VOL. 11, NO. 1, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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INFLUENCE OF CUTTING PARAMETERS ON CUTTING FORCE AND CUTTING TEMPERATURE DURING POCKETING OPERATIONS

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ABSTRACT

Determining of the effect of cutting parameters on cutting force and cutting temperature is particularly important during machining operation. This is because these machining conditions influence the surface quality of machined parts as well as tool life of the cutter. Numerous studies have been conducted to investigate the effect of cutting parameters on machining output. However, most of the studies focussed on straight cutting only. In mould and die making process, end milling process is required to form an empty volume of the part. This is known as pocketing operation. Different from normal cutting, the tool needs to travel in various straight and corner cutting following a particular tool path strategy depending on the shape of the pocket. The situation causes variation in the cutting force as well as cutting temperature due to variation of tool engagement during the process. Hence, this study concentrates on investigating the effects of cutting parameters on cutting forces and cutting temperatures when employing contour tool path strategy for pocket operation. Two different shapes of pocket was employed in this study. The result indicates that Taguchi method is suitable to determine the significant factor in pocketing operation of contour tool path strategy.

Keywords: Taguchi method, cutting forces, cutting temperature, contour tool path strategy.

INTRODUCTION

Pocketing is a common machining operation in mould and die making process. It is the process of creating an empty volume of the part. The process starts from the surface of the part until the required depth of the mould by following a particular tool path strategy. Surface roughness is usually used as an indicator to determine the quality of the mould since many functions of the product is affected by surface roughness [1]. However, cutting forces and cutting temperatures are two machining conditions that need to be controlled to achieve the goal. A high temperature has ability to shorten tool life of the cutter due to high wear rate and also deteriorate surface quality and dimensional accuracy of the part [2].

There are various machining parameters affecting the output of machining process. Among these parameters, cutting speed, feedrate and depth of cut are the primary parameters that should be selected properly for machining process to ensure good surface quality and to prolong tool life. The effect of cutting parameters on cutting force, cutting temperature, surface roughness and tool life have been modelled by various researchers. Recent experimental study by Bhardwaj et al. [3], investigated the effect of cutting parameters on surface roughness of AISI 1019 steel. He found that cutting speed, feedrate and nose radius is significant factor that affect surface roughness. They concluded that by increasing cutting speed and nose radius, surface roughness become well while increasing feedrate deteriorates the surface quality. Cui [4], presented a study on AISI H13 steel for face milling operation. The result showed that for cutting speeds below 1400m/min and low federate and depth of cut, the surface roughness was below 0.3µm. According to Kivak [5], feedrate is the most significant factor influencing surface roughness and cutting speed for flank wear. The study applied Taguchi method to evaluate the effect of cutting parameters on surface roughness and flank wear for machining Hadfield steel. However, the studies focussed on straight cutting only in which there is a constant engagement between cutting tool and work material during machining process.

There are only a few studies reported on the effect of cutting parameter for pocketing operation. Gologlu and Sakarya [1], applied different types of tool path strategies for pocketing operation of 1.2738 steel. Based on the result, feedrate was the most significant cutting parameters for spiral and one direction tool path strategy. However, for back and forth strategy, depth of cut is the most significant factor. some recent works on the role of tool path strategy on surface roughness and cutting force of a pocket has been carried out by Pinar [6] and Romero [7]. The findings showed that contour tool path strategy gave better surface roughness and lower cutting forces. However, there are another criteria needs to be taken into account in selecting the best tool path strategy such as the shape of the pocket itself, cutting parameters, and machining characteristics [8].

Hence, this study aims to analyse the effect of cutting parameters on cutting force and cutting temperature for different shapes of pocket. Contour tool path strategy is used to perform the machining process.

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MATERIALS AND METHOD

End milling process

Milling process was conducted using CNC Vertical Machining Centre (VMC) by Mazak Nexus VCN 410-II. This machine can perform high speed machining operation with maximum spindle speed of 12,000 rpm and driven by 25HP spindle motor. Milling is an intermittent cutting operation due to the multi-point cutting tool employed. End milling looks a lot like face milling but uses a smaller cutter. It is a type of peripheral milling used for profiling and slotting operations. Much like peripheral milling, in end milling the undeformed chip thickness is variable throughout the cutting operation, but the undeformed chip width corresponds to the depth of cut.

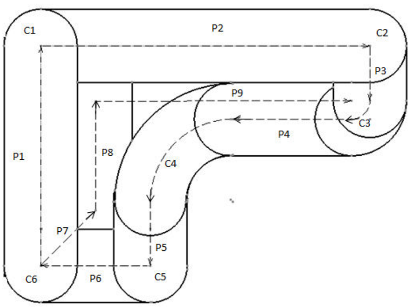
Work materials and cutting tools

The shapes of work material and tool path strategy are shown in Figure 1(a) and (b). In this study, AISI H13 has been used as work material. It is categorized as a difficult to cut material due to its high carbon content which contributes to its hardness. AISI H13 is the most common steel used for hot working dies. It is a chromium-molybdenum-vanadium alloyed steel which can attain high purity and very fine structure if produced by special processing techniques and progressive quality control. H13 tool steel is characterised by high hardenability, strength and toughness. These specific mechanical properties, along with its moderate cost, have led to extensive use of the steel in hot work applications [9]. Table-1 shows the chemical composition of AISI H13.

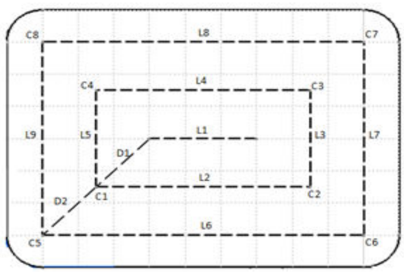
Table-1. Chemical composition of AISI H13.

C	Mn	Si	Cr	Mo	V	Ni	Fe
0.32-0.45	0.20- 0.50	0.0080-1.20	4.75-5.50	1.10-1.75	0.80-1.20	0.-0.30	Bal

To perform machining operation, CoroMill 490 cutting tool with coated carbide insert was used. The tool diameter was 20mm with two indexable insert positions.



(a)



(b)

Figure-1. Shape of the pocket (a) SHAPE 1 (b) SHAPE 2.

Cutting force measurement

Dynamometer was attached to the workpiece and was supported by charge amplifier and signal conditioning to measure cutting forces. Labview software was connected to the dynamometer for recording purposes. The charge generated at the dynamometer was amplified using multihannel charge amplifier (type 5070A). The sensitivities of the multi-channel charge amplifiers were set for -7.939 pC/N for normal force (Fx), −7.960 pC/N for feed force (Fy), and -3.722 pC/N for axial force (Fz). The sampling frequency of data was set at 7,000 Hz.

Cutting temperature measurement

The temperature has been measured using infrared thermal camera ThermoPro TP8. IrAnalyzer software was used to record temperature and to analyse the thermal image. This thermal camera has high thermal sensitivity of ≤ 60 mk at 30°C. The temperature range is form -20°C to 2000°C with high accuracy.

Experimental setup

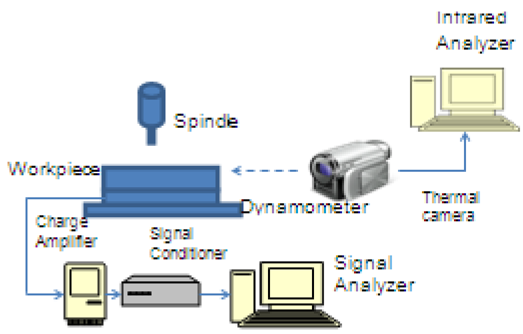


Figure-2. Experimental setup.

TAGUCHI DESIGN AND PARAMETER SELECTION

Taguchi method

Taguchi method is widely used in various engineering field for experimental planning design. Taguchi's method is an efficient and in complex technique for optimization especially to improve quality, cost and

VOL. 11, NO. 1, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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performance design. In this approach, number of experiments can be reduced by using a special orthogonal array developed by Taguchi. The method allows process optimization at the same time minimize the sensitivity of external variation of the experiments [5].

L9 orthogonal array had been used in this study as it has the capability to perform parametric study with three factors and three levels. As shown in Table 2, three cutting parameters have been selected to conduct the experiment. The number of experiments and combination of cutting parameters and level for L9 orthogonal array is shown in Table-2. To complete L9 orthogonal array, nine experimental runs need to be conducted.

Table-2. Experimental parameters and their levels.

Factors	Level		
	1(Low)	**2**(Medium)	**3**(High)
A:Cutting speed (m/min)	150	200	250
B: Feed rate (mm/tooth)	0.05	0.1	0.15
C:Depth of cut (mm)	0.1	0.15	0.2

Table-3. L9 Orthogonal array trials.

Trial number	Control factor		
	A (Cutting speed)	**B** (Feedrate)	**C** (Depth of cut)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	1
9	3	3	3

RESULT AND ANALYSIS

The result for cutting force and cutting temperature for SHAPE 1 and SHAPE 2 pocket with corresponding S/N ratio is shown in Table-4. Signal to noise (S/N) ratio is the common method used to study the effects of the parameters. Without further analysis of Analysis of Variance (ANOVA), the significant factor can be determined by calculating the average of S/N ratio. For cutting force and cutting temperature, 'smaller the better' characteristic in equation (1) is applied to calculate the S/N ratio.

$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2 \right) \quad (1)$$

where n is the number of measurements in trial and y is the observed data.

Table-4. Experimental result with their corresponding ratios.

	Factors			Shape 1				Shape 2			
Trial number	**A** (Cutting speed)	**B** (Feedrate)	**C** (Depth of cut)	**F** (N)	**S/N**	**T** (^{o}C)	**S/N**	**F** (N)	**S/N**	**T** (^{o}C)	**S/N**
1	1	1	1	135.17	-42.62	147.22	-43.36	101.80	-40.15	143.66	-43.15
2	1	2	2	175.42	-44.88	174.58	-44.84	143.49	-43.14	140.85	-42.98
3	1	3	3	233.40	-47.36	208.41	-46.38	192.86	-45.70	197.48	-45.91
4	2	1	3	142.13	-43.05	183.38	-45.27	189.58	-45.56	243.33	-47.72
5	2	2	1	201.26	-46.08	183.98	-45.30	193.50	-45.73	210.09	-46.45
6	2	3	2	211.38	-46.50	184.52	-45.32	391.80	-51.86	251.57	-48.01
7	3	1	2	165.01	-44.35	200.24	-46.03	102.36	-40.20	152.60	-43.67
8	3	2	1	266.91	-48.53	248.98	-47.92	273.95	-48.75	247.94	-47.89
9	3	3	3	467.38	-53.39	258.74	-48.26	232.54	-47.33	230.01	-47.23

VOL. 11, NO. 1, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Cutting force

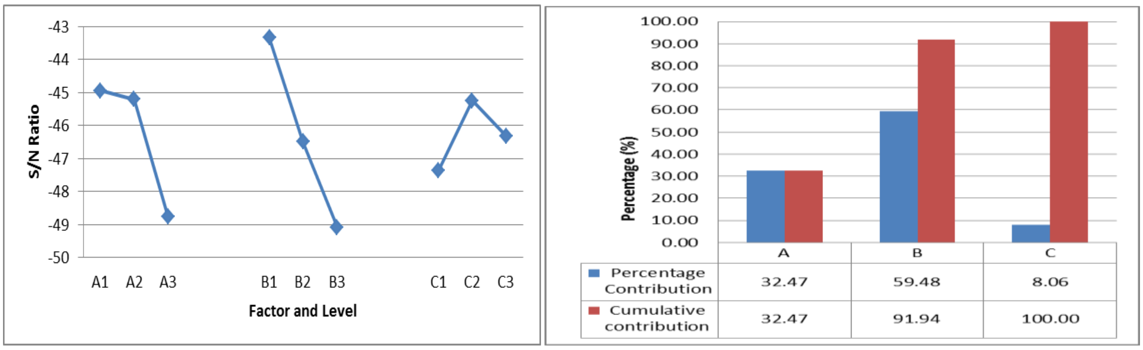
The effect of cutting parameters on cutting forces can be described using the response graph of S/N ratio. However, the percentage contribution for each factor cannot be determine using the graph. Pareto ANOVA is used to show the percentage contribution for the factors. Its simplified ANOVA by providing simple and faster step to determine the contribution of selected factor on experimental response.

The effect of changing parameters for different shape of pocket (SHAPE 1 and SHAPE 2) is shown in Figure-3 (a) and Figure-4 (a) respectively. The response graph and pareto ANOVA (Figure-3 (b) and 4 (b)) o showed that the combinations of cutting speeds and feedrates have significantly effected on cutting force for both shapes of pocket. However, feedrate had the strongest effect at 59.48% for SHAPE 1 while cutting speed contributes 32.47%. Figure-3(a) indicates to get lower cutting force in machining SHAPE 1 pocket, low cutting speed (A1) and feedrate(B1) is required. Increasing the feedrate increases the instantenous chip thickness. This affects the cutting force as the cutting force will increase with increasing instanenous chip thickness [10].

The result for SHAPE 2 agreed with that of SHAPE 1 which showed that the most significant effect is the feedrate followed by cutting speed. The percentage contribution of feedrate and cutting speed is 59.54% and 32.53% respectively. There is not much different in the contribution percentage as compared with SHAPE 1. However, to get lower cutting forces A2 and B1 are preferred. The results indicate that, different shapes of pocket contribute different results. SHAPE 2 has larger variation of tool enagagement at every turn of the corner. Cutting speed needs to slow down at the corner, which affects the cutting force.

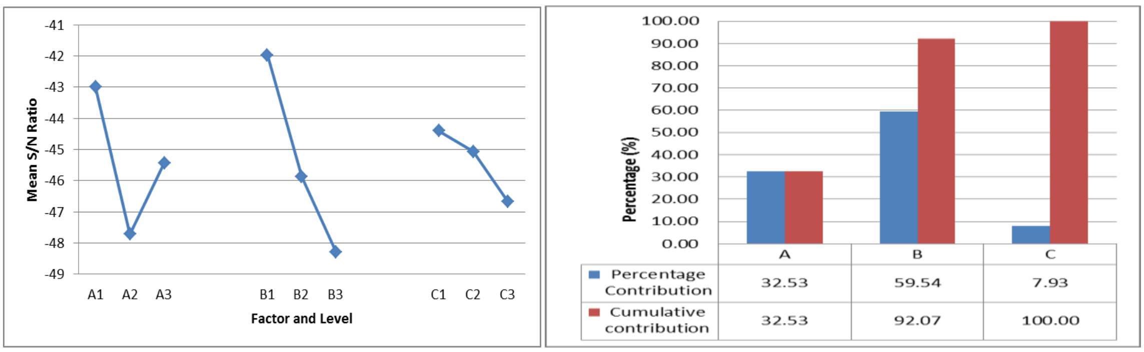
The small percentage contribution of depth of cut which is less than 10% for both shapes indicates that the influence of this parameter on cutting forces is weak.

Even though response graph and Pareto ANOVA has the ability to show the effects of cutting parameters on cutting force, the results need to go through the Fisher test (F-test) so that it can be critically evaluated. Table-5 and Table-6 show the result of F-test for SHAPE 1 and SHAPE 2 respectively. It was confirmed that feedrate is a significant factor and has the strongest effect on cutting force for both shapes. Significant factors can be determined by comparing F_{ratio} and $F_{critical}$. F_{ratio} is ratio of the factor variance to the error variance, whereas $F_{critical}$ is critical Fisher ratio that can be determine from F distribution table. The value of F_{ratio} above $F_{critical}$ is considered as significant and below $F_{critical}$ as insignificant or weakly significant.



(a) (b)

Figure-3. Effect of cutting parameters on cutting force for SHAPE 1 (a) response graph of S/N ratio (b) Pareto ANOVA histogram.



(a) (b)

Figure-4. Effect of cutting parameters on cutting force for SHAPE 2 (a) response graph of S/N ratio (b) Pareto ANOVA histogram.

Table-5. ANOVA result for cutting force of SHAPE 1.

Response factor	SS	DF	MS	F	% Contribution
A	27.11	2	13.55	5.63	31.37
B	49.66	2	24.83	10.31	57.47
C	(6.72)	-	-	-	-
Error	9.62	4	2.40		11.14
Total	86.40	8			100

*SS sum of square, DF degree of freedom, MS mean squares, F Fisher test, F_{ratio} at $_{2,4}$= 4.32

Table-6. ANOVA result for cutting force of SHAPE 2.

Response factor	SS	DF	MS	F	% Contribution
A	33.40	2	16.70	3.03	28.65
B	61.14	2	30.57	5.54	52.44
C	(8.14)	-	-	-	-
Error	22.03	4	5.50		18.91
Total	116.58	8			100

*SS sum of square, DF degree of freedom, MS mean squares, F Fisher test, F_{ratio} at $_{2,4}$= 4.32

Cutting temperature

Many factors affect cutting temperature during machining process. The factors include the properties of cutting material and cutting tool as well as geometry of the cutting tool. According to Silva [11], these factors and cutting parameters such as cutting speed feedrate and depth of cut have significant contribution to the temperature of the cutting area.

Response graph and Pareto ANOVA in Figure-5 shows the effect of selected cutting parameters on cutting temperature. The graph shows that cutting speed is the most influential cutting parameter on cutting temperature for SHAPE 1 with 63.4% contribution. Similar result was obtained in Figure-6 for SHAPE 2 with 55.28% contribution on cutting temperature came from cutting speed. This is due to the adiabatic effect at high cutting speed caused by the trapped heat in the shear deformation zone. The heat cannot escape in the very short time during the process causing highly localized temperatures in the chip [10-11].

However, there is a different effect of feedrate and depth of cut for the different shapes. Feedrate had a greater influence on the cutting temperature for SHAPE 1. However, depth of cut had the most influence for SHAPE 2.

The results can be confirmed through the Fisher test. The result of F-test for SHAPE 1 is displayed in Table-7. Depth of cut can be pooled as it has the lowest value of sum of square and can be considered as insignificant. The result indicates that feedrate has a weak effect on cutting temperature. However, for SHAPE 2 in Table-8 shows all the three factors can be considered as significant factor. F_{ratio} for the factors is above $F_{critical}$ with cutting speed having the strongest effect.

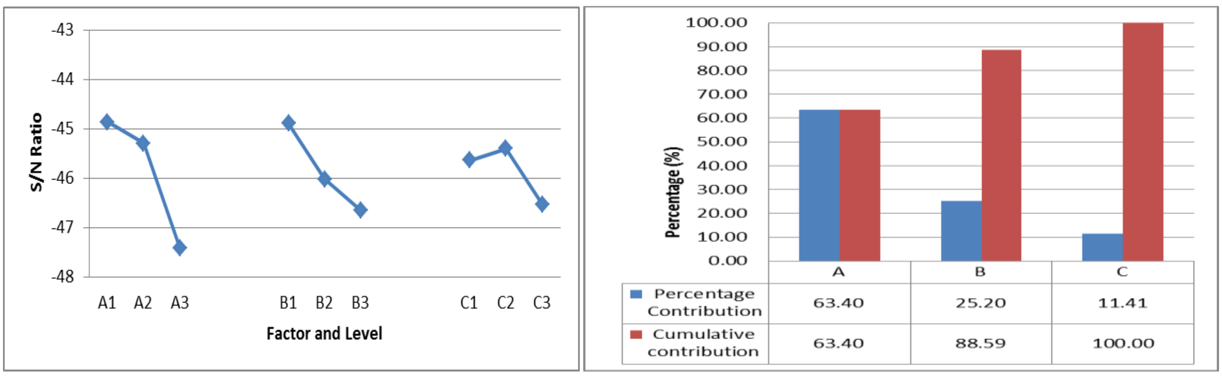


Figure-5. Effect of factors on cutting temperature for SHAPE 1 (a) response graph of S/N ratio (b) Pareto ANOVA histogram.

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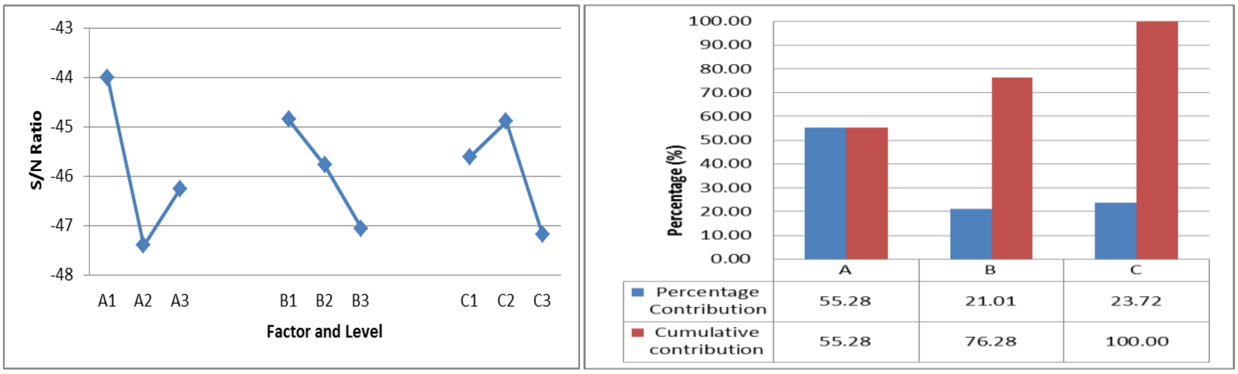

Figure-6. Effect of factors on cutting temperature for SHAPE 2 (a) response graph of S/N ratio (b) Pareto ANOVA histogram.

Table-7. ANOVA result for cutting temperature of SHAPE 1.

Response factor	SS	DF	MS	F	% Contribution
A	11.11	2	5.55	8.43	59.89
B	4.80	2	2.40	3.64	25.89
C	(2.10)	-	-	-	-
Error	2.63	4	0.66		14.22
Total	18.55				100

*SS sum of square, DF degree of freedom, MS mean squares, F Fisher test, Fratio at 2, 4= 4.32

Table-8. ANOVA result for cutting temperature of SHAPE 2.

Response factor	SS	DF	MS	F	% Contribution
A	17.81	2	8.90	22.95	51.00
B	7.36	2	3.68	9.48	21.07
C	8.20	2	4.10	10.56	23.48
Error	1.55	1	0.38		4.44
Total	34.92	8			100

*SS sum of square, DF degree of freedom, MS mean squares, F Fisher test, Fratio at 2, 1= 9.0

CONCLUSIONS

This paper reports on the effects of cutting parameters on cutting forces and cutting temperature for machining operation of AISI H13 for different shapes of pocket. Taguchi design of experiment is used to perform the study. Conclusions that can be drawn from the study are as follows:

i. Feedrate is the most influential factor on cutting forces for both shapes of pocket with 59.48% and 59.54% for SHAPE 1 and SHAPE 2 respectively. This is followed by cutting speed as the second dominant factor. However, for SHAPE 1, low cutting speed, A1 and low feedrate B1 gave lower cutting forces whereas for SHAPE 2, A2 and B1 is preferred to get lower cutting force.

ii. Depth of cut has less influence on cutting force and can be considered as insignificant factor.

iii. For cutting temperature, cutting speed has the highest percentage contribution compared to feedrate and depth of cut for both SHAPE 1 and SHAPE 2.

iv. The results demonstrated that the shapes of pocket play an important role that influence cutting force and cutting temperature. The variation of engagement during pocketing operation especially at the corner region affected cutting force and cutting temperature.

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