IOP Conference Series: Materials Science and Engineering

The Optimum Cutting Condition when High Speed Turning of Aluminum Alloy using Uncoated Carbide

To cite this article: B. Umroh *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **505** 012041

The Optimum Cutting Condition when High Speed Turning of Aluminum Alloy using Uncoated Carbide

B. Umroh[1], Muhathir[2], Darianto[1]
[1]Department of Mechanical Engineering, [2]Department of Informatics Engineering,
Faculty of Engineering, Universitas Medan Area (UMA)
Jalan Kolam No. 1, 20223 Medan Estate, Indonesia

Abstract

Objective of study reported in this paper is finding the optimum cutting condition respected to surface roughness (Ra), flank wear (VB) and tool life (TL) when high speed turning of aluminum alloy using uncoated carbide. Turning test was carried out by full factorial design where cutting speed (v), feed (f) and depth of cut (a) were determined as the independent variables. The high level values were set as v 1250 m/min, f 0.15 mm/rev, a 1.2 mm and for the low level were v 1000 m/min, f 0.12 mm/rev, a 1 mm. By multiple-linear regression method, the data of response variables resulted from the testing was used to developed 3 (three) mathematical models of Ra, VB and TL. Those models, φ(v, f, a), were then used as the fitness functions for finding the optimum cutting condition using Multi Objective Genetic Algorithm (MOGA) method. The results of study show that the optimum cutting condition for gaining the best roughness is at v 1000 m/min, f 0.12 mm/rev and a 1.2 mm. At that cutting condition, Ra and TL are recorded at 1.22 microns and 2.32 minutes, respectively.

Keywords: flank wear, roughness (Ra), tool life, optimization, multi objective genetic algorithm (MOGA)

1. Introduction

High speed machining is becoming the most advanced technology in the metal industry [1]. The concept of high speed turning can increase productivity up to five to ten times more than conventional machining [2]. Therefore, high-speed machining strategy has become a new interest in the manufacturing industry because it can reduce both machining time and production costs as well as impact on productivity improvements [2]. High speed turning is determined by the rate of cutting and its relation to the material to be cut. For Aluminum alloy materials, the rate of high speed machining cutting speed is at v > 1000 m / min [3]. In addition to the productivity that is closely related to high-speed machining, the concept of high-speed machining can also improve the surface quality for the better. The surface roughness value generated by high speed machining is less than the machining at a moderate rate that allows the build up edge resulting in disturbance to surface quality [4].

The use of uncoated carbide insert is actually commonly used in the Aluminum alloying process, which is done with the concept of high speed machining [2]. Uncoated carbide tool is suitable for machining of Aluminum alloys due to relatively low temperature of cutting comparing to machining of steel. Wear on the uncoated carbide tool is mainly determined by cutting speed and cutting temperature. Generally, the wear that occurs on an uncoated carbide tool is flank wear. The quality of surface roughness in machining of Aluminum alloys using uncoated carbide tool is strongly influenced by cutting speed. The value of roughness in Ra parameter decreases as the increasing of cutting speed. On the other hand, depth of cut and cutting force are reported to degrade the quality of surface roughness [5].

The cutting condition strongly influences surface roughness was reported [6] while conducting study with aim of minimizing surface roughness (Ra) and maximizing metal removal rate (MRR) on Aluminum alloy using uncoated carbide using tool by Taguchi Robust Design. They reported that optimum surface roughness were at high spindle speed (high), low feed (low) and low cutting depth (low). Besides Taguchi method, machining optimization is also reported using genetic algorithm (GA) [7]. They reported that (GA) was the solution to determine the optimal conditions of cutting parameters that affect the production cost, production time, and the final quality of the product. The other researcher reported that GA was successfully used to find optimal cutting conditions to minimize the cutting temperature and surface roughness of Aluminum Alloy 6061 [8]. From those references, it can be concluded that cutting condition greatly affects the surface roughness and thus, it is necessary to find the optimum conditions to obtain the best surface roughness (Ra) at high speed turning Aluminum alloy.

The objective of study in the present paper is finding the optimum cutting condition which subjected to surface roughness (Ra), flank wear (VB), and tool life (TL) when turning of Aluminum alloy under high speed machining condition. The genetic algorithm is utilized for obtaining the optimum cutting condition. There are 3 (three) fitness functions developed from the experimental data. The result of study is expected to be a useful supporting technology for the metal cutting industry in order to increase their productivity when producing components made of Aluminum alloy by using the uncoated carbide tool.

2. Materials and Method

2.1 Workpiece Material

The workpiece in this research is Aluminum alloy 6061. This type of material is widely used in the field and industry as a material for the application of automotive components. The chemical composition and mechanical properties of Aluminum alloy 6061 are given in Table 1 and Table 2.

Table 1. The Chemical Composition of Aluminum alloy 6061

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0,65	0,70	0,2	0,1	0,9	0,1	0,1	0,1	balance

Table 2. The Mechanical Properties of Aluminum alloy 6061

Property	value
Young Modulus	69 GPa
Tensile strength	125 MPa
Yield strength	55 MPa
Elongation	25–30%

2.2 Tool material

The tool used in this study is uncoated carbide of ISO K10 from Sandvik Coromant. The insert type tool used has initial of DCGX 11 T3 04-AL with tool radius (r_ε) of 0.4 mm and thickness of 4 mm. The insert tool is mounted on the tool holder coded by SDJCL 2020K 11 with back rake angle of -3^{o} .

Figure 1. The experimental setup.

2.3 Experiment

Machine tool CNC LATHE FOCUS with power of 3 hp and maximum rotation speed of 4000 RPM was utilized for turning test. The work piece with a diameter of 180 mm and 300 mm in length was rigidly installed on the machine.

The examination of flank wear was done by a digital microscope. Surface roughness measurements (Ra) was recorded by using stylus profilometer. The experimental setup is as shown in Figure 1.

The machining test was done by experimental design of the factorial method 2^3. The independent variables were the three variables of cutting condition, viz. cutting speed (v), feeding (f) and depth of cut (a), and as the response variables were surface roughness Ra), flank wear (VB), and tool life (TL). The values of cutting conditions selected in this study were at lower limit of v 1000 m / min, f 0.12 mm / rev and a 1 mm, and at the upper limit of v 1250 m / min, f 0.15 mmrev and a 1.2 mm. The selection of the cutting speed of the lower limit of v 1000 m / min was in accordance with the recommendation in [3] for high speed machining of Aluminum alloys. For the feed rate and depth of cut referred to tool's supplier.

The tool life criteria are determined by the flank wear value (VB) and its relation to the surface roughness measured in Ra parameter. In this case, in accordance with [9], the flank wear (VB) value for carbides is (0.2 - 0.5) mm and the surface roughness value is for the quality of medium finish at Ra (0.6 - 3.2) microns.

2.4 Optimization with Genetic Algorithm

The Genetic Algorithm (GA) is one of the optimization methods with its basic idea based on the evolution of a species. In particular, GA simulates the natural process in term of biological behavior that allows successive generations within a population to be able to adapt to their environment. The process is mainly adopted through the inheritance of the nature of the previous generation in population (parents) to the next generation (off spring or children) resulted by the previous population through the respected generation model.

GA is also a searching method through population that the end result is a search strategy tailored for broad, complex, and multimodal search spaces. GA starts with a randomly generated individual population, each created by a string of design variables, representing a chromosome set that includes the search space. Each individual is correctly encoded into a chromosome created by a series of genes. Each gene represents a parameter among the the design parameters and it can be presented using string bits, real numbers or other alphabets.

Since the objective of this study is finding the best surface roughness by considering 3 response variables simultaneously; the optimization is carried out by using Multi Objective Genetic Algorithm (MOGA) method. MOGA is one of the most widely used techniques and has the ability to find solutions to problems that have many conflicting parameters.

For the optimization process, the response variables are surface roughness (Ra), flank wear (VB) and tool life (TL) in cutting functional functions i.e. cutting speed (v), feed (f), and depth of cut (a). MOGA is done until the iteration termination criterion is resulted and the model output that meets the limit function at the end of the optimization process is generated.

3. Results and Discussion

3.1 Data of experiment

Eight runs of turning test by factorial design 2^3 for Aluminum alloys at high speed machining using uncoated carbide tool have been successfully performed. The data obtained is as shown in Table 3.

The data in Table 3 shows that at 8 tests, the criterion of surface roughness for medium finish quality has been fulfilled by Ra (1.08 - 2.31) microns and the flank wear recorded is at VB (0.021 - 0.036) mm and the tool life is still at (0.576 - 0.994) minute.

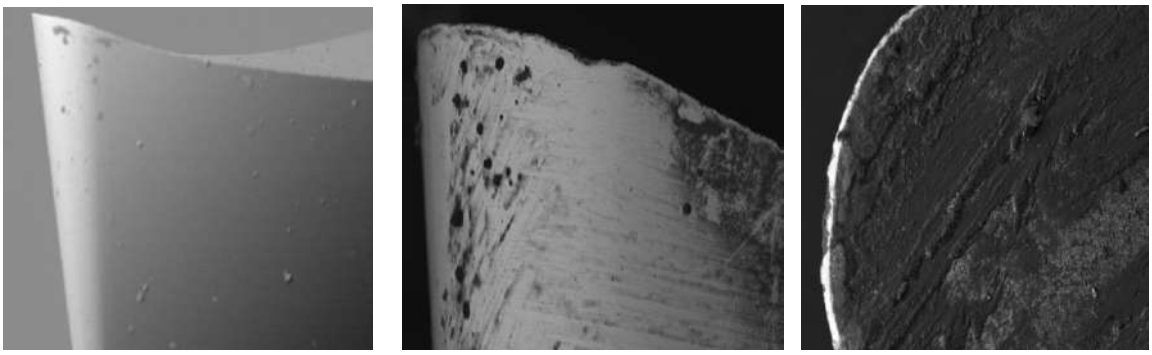
Tabel 3. Data of experiment

No	v	f	a	VB	Ra	TL	TL^1	Ra^1	VB^1
	(m/min)	(mm)	(mm)	(mm)	(µm)	(min)	(min)	(µm)	(mm)
1	1000	0.12	1.0	0.021	1.33	0.951	-	-	-
2	1250	0.12	1.0	0.032	1.53	0.769	-	-	-
3	1000	0.15	1.0	0.027	2.15	0.739	-	-	-
4	1250	0.15	1.0	0.034	2.31	0.576	-	-	-
5	1000	0.12	1.2	0.022	1.08	0.994	18.92	1.56	0.247
6	1250	0.12	1.2	0.036	1.41	0.732	9.20	1.90	0.129
7	1000	0.15	1.2	0.028	2.27	0.683	-	-	-
8	1250	0.15	1.2	0.036	2.31	0.645	-	-	-

Subsequently, two cutting conditions were selected for further testing. In this case, the selected cutting conditions were numbered 5 and number 6. For both of these cutting conditions, the tests were continued until the tool life criteria VB (0.2 - 0.4) mm without neglecting surface roughness limits at medium finish Ra (0.6 - 3.2) microns. From the data in Table 3, it can be seen that the test was successfully performed on the flank wear of VB^1 (0.129 - 0.247) mm. The flank wear limit was reached and tool life recorded at TL^1 (9.20 - 18.92) minutes while the surface roughness Ra^1 of (1.56 - 1.90) microns. Based on this data, it can be concluded that to the extent of flank wear of VB 0.2 mm, the expectation of obtaining surface roughness at the medium finish quality and reliable tool life according to ISO 3685 [10] i.e. TL > 5 minutes can be produced.

3.2 Tool Wear

Of the 8 cutting conditions performed, generally the wear mode was flank wear. The observation was strengthened by observation using Scanning Electron Miroscope (SEM) and the evidences are as shown in Figure 2. The examination using SEM confirms that the value of flank wear is determined by the cutting speed. At the cutting speed of 1250 m/min, the flank wear (VB) width is recorded VB 0.2 mm. This is in line with the results of the previous researcher in [5]. In addition to the flank wear experienced by the uncoated carbide tool, Fig. 2 shows some other distortions such as micro-chipping on the left side of the sculpting eye and the impression of a blow that is thought to be caused by the silica element contained in the workpiece Aluminum alloy.

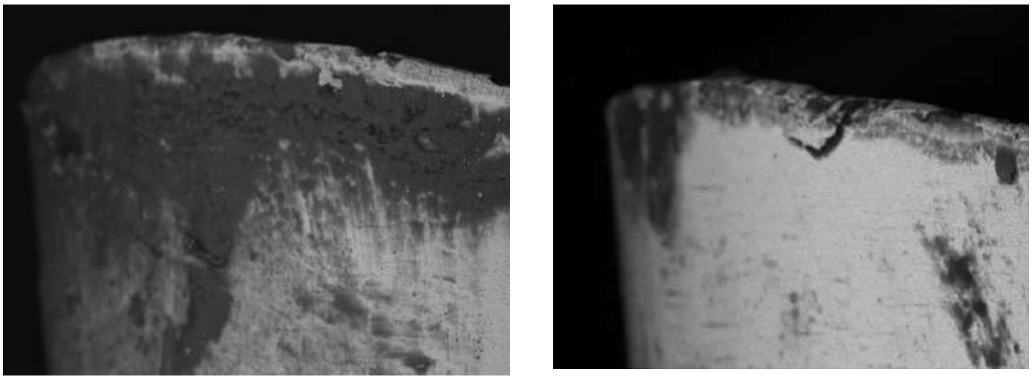


(a) (b) (c)

Figure 2. (a) Fresh insert, (b) and (c) worn insert resulted by testing number 1.

3.3 Tool Life

Tool life in this study was determined by criteria as described above. As previously described, a randomly selected 2 (two) cutting conditions at v 1000 m / min, f 0.12 mm / rev, a 1.2 mm, and at v 1250 m / min, f 0.12 mm / rev, a 1.2 mm.



(a) (b)

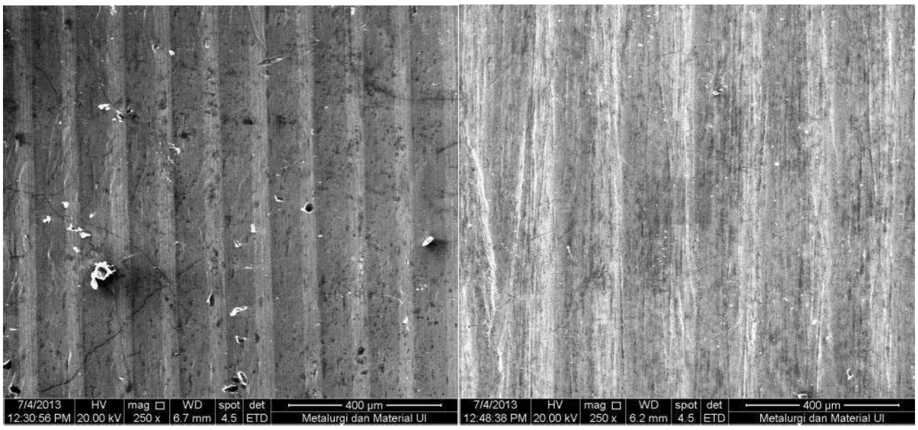
Figure 3. Worn tool resulted (a) when TL 9.2 minutes, and (b) TL 18.92 minutes.

According to the data in Table 3 that in both cutting conditions, initially the surface roughness data is Ra 1.08 microns for cutting condition number 5 (five) and Ra 1.41 microns for cutting condition number 6 (six). Furthermore, for both cutting conditions, intensive testing was done until successful data obtained for cutting condition number 5 (five) with TL^1 of 18.92 minutes on VB^1 of 0.247 mm and surface roughness Ra^1 1.56 microns. For the cutting condition number 6 (six) was obtained TL^1 9.2 minutes at VB^1 0.129 mm and it was noted that surface roughness Ra^1 1.9 microns. The condition of tool wear (VB^1) and its relation to tool life (TL^1) in both cuttings number 5 (five) and 6 (six) are given in Figure 3. From the data it can be concluded that the best tool life value is determined by the cutting speed.

3.4 Surface Roughness

The surface roughness (Ra) obtained from the 8 (eight) cutting conditions is also given in Table 3. All indicate that high speed machining of Aluminum alloy 6061 using uncoated carbide tool is capable to produce medium finish quality of surface roughness.

From observations made and the measurement using the stylus profilometer show that the roughness value (Ra) is largely determined by the feed. At feed of 0.15 mm/rev, it was obtained an average surface roughness value Ra ≥ 2 microns. At feed of 1.2 mm/rev, Ra obtained ≤ 1.53 microns. An increase in the value of feed (f) indicates the increasing behavior of the surface roughness value (Ra). Observation on the topography of the machined surface, the lay condition is as shown by the photograph of the machined surface in Figure. 4.

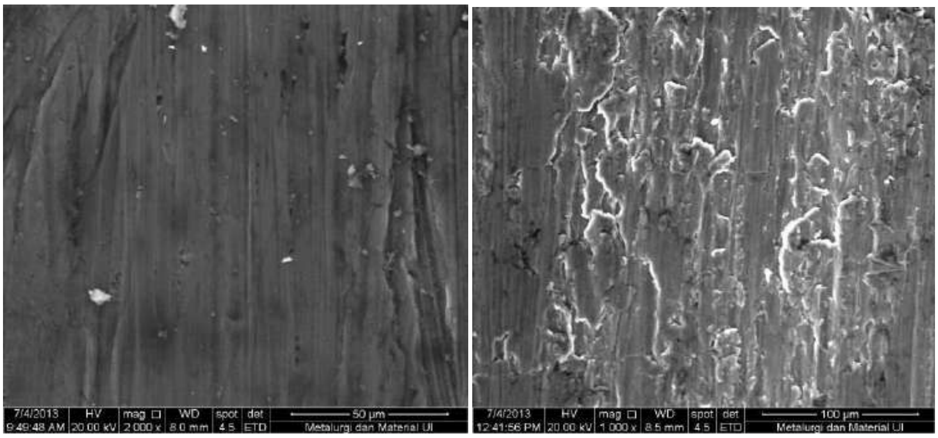


(a)

(b)

Figure 4. Topography (lay) of the machined surfaces: (a) f 0.12 mm/rev, and (b) f 0.15 mm/rev

Previous researchers [6], reported that depth of cut (a) was a variable that gave effect to the surface quality of the surface. In relation to the results of this study, Fig. 5 shows the surface topography of the surface of the machined surface produced by two depth of cut (a) conditions, Fig. 5 (a) by a 1 mm cutting depth and Fig. 5 (b) by a 1.2 mm cutting depth. Both SEM topographical surface images show that the expanding chip (molten chip) covers the surface of the machined surface. This causes the enclosure of the valley and the peak formed at the time of the cut so that the measured Ra value as the valley mean value and the peak becomes smaller.



(a) (b)

Figure 5. Topography of machined surfaces: (a) a 1 mm, and (b) a 1,2 mm.

3.5 Optimum Cutting Condition

The optimization provides an excellent solution for finding the optimal cutting condition for machining process. The optimization procedure has two phases. The first phase is mathematical modeling with variable constraints. The second phase is to find the minimum objective function with all the defined lower limit and upper limit values.

The first phase of this study was conducted with a multi linear regression model to produce a mathematical equation with two conditions. The first condition was searched with tool life <1 min, and the second was searched by involving 2 cutting conditions with tool life> 1 min. The equations obtained are as follows:

a. Tool life condition < 1 minute

$$Ra = -2.83 + 0.000730\,V + 30.8\,f - 0.313\,a \tag{1}$$

S = 0.113413 R-Sq = 97.2% R-Sq(adj) = 95.1% (2)

$$VB = -0.0422 + 0.000040\,V + 0.117\,f + 0.0100\,a \tag{3}$$

S = 0.00196850 R-Sq = 93.8% R-Sq(adj) = 89.1% (4)

$$TL = 2.36 - 0.000645\,V - 6.69\,f + 0.024\,a \tag{5}$$

S = 0.0567748 R-Sq = 91.1% R-Sq(adj) = 84.5% (6)

b. Tool life condition > 1 minute

$$Ra^1 = -2.96 + 0.000740\,V + 22.7\,f + 0.900\,a \tag{7}$$

S = 0.113743 R-Sq = 95.3% R-Sq(adj) = 91.8% (8)

$$VB^1 = 0.066 - 0.000092\,V - 2.53\,f + 0.408\,a \tag{9}$$

S = 0.0685948 R-Sq = 57.9% R-Sq(adj) = 26.3% (10)

$$TL^{1} = 9.7 - 0.0101\,V - 227\,f + 33.0\,a \qquad (11)$$

$$S = 5.51238 \quad \text{R-Sq} = 61.3\% \quad \text{R-Sq(adj)} = 32.3\% \qquad (12)$$

3.6 Multi Objectif Genetic Algorithm (MOGA) optimization using MATLAB®

The optimization is done using Multi Objective Genetic Algorithm from MATLAB® software. Multi Objective Genetic Algorithm (MOGA) becomes the preferred method of optimization in this study due to fitness functions (Ra, VB, TL) are more than one. Furthermore, the above mathematical models are used as fitness functions to find the optimum of maximum and minimum values. The optimum value of cutting condition resulted are as shown by the output in Figure 6 and Figure 7.

Table 4. The Optimum Cutting Condition with MOGA.

Condition	Value of optimum conditions	Ra (µm)	VB (mm)	TL (min)
≤ 1 menit	V= 1000, f= 1.2 a=1	1.40	0.020	3.90
≥ 1 menit	V= 1000, f=1.2 a= 1	1.22	0.021	2.32

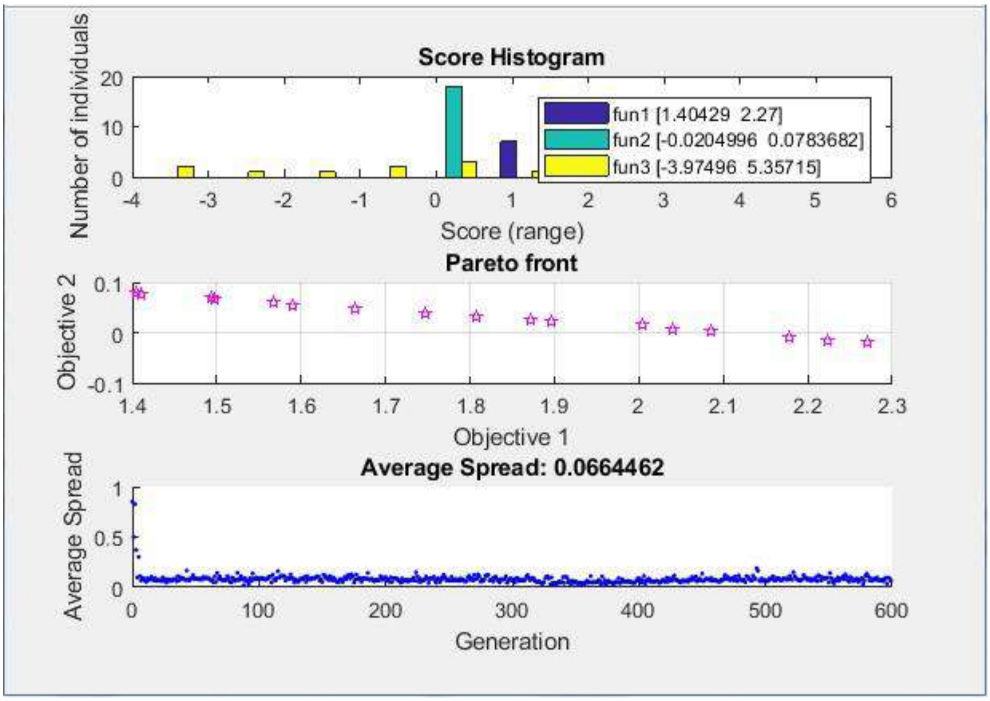


Figure 6. The output of MATLAB when processing the fitness functions resulted from tool life data < 1 minute.

Figure 6 shows the results using fitness functions in the form of mathematical models for Ra, VB and TL generated from compilation of experimental data for cutting time <1 min. The utilization of MOGA for this condition with the boundary condition limit of the lower limit [1000 0.12 1.00] and the upper limit [1250 1.15 1.20] gives the optimal result is as shown in Table 5. The same is done for the mathematical model compiled from the experimental data of tool life > 1 minute. Figure 7 shows that the Pareto front is more random and irregular. This position is different from Figure 6 when Pareto front looks more regular. This condition is due to data retrieval with condition > 1 minute has a very long range of values. However, the value of the optimum cutting condition is still in the same condition.

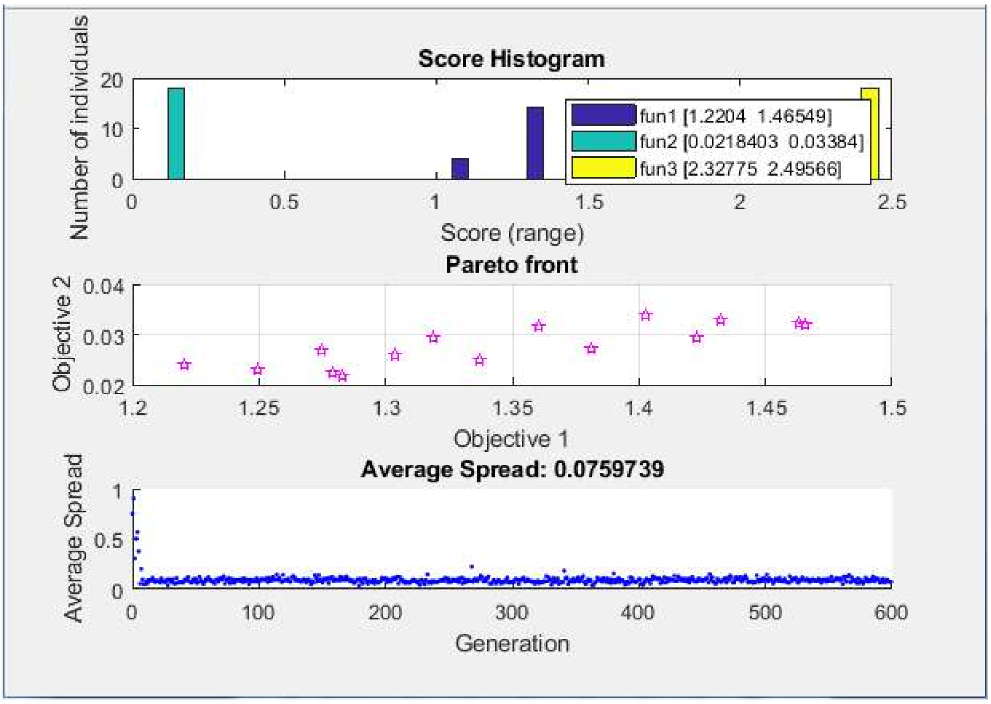


Figure 7. The output of MATLAB when processing the fitness functions resulted from tool life data > 1 minute.

4. Conclusions

1. At high speed machining up to v 1250 m / min, f 0.15 mm/rev and a 1.2 mm applied to Aluminum alloy 6061 using tool uncoated carbide, the wear mode of the uncoated carbide tool is dominated by flank wear. The value of flank wear (VB) is still within the acceptable value for tool carbide of VB 0.2 mm.
2. Up to the flank wear of VB 0.2 mm, the quality of the machined surfaces measured in Ra parameter indicates that surface quality of medium finish can be produced. The Ra value generated at the high speed machining of Aluminum alloy 6061 in this study is Ra < 2.31 microns.
3. The surface roughness in this study is mostly determined by feed variable (f) while the flank wear is more affected by the cutting speed (v).
4. The optimum cutting condition obtained by using Multi Objective Genetic Algorithm (MOGA) using MATLAB is at cutting condition v 1000 m / min, f 1.2 mm / rev, and a 1.2 mm. Under this cutting condition, the values of Ra, VB and TL are Ra (1.22 - 1.40) µm, VB (0.020 - 0.021) mm and TL (2.32 - 3.90) minutes, respectively.
5. Experiment and optimization results show that high speed machining for Aluminum 6061 alloy using uncoated carbide tool can be done successfully and

can be recommended to support or to increase the productivity in metal cutting industry.

Acknowledgements

Sincere gratitude is addressed to Prof. A. Ginting for his suggestion during writing the manuscript. The research grant from the Ministry of Research and Technology and Higher Education is acknowledged.

References

[1] D. D'Addona, S. J. Raykar and M. Narke, "High speed machining of Inconel 718: tool wear and surface roughness analysis," *Procedia CIRP 62,* p. 269 – 274, 2017.
[2] S. Raykar, D. D'Addona and A. Mane, "Multi-objective optimization of high speed turning of Al 7075 using grey relational analysis," *Procedia CIRP 33,* p. 293 – 298, 2015
[3] H. Schultz and T. Moriwaki, "High speed Machining," *Annals of the CIRPP,* 1992.
[4] C. Kalyan and G. Samuel, "Cutting mode analysis in high seed turning of ALMgSi alloy using edge chamfered PCD tools," *Journal Of Material Processing Technology 216,* pp. 146-159, 2015.
[5] P. Bansal and L. Upadhyay, "Effect of Turning Parameters on Tool Wear, Surface Roughness and Metal Removal Rate of Alumina Reinforced Aluminum Composite," *Procedia Technology 23,* p. 304 – 310, 2016.
[6] A. Saravanakumar, S. Karthikeyan, B. Dhamotharan and V. G. Kumar, "Optimization of CNC Turning Parameters on Aluminum Alloy 6063 using TaguchiRobust Design," *Materials Today: Proceedings 5,* p. 8290–8298, 2018.
[7] Doriana, M. Addona and T. Roberto, "Genetic algorithm-based optimization of cutting parameters in turning processes," *Forty Sixth CIRP Conference on Manufacturing Systems, Procedia CIRP 7,* p. 323 – 328, 2013.
[8] N. Rajesh, M. Yohan, P. Venkataramaiah and M. V. pallavid, "Optimization of Cutting Parameters for Minimization of Cutting Temperature and Surface Roughness in Turning of Al6061 Alloy," *Materials Today: Proceedings 4,* p. 8624–8632, 2017.
[9] S. Kalpakjian and S. Schmid, "Manufacturing Engineering and Technology," *fifth Edition In SI Units,* 2006.
[10] ISO. 3685:1993, "Tool-life testing with single-point turning tools".
[11] P. Jayaraman and L. M. Kumar, "Multi-response Optimization of Machining Parameters of Turning AA6063 T6 Aluminium Alloy using Grey Relational Analysis in Taguchi Method," *Procedia Engineering 97* , p. 197 – 204 , 2014 .
[12] P. Roy, S. Sarangi, A. Ghosh and A. Chattopadhay, "Machinability study of pure aluminium and Al–12% Si alloys against uncoated and coated carbide inserts," *Int. Journal of Refractory Metals & Hard Materials 27,* p. 535–544, 2009.
[13] A. Torres, I. Puertas and C. Luis, "Surface roughness analysis on the dry turning of an Al-Cu alloy," *Procedia Engineering 132,* p. 537 – 544, 2015.