).

$$R_a = b_{n0}.P^{b_{n1}}.v^{b_{n2}}.f^{b_{n3}} \quad (1)$$

Applying the Matlab software, the function has been determined by using the "least squares" method and shown in equation (2).

$$R_a = 6{,}239.10^6 * P^{-2{,}760} * v^{0{,}094} * f^{0{,}298}, (\mu m) \quad (2)$$

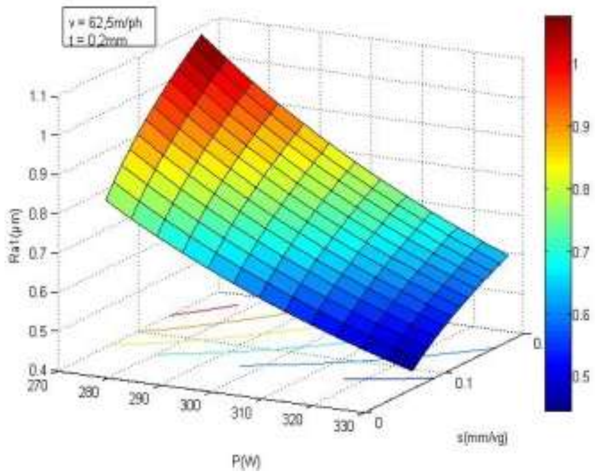

Fig. 6. Effect of laser power and feed rate on surface roughness (v=62,5m/min).

The figure 6 shows the effect of laser power and feed rate on the when fixing the cutting speed at 62.5m/min in the laser-assisted turning process. The results indicated that the surface roughness decrease when the laser power increase from 270W to 330W and the feed rate decrease from 0.18 mm/rev to 0.06 mm / rev resulting in small surface roughness. And when decreasing the power smaller than 290W, the surface roughness increase quickly.

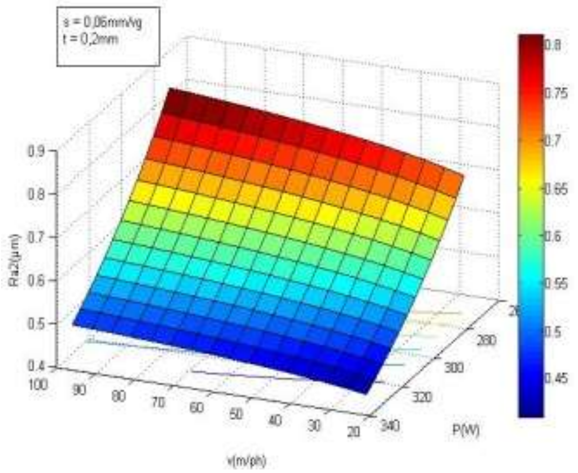

Fig. 7. Effect of laser power and cutting speed on surface roughness (f=0,06mm/rev).

The figure 7 presents the effect of laser power and cutting speed on surface roughness with fixed feed rate at 0.06mm/rev in the laser-assisted turning process. The values of surface roughness rise when the laser power increases and the cutting speed decreases. The figure 8 indicated that the surface roughness decreases when the cutting speed and feed rate decrease if the laser power is fixed at 300W.

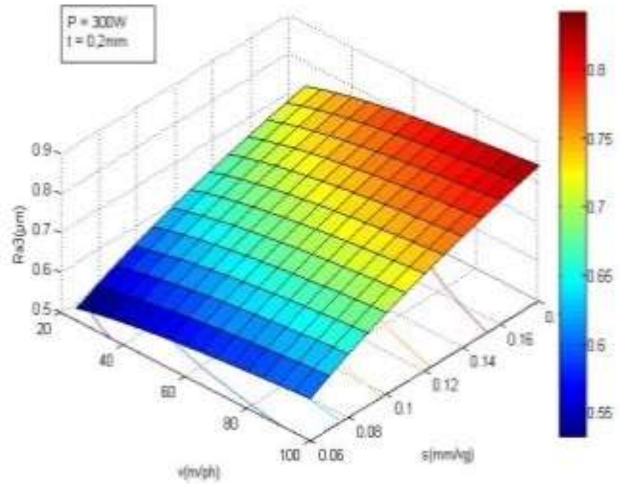

Fig. 8. Effect of cutting speed and feed rate on surface roughness (P=300W).

IV. CONCLUSION

The results of this study indicated that the assisted laser power (A) is the most significant parameter. The feed rate is the second statistically significant parameter and the cutting speed ranks on the third in term of surface roughness in laser-assisted turning process. The minimum surface roughness in the laser-assisted turning process can be obtained by setting the laser power (A), feed rate (C) and the cutting speed (B) with high, low, and low levels respectively. The result also shows that the interactions between the survey factors are low. The response model of surface roughness in uncoded units, based on the parameter estimates equation, is determined by the "least squares" method with the Matlab software. However, this experiment only set up at the low laser power, and other studies for the surface roughness using the assisted lased power turning process should be made in the future.

In this study, a quadrotor UAV integrated with camera have been developed and tested in order to provide real time aerial video for traffic and emergency management. Through this study, the quadrotor can provide suitable information for ground staff to determine level of congestion and at the same time can monitor traffic violation by driver. This situation can be used when incident or accident happened which is can prevent road users used emergency land since this platform can send real time condition so that the authorities can take immediate action.

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