Optimization of Machining Factors Affects Chip Shrinkage Coefficient, Surface Roughness When High-Speed Milling of Aluminum Alloy A7075

Thi-Hoa Pham, Duc-Toan Nguyen, Viet-Hoi Tran, and Dang-Thuc Phan

Abstract This study uses the Taguchi method to estimate the influence of cutting factors: cutting speed, depth of cut and feed rate (*V, t, S*) on chip shrinkage coefficient (*K*) and surface roughness (*Ra*) when high-speed milling (HSM) of A7075 aluminum alloy. The results show that the *t* greatly influences the *Ra* is 51.16%, the second level of influence on the feed rate is 29.77%, then the cutting speed is 19.06%. With the chip shrinkage coefficient, the *t*, *S*, and *V* affecting *K* are 64.9%, 21.8%, and 13.4%, respectively. Research using Gray multi-objective optimization to invent the applicable set of cutting factors for *K* and *Ra* with the corresponding minimum criteria as follows: $V = 1695$ (m/min), $t = 1.0$ (mm), and $S = 600$ (mm/min) respectively.

Keywords A70751 aluminum alloy · Chip shrinkage coefficient · Surface roughness

1 Introduction

Chip shrinkage coefficient and surface roughness are factors that reflect phenomena occurring during chip formation such as material deformation and cutting heat [1]. Joshi et al. [2] analyzed *Ra* and chip parts during the machining of circular milling cutters. The results presented that the *Ra* is affected by the inclination angle.

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Increased tilt angle reduces surface roughness. As the irritated sectional part of the chip increases, the angle of inclination decreases. The *S* and *t* increase the chip irritated-sectional width and height and significantly affect the chip cross-sectional area. Ribeiro et al. [3] studied on optimization of cutting factors to minimize *Ra* during finishing by the Taguchi method. The result showed that the parameter of cutting depth has the most effect on the *Ra*. Joshua et al. [4] investigated the parameters affecting the *Ra* during the milling of A6061 aluminum alloy using MQL (Minimum Quantity Lubrication). Their result showed that the surface roughness in milling by MQL is better than in rough milling. *Ra* is mostly predisposed by cutting speed and cutting depth. Besides, several surface roughness optimization methods are based on response surface methodology and genetic algorithms [5]. In the study [6], the author experimented and showed the effect of cutting factors on the *Ra* in the finishing milling of 6061 aluminum alloy. Madariaga et al. [7] studied the effect of *V* on *Ra* responsiveness in the milling of A7050 aluminum. Pham et al. [8] experimented with evaluated the effect of cutting factors on the *Ra*, vibration, and tool–chip contact length. It can be observed that previous studies mainly investigate the cutting factors affecting the *Ra* of machine parts. There are very few studies on the chip shrinkage that occurs during the machining of A7075 aluminum alloy. This study evaluates the percentage influence of cutting factors, including *V* (cutting speed), *S* (feed rate), and *t* (cutting depth), on *Ra* and *K* during high-speed milling (HSM) of the A7075 aluminum alloy. The multi-objective optimization by Taguchi Gray method for cutting factors is applied to minimize the *Ra* and *K* values. As a result, a common set of cutting factors satisfying the requirements for *Ra* and *K* is revealed.

2 Experimental Conditions

2.1 Cutting Workpiece

An experimental study using A7075 aluminum alloy (Fig. 1). This is a line of durable deformed alloys and is the highest-strength aluminum alloy. It is commonly used mainly in the aerospace industry and blow molding and precision mechanics… The physical and motorized properties of A7075 are exposed in Table 1.

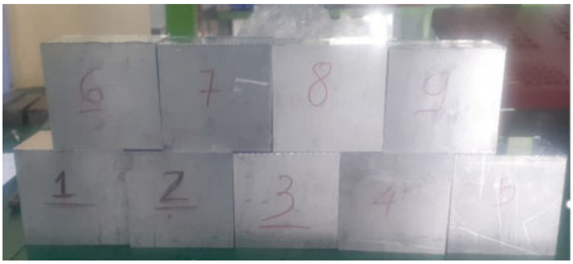

Fig. 1 A7075 aluminum alloy workpiece

Table 1 Chemical compositions of aluminum alloy A7075 (%)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4	0.5	1.2–2.0	0.3	2.1–2.9	0.18–0.28	5.1–6.1	0.2	87.1–91.4

2.2 *Machining Machine and Cutting Tools*

The study used end mills with size $\Phi 63$ (mm), carbide alloy pieces and hardness. The dimensions of the tool cutting as shown in Fig. 2 are respectively $l = d = 12$ (mm), $m = 3$ (mm), $d_1 = 6$ (mm). Investigational study on high-speed milling of A7075 aluminum alloy on CNC 700HS (Fig. 3). The machine is a trademark of Knuth of Bac Ninh Industrial College, the table size is 750 × 450 mm, the X, Y, Z axis travel is 700 × 500 × 500 mm. The machine uses the control system of Siemens828D. The speed of the X, Y, and Z axes advances as fast as 60,000 mm/min. A-axis rotation ranges from 30 to 1200, and C-axis rotates at 3600.

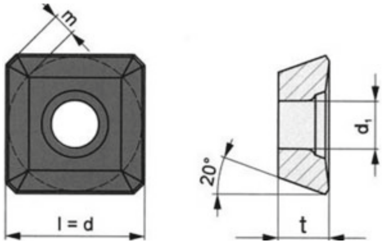

Fig. 2 Cutting tool geometry

Fig. 3 CNC 700HS milling machine

Fig. 4 Roughness measuring device SJ410

2.3 Measuring Devices

Research using the roughness measuring device SJ410, metrology laboratory—Department of mechanical engineering—Hung Yen University of Technology and Education (Fig. 4). The SJ410 can measure micro-steps and strength using the non-slip measurement function. The roughness parameter conforms to the latest ISO, DIN, ANSI, and JIS standards. Figure 3 shows the surface roughness measurement diagram after high-speed machining of A7075 aluminum alloy. We are measuring range: 800 μm, resolution 0.000125 μm.

2.4 Experimental Conditions

The Taguchi method prepared experimental parameters for HSM of aluminum alloy A7075. The levels of cutting factors are selected based on the machining equipment, tool material, and rigidity of the machine-tool-jigsaw system, given according to the following levels: 942 (m/min) $\leq V \leq$ 1695 (m/min); 600 (mm/min) $\leq S \leq$ 1000 (mm/min); 1.0 (mm) $\leq t \leq$ 2.0 (mm).

The experimental matrix and measurement results of *Ra* and *K,* respectively, are given in Table 2.

Table 2 L9 orthogonal array and measurement results

No	Cutting parameters			*Ra* (μm)	*K*
	V (m/min)	*t* (mm)	*S* (mm/min)		
1	1(942)	1(1.0)	1(600)	0.1580	1.597
2	1(942)	2(1.5)	2(800)	0.1620	1.585
3	1(942)	3(2.0)	3(1000)	0.1803	1.675
4	2(1318)	1(1.0)	2(800)	0.1190	1.633
5	2(1318)	2(1.5)	3(1000)	0.1766	1.596
6	2(1318)	3(2.0)	1(600)	0.1790	1.644
7	3(1695)	1(1.0)	3(1000)	0.1583	1.512
8	3(1695)	2(1.5)	1(600)	0.1143	1.599
9	3(1695)	3(2.0)	2(800)	0.1703	1.646

Table 3 Analysis of the effect of cutting factors on *Ra*

Parameters	S/N			Sum of squares	Distribution percentage
	1	2	3		
V (m/min)	15.57	16.16	16.74*	2.05	0.1906
t (mm)	16.84*	16.57	15.06	5.49	0.5116
S (mm/min)	16.60*	16.56	15.32	3.19	0.2977

*optimum values

3 Results and Discussion

3.1 *Effect of Cutting Factors on* Ra

ANOVA analysis for surface roughness affected by cutting factors is assumed in Table 3. The table shows that the *t* greatly influences the *Ra* is 51.16%, then the feed amount is 29.77%, and finally, the cutting speed is 19.06%. From Table 3, a set of cutting parameters can be selected so that the *Ra* is the minimum consistent with the cutting factors: $V = 1695$ (m/min); $t = 1.0$ (mm); $S = 600$ (mm/min). The influence of these parameters is also shown visually in Fig. 5, corresponding to the highest peak of the parameters compared to the average value curve.

3.2 *The Influence of Cutting Factors on* K

Measure the chip shrinkage coefficient when high-speed milling of aluminum alloy A7075 according to the chip weight method. The measurement results agree to the experiments shown in Table 4.

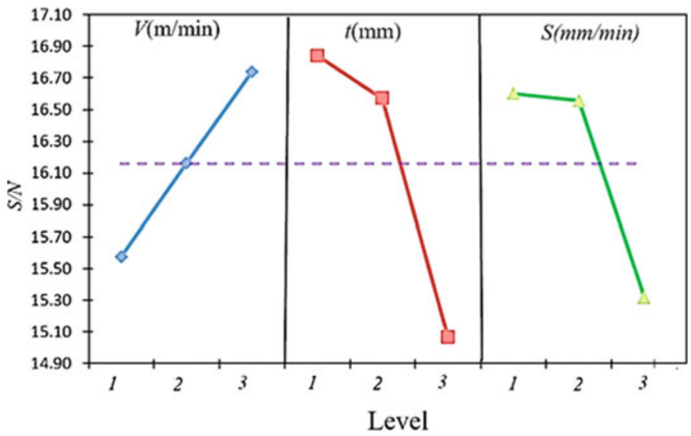

Fig. 5 S/N ratio of *Ra*

Table 4 Analyze the influence of cutting factors on *K*

Parameter	Meaning of S/N of each level			Sum of squares	Distribution percentage
	1	2	3		
V (m/min)	−3.794	−3.948	−3.617*	0.165	0.094
t (mm)	−3.440*	−3.610	−4.309	1.272	0.722
S (mm/min)	−3.578*	−4.037	−3.744	0.323	0.184

*optimum values

ANOVA analysis of the influence of cutting factors on the *K* when HSM of aluminum alloy A7075 is given in Table 4. On the table, the effect of the cutting factors is as follows: $t = 72.2\%$, $S = 18.4\%$, and $V = 9.4\%$. Thus, the optimal set of cutting factors for the smallest *K* is respectively $V = 1695$ (m/min); $t = 1$ (mm); $S = 600$ (mm/min). This set of cutting factors is also shown in Fig. 6 as the highest point of the *S/N* relation for each factor.

3.3 Multi-objective Optimization of the Influence of Cutting Factors on **K** *and* **Ra**

Gray correlation analysis is used to simultaneously assess the effect of the cutting factor on the outputs *Ra* and *K*. With the slightest characteristic being the best, and the initial sequence is normalized as follows:

$$S_{kj} = \frac{\max X_{kj} - X_{kj}}{\max X_{kj} - \min X_{kj}} \tag{1}$$

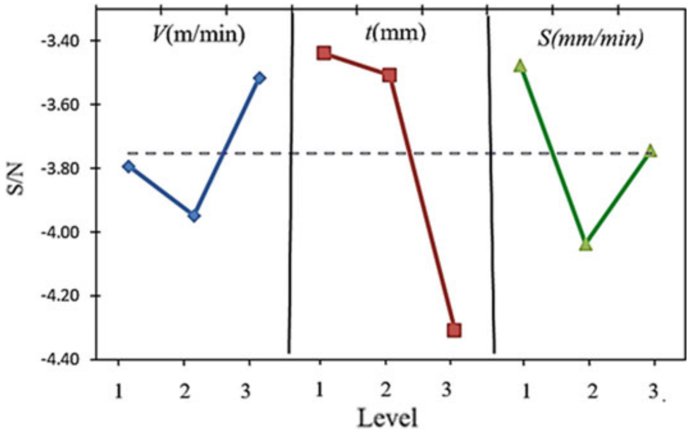

Fig. 6 S/N ratio of *K*

where: $j = 1,2,3,\ldots m$, m is the amount of experiments in the Taguchi orthogonal array; k = 1, 2, … n, n is the amount of experiments; max X_{kj} is the maximum significance of X_{kj}; min X_{kj} is the minimum significance; S_{kj} is the value after Gray correlation analysis; GRG is the weight of the real Gray relationship.

The properties are evaluated based on the relationships between each Gray relation given by formula (2)

$$GZ_{kj} = \frac{S_{k\min} + \mu S_{k\max}}{S_{kj} + \mu S_{k\max}} \quad (2)$$

where μ is the discriminant coefficient in the range $(0 \div 1)$ and choose $\mu = 0.5$

The output parameter is better when the Gray correlation coefficient has the most significant value, and in 9 experiments, there are three experiments with good results, which is experiment 8, 1, and 7, as shown in Table 5. The most considerable Gray relation classification value in experiment 8 is 0.893. The highest level of *GRG* is said to be optimized for the parameters.

From the table of features of the Gray relationship classification, Table. 6 shows the rank order of the cutting factors to the output parameters *K* and *Ra* with a depth of cut of 60.89%, a feed rate of 21.80%, and a cutting speed of 17.31%. The cutting speed is 14.133%. The common set of cutting factors for the smallest *K* and *Ra* are $V = 1695$ (m/min), $t = 1.0$ (mm), and $S = 600$ (mm/min) respectively.

Table 5 Grey relationship rating

No	S (*K*)	S (*F*)	GZ-(*K*)	GZ-(*F*)	G
1	0.136	0.710	1.000	0.413	0.707
2	0.655	0.765	0.454	0.395	0.425
3	1.000	1.000	0.333	0.333	0.333
4	0.684	0.088	0.441	0.850	0.645
5	0.496	0.955	0.545	0.344	0.444
6	0.949	0.984	0.347	0.337	0.342
7	0.180	0.714	0.907	0.412	0.659
8	0.000	0.000	0.830	1.000	0.915
9	0.988	0.875	0.336	0.364	0.350

Table 6 Grey relationship grade

Parameter	Grey relationship grade			Max–min	Rank	Sum of squares	Distribution percentage
	1	2	3				
V	0.488	0.477	0.641*	0.164	1	0.0168	17.307
t	0.670*	0.595	0.342	0.329	2	0.059	60.891
S	0.654*	0.473	0.479	0.181	3	0.021	21.802

*optimum values

4 Conclusions

The study evaluates the effect of cutting factors on *Ra* and *K* in HSM of A7075 aluminum alloy. The results show that cutting depth has the greatest influence on *Ra* with 51.16%, followed by the effect of *S* at 29.77%, and the effect of *V* at 19. 0.06% is the smallest. With the *K*, the cutting depth, feed rate, and cutting speed affecting *K* value are 64.9%, 21.8%, and 13.4%, respectively. The set of cutting factors for *K* and *Ra* matching the minimum criteria using Gray multi-objective optimization is found as follows: cutting depth of 60.89%, feed rate of 21.08%, and cutting speed of 17.31%.

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