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AN EXPERIMENTAL INVESTIGATION INTO THE IMPACT OF VIBRATION ON THE SURFACE ROUGHNESS AND ITS DEFECTS OF Al6061-T6

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Surface roughness is identified as an important response which is affected by the vibration of spindle and worktable. This paper is focused on the effect of machining and geometrical parameters such as spindle speed, feed rate, axial and radial depth of cut and radial rake angle on responses during end milling operation. Experiments were conducted on Aluminum alloy 6061-T6, based on Central Composite Design (CCD). Response Surface Methodology (RSM) has been used to develop the predictive models. The scanning Electron Microscopy (SEM) results indicates that the formation of surface defect on Al 6061-T6 are adhered material particles, plucking, feed marks, micro-pits and debris of microchips. Multi Objective Genetic Algorithm (MOGA) was used to predict surface roughness, amplitude of spindle and worktable vibration.

Key words: aluminum alloy, milling, SEM, surface defect, vibration

INTRODUCTION

In machining process, increase of vibration amplitude resulting the tool intermittently loses contact with the chip leading to an increase in cutting forces, friction and temperature rise in the cutting zone and the formation of built up edge. Controlling vibration is one of the approaches for enhancing the quality of the product. [1] investigated the effects of three levels of spindle attributed forced vibrations. [2,3] Several researchers have studied the effect of cutting parameters such as spindle speed, feed rate, axial and radial depth of cut, appropriate selection of tool material and tool geometry in machining of aluminum based alloys. [4] investigated of tool wear, surfaces finish and surface defects affected by vibration of cutting tool. [5] developed experimental plan and conducted experiments based on central composite design (CCD) of response surface methodology (RSM)

[6] determined second-order models of the responses as a function of the cutting conditions. [7,8] multi objective genetic algorithm (MOGA) has proven its effectiveness and efficiency in finding the well-distributed and well converged sets of near-Pareto-optimal solutions. Machined surface with cutting processes topography depends on several factors, in depth analysis of various characteristics of these surface and sub-surface alteration has been carried out with the help of advanced techniques such as scanning electron microscopy (SEM) [9]. In the present work, efforts have been made to optimize the machining parameters such as spindle speed (N), feed rate (F), axial depth of cut (Da), radial depth of cut (Dr) and radial rake angle (γ), with spindle vibration and worktable vibration to minimize surface roughness Ra during slotting experiments in vertical milling machining of aluminum 6061-T6. Formation of surface defect on machined surface texture has been analyzed using scanning electron microscope (SEM).

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EXPERIMENTAL METHODOLOGY

Experimental setup

The experiments have been performed under wet cutting condition on a MAKINO CNC vertical machining Center equipped with spindle Rpm - 13 000, cutting feed rate 1,575 inch/min, positioning accuracies to within ± 0,00012 inch (0,003 mm) and repeatability of ± 0,000078 inch (0,002 mm). The tool used for carried out end milling operation is high speed steel end mill cutter (3 - Flute, 45° Helix) catalogue no. F3A-H0200ADK45 as recommended by the tool manufacturer (kenna metal). The workpiece material used was Al 6061 - T6 square block in the form of size 50mm × 50mm × 50mm. The experimental setup of workpiece for operation is shown in Figure.1

Experimental Design

Design expert V10 was adopted to develop design matrix. The design matrix selected to perform experiments was a five-factor central composite face centered design (CCD) consisting of 32 sets of actual values and comprising a ½ fraction, six center points with one replicates of factorial points and replicates of axial points.

Each of the 32 runs is replicated thrice and the average response values are recorded and used for analysis.

The machining parameters were selected are spindle speed (1 400 2 500 and 3 600) rpm, feed rate (0,04 0,08 and 0,12) mm/rev, axial depth of cut (0,4 0,7 and 1) mm, radial depth of cut (0,4 0,7 and 1) mm and Radial rake angle (12 18 and 24)°. Experimental values with measured responses are presented in Table1

Experimental Procedures

In end milling process, the slotting path of machining operation was performed on the work piece to investigate the vibration and surface roughness. The response variables selected for this study are surface roughness (Ra), spindle vibration (channel-I) and worktable vibration (channel-II). During the experiments, spindle and worktable vibration amplitude was measured by connecting a two unidirectional piezoelectric accelerometer to the machine spindle and worktable. Data acquisition has been developed and recorded the vibration amplitude channel-1 (x - axes) and channel-2 (y - axes) during machining process by using lab view software shown in Figure 1. The data acquired are noted to obtain the second order mathematical model. Surface roughness is an important parameter to evaluate the quality of machining product. In this study, a surf tester SJ-210 was used to measure the machined surface at three different positions and the average surface roughness (Ra) is noted in microns.

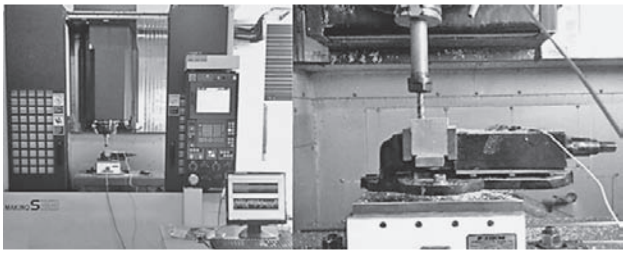

Figure 1 Experimental setup for test

RESULTS AND DISCUSSION
Response surface methodology

In this study, ANOVA was performed at 95 % confident level. Design Expert V.10 statistical software was used to determine the values of coefficients. The developed model P-Value Prob > F for Ra (0,0162), channel-

Table 1 **Experimental design and their responses**

N / Rpm	F / mm/rev	D_a / mm	D_r / mm	γ / °	Ra / µm	Channel-I / mm/sec^2 actual	Channel-II / mm/sec^2) actual
2 500	0,08	0,7	1	18	0,51	0,022	0,0043
1 400	0,12	1	1	12	0,61	0,016	0,0033
3 600	0,04	1	0,4	24	0,46	0,019	0,0037
2 500	0,08	0,7	0,4	18	0,45	0,02	0,0036
3 600	0,04	0,4	1	24	0,51	0,019	0,0036
3 600	0,04	0,4	0,4	12	0,43	0,016	0,0034
3 600	0,12	0,4	1	12	0,41	0,015	0,0032
2 500	0,08	1	0,7	18	0,52	0,022	0,0042
2 500	0,08	0,7	0,7	18	0,45	0,02	0,0036
2 500	0,08	0,4	0,7	18	0,43	0,019	0,0036
1 400	0,12	1	0,4	24	0,53	0,021	0,0038
1 400	0,04	1	0,4	12	0,58	0,014	0,003
1 400	0,04	0,4	1	12	0,53	0,014	0,0031
1 400	0,12	0,4	0,4	12	0,52	0,015	0,0032
3 600	0,12	0,4	0,4	24	0,5	0,022	0,0039
2 500	0,08	0,7	0,7	18	0,45	0,023	0,0043
2 500	0,08	0,7	0,7	18	0,45	0,024	0,0045
3 600	0,08	0,7	0,7	18	0,44	0,024	0,0044
2 500	0,08	0,7	0,7	24	0,55	0,023	0,0042
1 400	0,12	0,4	1	24	0,61	0,019	0,0037
1 400	0,08	0,7	0,7	18	0,53	0,018	0,0035
1 400	0,04	1	1	24	0,60	0,02	0,0037
2 500	0,04	0,7	0,7	18	0,55	0,02	0,004
2 500	0,08	0,7	0,7	18	0,48	0,02	0,0037
1 400	0,04	0,4	0,4	24	0,53	0,015	0,003
3 600	0,12	1	0,4	12	0,45	0,022	0,0041
3 600	0,04	1	1	12	0,48	0,023	0,0043
3 600	0,12	1	1	24	0,49	0,024	0,0044
2 500	0,08	0,7	0,7	12	0,45	0,018	0,0035
2 500	0,08	0,7	0,7	18	0,46	0,023	0,0044
2 500	0,08	0,7	0,7	18	0,52	0,021	0,0041
2 500	0,12	0,7	0,7	18	0,60	0,026	0,0046
2 500	0,08	0,7	1	18	0,51	0,022	0,0043

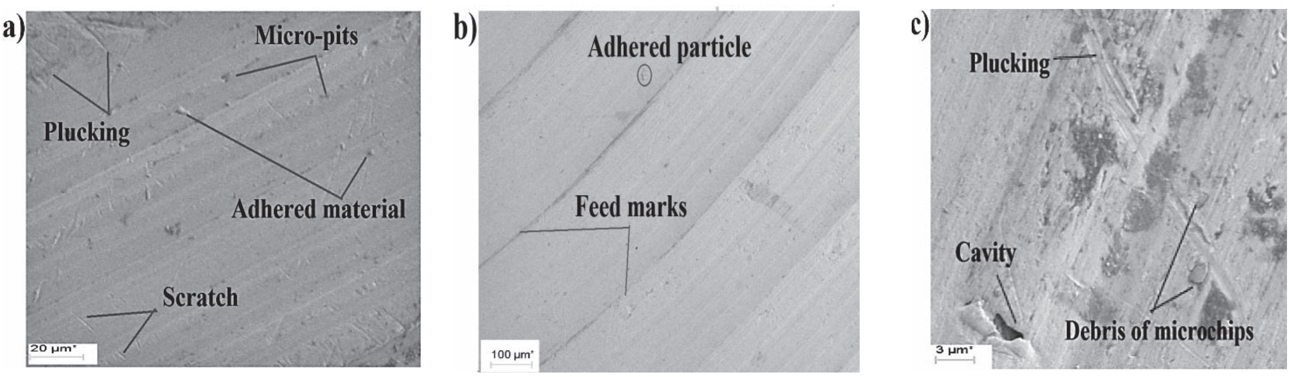

Figure 2 SEM of machined surface a) N = 1 400 Rpm, F = 0,12 mm/rev, D_a = 1 mm, D_r = 0,4 mm, γ = 24°, b) N = 2 500 Rpm, F = 0,08 mm/rev, D_a = 0,7 mm, D_r = 0,7 mm, γ = 24°, c) N = 2 500 Rpm, F = 0,12 mm/rev, D_a = 0,7 mm, D_r = 0,7 mm, γ = 18°

I (0,0024) and channel-II (0,0357) less than 0,0500 indicate model terms are significant. The Lack of Fit F-value of Ra (0,2748), channel-I (0,6198) and channel-II (0,8223), shows it is not significant relative to the pure error. There is chance that a Lack of Fit F-value Ra (27,48 %), channel-I (61,98 %) and channel-II (82,23 %), occur due to noise. Non-significant lack of fit is good. R^2 for Ra (86 %), channel-I (91 %) and channel-II (94 %) indicates the closeness of the model representing the process. It is evident from the interaction effects of surface plots, the minimum surface roughness in range of (0,36 to 0,40 µm) can be achieved at spindle speed (3 050 - 3 600) rpm, feed rate (0,06 - 0,1) mm/rev, axial and radial depth of cut less than 0,5 mm and radial rake angle (14 - 17) degree , minimum spindle vibration (0,01 to 0,016 mm/sec^2) can be achieved at spindle speed (2 000 - 2 500) rpm, feed rate (0,06-0,8) mm/rev, axial and radial depth of cut less than 0,5 mm and radial rake angle (12 - 15) degree and minimum worktable vibration (0,0030 to 0,0035 mm/sec^2) can be achieved at spindle speed (3 050 - 3 600) rpm, feed rate (0,06 - 0,8) mm/rev, axial and radial depth of cut less than 0,5 mm and radial rake angle (12 – 15) degree. It is also noticed that reduction of vibration improves surface finish considerably shown in Table 1.

Surface defect

SEM micrographs of machined surface with the combination of different milling parameters are shown in Figure 2.The micrographs shows the main forms of surface damage in machining of aluminum 6061-T6 is adhered material particles, plucking, feed marks, micro-pits and debris of microchips onto a surface generated after milling are shown in Figure 2a-c. The increase of cutting force due to improper selection of machining and geometrical parameters induces the spindle and worktable vibration to occur, which produces surface deformation on the machined surface and hence creates worst surface finish.

Multi objective genetic algorithm

In this study, MOGA has been employed for multi objective optimization with constrained limits. The developed second order mathematical model has been uti-

Table 2 **Pareto optimal solutions**

N / Rpm	F / mm/rev	D_a / mm	D_r / mm	γ / °	Ra / µm	Channel-I / mm/sec^2 predicted	Channel-II / mm/sec^2) predicted
1 623,31	0,08493	0,40976	0,99447	12,0086	0,45029	0,01263	0,00289
3 240,78	0,08337	0,40903	0,99304	12,0515	0,36728	0,01528	0,00321
2 764,57	0,08465	0,40918	0,99777	12,0152	0,39573	0,01484	0,00317
1 623,31	0,08493	0,40976	0,99447	12,0086	0,45029	0,01263	0,00289
2 977,11	0,0846	0,40907	0,99632	12,0153	0,38344	0,01505	0,00319
2 710,19	0,0847	0,40927	0,99603	12,0195	0,39902	0,0148	0,00317
1 798,31	0,0848	0,40979	0,98762	12,0292	0,44396	0,01317	0,00296
3 173,64	0,08372	0,40913	0,99313	12,0355	0,37155	0,01524	0,00321
1 910,22	0,0844	0,40916	0,99577	12,0261	0,43831	0,01338	0,00299
2 009,59	0,08472	0,40952	0,99303	12,0379	0,43449	0,01364	0,00302
3 240,78	0,08337	0,40903	0,99304	12,0515	0,36728	0,01528	0,00321
2 400,48	0,08487	0,40943	0,98746	12,0162	0,41635	0,01442	0,00312
2 155,68	0,08471	0,40944	0,99535	12,0367	0,42762	0,01393	0,00306
3 120,49	0,08414	0,40905	0,99303	12,0419	0,37504	0,0152	0,00321
1 834,55	0,08432	0,40966	0,99324	12,0142	0,44173	0,01321	0,00297
2 289,42	0,08486	0,40944	0,98708	12,085	0,42229	0,01429	0,00311
2 606,92	0,08454	0,40914	0,99439	12,0386	0,40487	0,01469	0,00316
2 507,32	0,08419	0,40936	0,99062	12,0337	0,4104	0,01458	0,00314

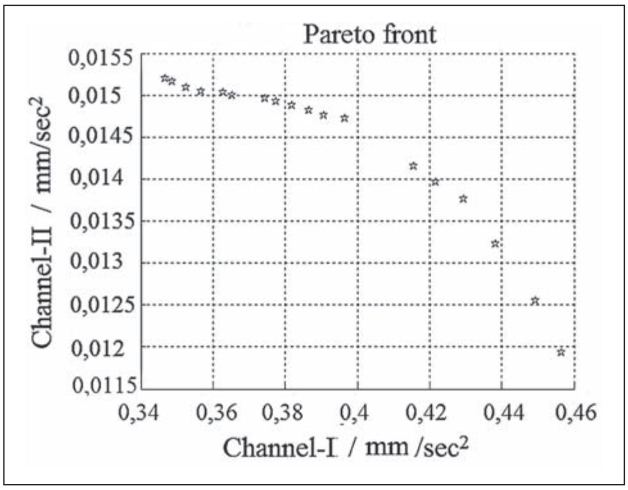

Figure 3 Pareto optimal frontier chart

lized to observe the optimal relationship between the machining parameters such as N, F, D_a, D_r, γ and responses are Ra, Channel-I and Channel-II, subjected to constraint limits Ra ≤ Ra limit; Channel-I ≤ Channel-I limit; Channel-I ≤ Channel- II limit. This function was input to the GA Toolbox of MATLAB 2009a as the objective function. The parameter combinations of 18 non-dominated Pareto optimal solutions obtained with the application of constraint limits such as lower and upper boundary 1 400 ≤ N ≤ 3 600 rpm; 0,04 ≤ F ≤ 0,12 mm/rev ; 0,4 ≤ D_a ≤ 1 mm; 0,4 ≤ D_r ≤ 1 mm;12 ≤ γ ≤ 24 ° are presented in Table 2 and Figure 3.

CONCLUSION

From this investigation, the following conclusion has been drawn.

- The aggressive feed marks can be reduced by selecting lower feed rate values.
- Adhered material particles and plucking are confirmed to appear at the low spindle speed condition, while debris of microchips and scratches are at the larger value of axial and radial depth of cut condition.
- In the analysis of surface roughness, it was found that the minimum surface roughness can be achieved at spindle speed (3 050 - 3 600) rpm, feed rate (0,06 - 0,1) mm/rev, axial and radial depth of cut less than 0,5mm and radial rake angle (14 - 17) degree. In the analysis of spindle vibration, it was found that the minimum spindle vibration can be achieved at spindle speed (2 000 - 2 500) rpm, feed rate (0,06 - 0,8) mm/rev, axial and radial depth of cut less than 0,5 mm and radial rake angle (12 - 15) degree.
- In the analysis of worktable vibration, it was found that the minimum worktable vibration can be achieved at spindle speed (3 050 - 3 600) rpm, feed rate (0,06 – 0,8) mm/rev, axial and radial depth of cut less than 0,5 mm and radial rake angle (12 - 15) degree.
- Based on multi-objective optimization by MOGA the parameter combinations of 18 non-dominated Pareto optimal solutions are obtained, and also it has been verified that the solutions generated from MOGA are equally good.

REFERENCES

[1] Zahoor., Mufti N.A., Saleem M.Q. Effect of machine tool's spindle forced vibrations on surface roughness, dimensional accuracy, and tool wear in vertical milling of AISI P20, Int J Adv Manuf Technol, (2016).

[2] Sayuti M., Ahmed A.D., Sarhan M. An investigation of optimum SiO2 nanolubrication parameters in end milling of aerospace Al6061-T6 alloy. Int J Adv Manuf Technol 67(2013), 833–849.

[3] Mahesh G., Muthu S. Prediction of surface roughness of end milling operation using genetic algorithm, Int J Adv Manuf Technol 77(2014),369–381.

[4] Zhang G., Li J., Chen Y., Huang Y, Shao X., Li M. Prediction of surface roughness in end face milling based on Gaussian process regression and cause analysis considering tool vibration, Int J Adv Manuf Technol, 75(2014), 1357–1370.

[5] Baraskar S.S., Banwait S. S., Laroiya S. C. Multiobjective Optimization of Electrical Discharge Machining Process Using a Hybrid Method, Materials and Manufacturing Processes 8(2013),348–354.

[6] Santos M.C., Machado Jr A.R., Barrozo M.A.S., Jackson M.J., and Ezugwu E.O. Multi-objective optimization of cutting conditions when turning aluminum alloys using genetic algorithm. Int J Adv Manuf Technol 76 (2013) 5, 1123–1138.

[7] N. Zeelanbasha., V. Senthil., B. Sharon Sylvester., N. Balamurugan. Modeling and experimental investigation of LM26 pressure die cast process parameters using multi objective genetic algorithm (moga)", metalurgija 56 (2017) 3-4, 307-310.

[8] Wang D, Jiang R., Wu1 Y. A hybrid method of modified NSGA-II and TOPSIS for lightweight design of parameterized passenger car sub-frame, Journal of Mechanical Science and Technology 30 (2013) 11, 4909-4917.

[9] Yang D., Liu Z. Surface topography analysis and cutting parameters optimization for peripheral milling titanium alloy Ti–6Al–4V, Int. Journal of Refractory Metals and Hard Materials 51(2015),192–200

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