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Optimizing power consumption for sustainable dry turning of treated aluminum alloy

Rusdi Nur\textsuperscript{a,b}, D. Kurniawan\textsuperscript{b}, M.Y. Noordin\textsuperscript{b, *}, S. Izman\textsuperscript{b}

\textsuperscript{a}Politeknik Negeri Ujung Pandang, Makassar 90245, Indonesia
\textsuperscript{b}Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai 81310, Malaysia

Abstract

Machining companies can implement sustainable manufacturing using steps to improving the performance of economic, environmental and social. One of the steps is to perform the efficiency of energy consumption (mainly electricity) in machining. This paper describes a case study which investigates the effect of cutting parameters on power consumption and surface roughness by applying design of experiments. Dry turning of treated Al-11%Si alloy using coated carbide tool at different cutting speed (70, 130 and 250 m/min) and feed (0.05, 0.10 and 0.15 mm) was investigated. The results showed an optimum effect of cutting parameters that was obtained at low feed rate and high cutting speed, as shown by the model solutions.

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Keywords: Power consumption, Surface roughness, Aluminum alloy, Design of experiments

1. Introduction

By an increasing pressure on the machining companies as the result of competition, tightening environmental legislation, request supply chain to enhance the environmental performance, and declining the ability of expertise in the industry. For addressing the issue, machining companies adopt sustainable manufacturing on all items to get cost-effective and enhance the ability of the pillars of sustainability (economic, environmental and social) [1]. The basic problems above can be resolved by sustainable product design and manufacturing. Sustainability of a product or production can be achieved by arrangement at all phases undertaken.

* Corresponding author. Tel.:+6075534734; fax: +6075566159
E-mail address: denni@utm.my
The industries of manufacturing always try to reduce costs and improve the quality of machined parts as the request for manufactured goods with tighter tolerance has increased speedily. Towards sustainability, these should also be complemented with other aspects of machining output, with power consumption being one of them. Related researches have been conducted to study the influence of machining parameters, tool geometry, and cutting fluid on the surface integrity and power consumption when machining several workpiece materials. These include the work to analyzing power consumption and surface roughness when turning of nickel-based, Inconel 718 alloy [2]. Another work investigated the influence of machining parameters on surface roughness and power consumption when turning of AISI 1045 utilizing coated carbide tools [3]. Related work analyzed trends of cutting power consumption in conjunction with various combinations of machining variables such as feed rate, cutting speed, depth of cut, and tool nose radius [4]. Regarding machining parameters, cutting speed was suggested as one of determining factors. High-speed cutting translates to higher material removal rate, which is preferred. It also benefits from severe and rapid chip generation, limiting the heat transfer to the workpiece and resulted in only slight thermal distortion [7]. But it will cause the tools wear rapidly due extensive heat generated from the friction on the surface of the cutting [6], increase vibrations, and enlarge power consumption.

Hence, this study is conducted to determine the effect of machining parameters, i.e. cutting speed. Also of interest is the effect of feed. The effect of machining parameters to the machining output was developed using empirical models on machinability responses, including power consumption and surface roughness during turning of aluminum alloy under no cooling. For this purpose, design of experiment approach was used, as it was previously reported to be applicable for machining using coated carbide tools [8,9].

2. Calculating power consumption

The power profile during machine tool operation has been studied and given for many types of machining processes [11]. Power was supplied to turn on parts (e.g. CNC control unit, spindle, and feed axis) of the CNC machine tool to realize a series of actions (e.g. set up, loading, cutting, and automatic tool change) during the machining process. The power curve can be subdivided by three items: power of constant, variable, and peak. Peak power is usually in small portion to contribute for the cumulative energy consumption, and can be neglected when calculating the total energy consumption. With consideration of these states, the power demand can generally be differentiated into a variable and a constant power [12].

Gutowski et al. (2006) notified that energy used during the process of cutting the material is relatively small when compared with the total energy use for the operation of the machine [12]. Following his earlier work, the electrical power requirement, $P$, for machining was calculated as equation below:

$$P_m = P_o + k \cdot \dot{v}$$

where, $P_m$ is the power used for the cutting process [W]. $P_o$ is the power used at the time without loading the machining [W] such as motors, computers and fan, cooling pump etc. The unloading power was using a three-phase motor to drive the machine tools, $P_o$. It can be formulated with:
\[ P_o = V \cdot I \cdot \sqrt{3} \]  

(2)

where \( V \) is the voltage and \( I \) is the current [A]. In this paper, \( P_o \) was estimated as 35% from total power capacity of lathe machine. \( k \) is the specific energy [Ws/mm³] in cutting operations and valued 0.7 for aluminum alloy, referring to [13], and \( \dot{V} \) is material removal rate (MRR), in [mm³/s].

3. Experimental details

The workpiece used for experiment was treated Al-11%Si base alloy, with compositions of 0.67% Fe, 0.253% Mn, 10.68% Si, 0.036% Cr, 0.032% Ti, 0.235% Mg, 0.253% Mn, 1.61% Cu, 0.049% Ni and balance Al). An experimental study was carried out on 2-axes CNC lathe machine with a 8.3kW power rating [14]. Dry turning was used as the cutting method for 70, 130 and 250 m/min of cutting speed, 0.05, 0.10 and 0.15 mm of feed, and 0.5mm for depth of cut. A coated carbide with TiN coating was used as cutting tool. It has 0.2mm nose radius, positioned at 5° relief angle using tool holder.

4. Results and discussion

The experimental results for power consumption and surface roughness are presented in Figs. 1 and 2.

From Fig. 1, it shows that a smoother surface was obtained at high cutting speed and low feed rate, and the minimum power consumption was reached at small cutting speed and feed rate.

In Table 1, it is shown that \( \text{Prob.}>F \) has a value of less than 0.05 which means that the desired model has a significant impact on the response. The following is the final equation resulting empirical models, in the form of actual factors, namely:

\[ Ra = +3.04 - 0.01*Vc + 18.91*f \]  

(3)

\[ P_m = +2904.61 + 0.02*Vc + 273*f + 6.49*Vc*f \]  

(4)

where \( Vc \) and \( f \) are cutting speed [m/min] and feed rate [mm/rev], respectively.

Each input factor can be measured of its influence on the output response. This can be done by creating a model to optimize the selection of the cutting speed range and feed rate that will generate value criteria established in the power consumption and the surface roughness. This criterion will bring together cutting speed and feed rate in a combination that is sketched in the gray area of the overlay plot (Fig. 3). As the solution is the intersection between
the criteria of power consumption (area under the contour $P_c$ of 3000 W) and the criteria of the surface roughness (the area right next to the contours of $R_a$ of 2.4 $\mu$m).

Table 1. ANOVA analysis for surface roughness and power consumption

| Source          | Sum of squares | Degree of freedom | Mean square | F-value | Prob. < F |
|-----------------|----------------|-------------------|-------------|---------|-----------|
| **Surface roughness** |                |                   |             |         |           |
| Model           | 12.19          | 2                 | 6.09        | 12.96   | 0.0066    |
| A               | 6.82           | 1                 | 6.82        | 14.52   | 0.0089    |
| B               | 5.36           | 1                 | 5.36        | 11.41   | 0.0149    |
| **Power consumption** |            |                   |             |         |           |
| Model           | 49098.43       | 3                 | 16366.14    | 137.10  | < 0.0001  |
| A               | 13966.09       | 1                 | 13966.09    | 116.99  | 0.0001    |
| B               | 19070.03       | 1                 | 19070.03    | 159.75  | < 0.0001  |
| AB              | 3541.55        | 1                 | 3541.55     | 29.67   |           |

Fig. 3. Overlay plot of the input factors for the prearranged response criterion of maximum 3000W-$P_m$ and 2.4$\mu$m-$R_a$

Fig. 4. Overview of desirability of the input factors to attain power consumption and surface roughness that is optimum

The obtained solution can be specified by having more specific criteria of the responses. This determination can be made use in order to obtain power consumption and the surface roughness to be minimum, by calculating the desirability from the numerical equations. The calculation shows that the maximum value of desirability is achieved
at a combination of high cutting speed (170 m/min) and low feed rate (0.05 mm/rev) as given in Fig. 4.

5. Conclusion

In studying the turning of treated Al-11%Si alloy employing TiN coated carbide with different cutting speed (70, 130 and 250 m/min) and feed (0.05, 0.10 and 0.15 mm), it was found that the optimal of cutting parameter in terms of power consumption and surface roughness was found to be at high cutting speed and low feed. It was concluded that for the particular machining, power consumption decreases with the decrease of feed rate and increase of the cutting speed.

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a Politeknik Negeri Ujung Pandang, Makassar, 90245, Indonesia
b Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, 81310, Malaysia

Abstract
Machining companies can implement sustainable manufacturing using steps to improving the performance of economic, environmental and social. One of the steps is to perform the efficiency of energy consumption (mainly electricity) in machining. This paper describes a case study which investigates the effect of cutting parameters on power consumption and surface roughness by applying design of experiments. Dry turning of treated Al-11%Si alloy using coated carbide tool at different cutting speed (70, 130 and 250 m/min) and feed (0.05, 0.10 and 0.15 mm) was investigated. The results showed an optimum effect of cutting parameters that was obtained at low feed rate and high cutting speed, as shown by the model solutions. © 2015 The Authors

Author Keywords
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Correspondence Address
Noordin M.Y.; Faculty of Mechanical Engineering, Universiti Teknologi Malaysia

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|-------------------|---------------------|-----------------|
| Kurniawan, Denni  | C-2703-2008         | 0000-0002-4179-0454 |
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