Analysis of Solid Carbide Drilling Performance on AISI 316L Austenite Stainless Steel using MQL (Minimum Quantity Lubrication) using Peck Drilling Approach

M Mukhtar¹, Mohd Effendee¹, Mohd Habir Ibrahim¹, M Syahrir¹
¹Faculty of Engineering Technology, University College TATI, 24000 Kemaman, Terengganu, Malaysia.

Abstract. Minimum Quantity Lubrication (MQL) minimizes refrigerants and lubricants mixed with air to foster environmental sustainability. Austenitic AISI 316L stainless steel is often used for the aviation, biomedical equipment and food appliances. However, low machinability of this material makes it difficult to cut resulting low hole surface quality. The objective of the study is to evaluate the drill performance of solid carbide tools while drilling AISI 316L austenite stainless steel and to study the effect of drilling parameters, cutting speed (Vc), feed rate (Fr) and drill geometry (point angle) on tool life, surface integrity and holes accuracy. Solid carbide drilling performance analysis on AISI 316L Austenite Stainless Steel using MQL was assessed in terms of tool life, surface roughness, and hole accuracy. Investigation for optimal conditions of cutting speed, feed rate and point of angle when drilling AISI 316L austenite stainless steel would obtain the optimum output indicates longer tool life, better surface roughness and adequate accuracy in high-speed machining conditions. This MQL oil-air flow is accurately measured and sent to the drill tool edge. The cutting speeds applied for the machining process are 100m / min, 130m / min and 150m / min. For feed rate parameters, the selected values are 0.05mm / rev, 0.1mm / rev and 0.15mm / rev. Rotational drill angles are 110 °, 120 ° and 130 °. The peck drilling investigation is performed on high-speed milling machines keenly will provide guidance to produce good and optimal machining settings of cutting speed, feed rate and angle point to others when they want to drill a hole.

1. Introduction
Drilling is the machining activities that commonly representing 30% of manufacturing process used to originate a hole [1]. However, the drilling process is a difficult process to make holes with high precision along with good surface because drilling operation will produce vibration. This study will manipulate drill point angle, cutting speed and feed rate to find the fine surface integrity while drilling the austenite stainless steel 316L with MQL. The selection of 300 series of stainless steel because according to the International Stainless-Steel Forum (ISSF) in Brussel on March 2018, 300 series stainless steel still dominates the worldwide production [2]. This steel is commonly used in the medical and food industries because it is easier to clean and sanitize compared to other materials [3]. Among the research trends to extend the life of the tool and achieve a good surface finish is by applying dry, cryogenic air and cold air [4]. Machinist will have difficulty in producing quality holes, hole accuracy, cutting geometry and at the same time have durability in the tool point because a combination of certain parameters can affect the drilling process. In addition to the influence of
parameter machining, other independent influences that may be able to shape the drilling process are the condition of the machine, cutting fluid, operator skill, experience in cutting, choosing the right measurement strategy as well as data processing and evaluation. It is also reported that cutting fluid plays an important factor in achieving good surfaces \[5\] but it can also cause problems to workers' health and environmental protection.

2. Experimental set-up

The main purposes of this study are to search the optimum machining parameters by investigate the performance of drilling on difficult to cut materials (austenite stainless steel) using 6 mm diameter solid carbide twist drill. The austenite stainless steel 316L bond very strongly to the tool, and chips often remain stuck to the tool during cutting, therefore, the hole was drilled by peck drilling approach. This technique was used to reduce the material from tangling with tool because of gummy properties. Coordinate Measuring Machine (CMM) was used to measure for the hole accuracy and the surface roughness tester Mitutoyo’s Surftest SJ-301 for surface finish checking. Tool wear progress was been measured by Video Optical Measuring System. The limits for the drill bit wear is when the average flank wear reach at 0.3 mm based ISO Standard. By using optical video measuring system, the drill bit image will enlarge to measure the wear progress. All the drilling tests were carried out using a Mori Seiki High Speed Milling Machine NV4000 DCG. For this experiment, the cutting tool used for this project is Solid Carbide drill Ø6 mm with 12 degrees rake angle and 30 degrees helix angle. Three level of point angles, 110°, 120° and 130°, drill was used to drill holes with the combinations of 110, 130 and 150m/min cutting speed and 0.05, 0.1 and 0.15mm/rev feed rate with the Minimum Quantity Lubrication (MQL) condition. Table 1 shows how the experiment was conducted using full factorial, in constructing factorial designs, Design Expert has the option to add a midpoint, so that the range of data can be set more comprehensively. The inclusion of the midpoint allows us to examine whether the installed model is appropriate or whether we need to include some quadratic terms to allow for curvature. The design will be expanded to RSM if there is a curvature mark for more accurate analysis.

| RUN | BLOCK | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|-----|-------|----------|----------|----------|
| 1   | BLOCK 1 | 110.00   | 0.05     | 130.00   |
| 2   | BLOCK 1 | 110.00   | 0.15     | 110.00   |
| 3   | BLOCK 1 | 110.00   | 0.15     | 130.00   |
| 4   | BLOCK 1 | 150.00   | 0.05     | 130.00   |
| 5   | BLOCK 1 | 150.00   | 0.05     | 110.00   |
| 6   | BLOCK 1 | 110.00   | 0.05     | 110.00   |
| 7   | BLOCK 1 | 150.00   | 0.15     | 130.00   |
| 8   | BLOCK 1 | 150.00   | 0.15     | 110.00   |

The experimental was set up as shown in Figure 1. The peck drilling process is based on canned cycle G78 peck drilling on CNC programming. Then Minimum Quantity Lubricant (MQL) was applied to tool tips and materials interface. The lubricants were act as lubrication and chips breaking flushing. Figure 2, exhibit the video measuring system that used to measure progressive wear. Figure 3 shows the tool life criterions for drill based on ISO standard According to ISO 3685 (1977), the criteria recommended defining the effective tool life for sintered carbide tools are either: Catastrophic failure; or the average flank wear, VB= 0.3 mm; or the maximum flank wear VB\(_{\text{max}}\)= 0.6 mm; or KT = 0.06 + 0.3f, where f is the feed and KT is the crater wear on the rake face of the tool.
Figure 1. Drilling Process Set-Up

Figure 2. Tool wear checking by Optical Video Measuring System

Figure 4 shows the measurement of progress wear done by video measuring system. According to ISO Standard, the end of tool life of drilling is defined by a flank wear of 0.3 mm. Figure 3 shows the tool life criterion used for this experiment. Figure 4 shows the drill bit flank wear reached 0.3 mm. So, by this point, the tool would probably have reached the catastrophic failure stage beyond the end of normal tool life criterion or incapable of producing the desirable surface qualities and considered the tool life benchmarks.

Figure 3. Tool life criterions for drilling

Figure 4. Tool wear after drilling process

Surface topography is a term used to describe the general quality of machined surface, it is also known as surface texture associated with geometric deviations such as roughness, ambiguity, shape errors and defects in the outermost layers of the workpiece. In surface topography, the first sequence deviation from the ideal geometric surface is macro geometry. The second sequence deviation is the wave while the third and higher sequence deviation is referred to as surface roughness as in Figure 5.

Figure 5. The nominal shape, waviness, and roughness of a surface [6]
Cutting speed and feed rate significantly affect the surface roughness of the machined surface whereby high cutting speed and low feed rate resulted in the better surface finish [7]. Figure 6 and 7, show the procedure of surface roughness test of holes surface and the result will obtained from appear screen.

Figure 6. Stylus Test Surface Roughness
Figure 7. Result obtained from test

3. Result and Discussion
The experimental results for the series of drilling test are presented in this section. The three cutting parameters that were used are cutting speed, feed rate and point angle of drill that were set as controlled variables. The machining responses that were investigated were tool life of drill and surface roughness of hole. Table 2, shows the details of results. The result from the experiment were analyzed and studied.

Table 2. Effect of Cutting speed in drilling AISI 316L Austenite stainless steel

| RUN | Block | FACTOR 1 | FACTOR 2 | FACTOR 3 | RESP 1 | RESP 2 | RESP |
|-----|-------|----------|----------|----------|--------|--------|-------|
|     |       | A:Vc     | B:fr     | C:Pa     | TL min | Ra um  | Er mm |
| 1   | Block 1 | 110.00   | 0.05     | 130.00   | 30.5   | 0.93   | 6.053 |
| 2   | Block 1 | 110.00   | 0.15     | 110.00   | 27.6   | 1.13   | 6.043 |
| 3   | Block 1 | 110.00   | 0.15     | 130.00   | 28.3   | 1.27   | 6.056 |
| 4   | Block 1 | 150.00   | 0.05     | 130.00   | 29.5   | 0.76   | 6.048 |
| 5   | Block 1 | 150.00   | 0.05     | 110.00   | 32.4   | 0.61   | 6.035 |
| 6   | Block 1 | 110.00   | 0.05     | 110.00   | 33.7   | 0.61   | 6.027 |
| 7   | Block 1 | 150.00   | 0.15     | 130.00   | 27.3   | 2.45   | 6.063 |
| 8   | Block 1 | 150.00   | 0.15     | 110.00   | 28.5   | 1.64   | 6.048 |

3.1. Cutting Speed vs. Tool life
The result was obtained as shown at Figure 8 shows the influenced between cutting speed with the tool life.
Based on results, the best cutting speed for longer life span (tool life) is at lower cutting speed 110 (m/min) for 33.7 minutes. It can be concluded that at low cutting speed associate with low feed rate cause the progress of tool wear is slow, this phenomenon will increase tool life.

3.2. Cutting speed vs. Surface roughness
The result was illustrated in Figure 9 shows the influenced of cutting speed on surface roughness.

Based on Figure 9, the best cutting speed for fine surface finish is 150m/min and 110m/min with Ra 0.61μm. At the starting phase the higher cutting speed produced fine surface finish. Then, when the tool tip worm the standard phase of machining pattern is occurred and the drilling pattern can be concluded as the higher cutting speed with the combination of higher feed rate will produced coarse surface finish.
3.3. **Cutting speed vs. Hole accuracy.**
The result was obtained as shown in Figure 10 shows the influenced of cutting speed towards hole accuracy.

**Figure 10.** Hole accuracy (mm) period of effect point angle (degree) with different parameter of drilling operation

Based on Figure 10, 110 (m/min) and 130 (m/min) the best cutting speed in order to achieve minimum dimensional error. The result shows that the hole accuracy is fluctuate and the effect of cutting speed is not significant.

3.4. **Feed Rate vs. tool life.**
The result was obtained as shown in Figure 11 shows the influenced of feed rate toward tool life.

**Figure 11.** Effect of feed rate (mm/rev) on tool life (min)
Based on result, feed rate 0.05mm/rev is the best feed rate for longest tool life 33.7 minutes. It concluded that, low feed rate will be produced longer tool life. It is because wear progressive is slow compare to higher feed rate [8].

3.5. Feed Rate vs Surface Roughness.
The result was obtained as shown in Figure 12 shows the influenced between feed rate towards surface roughness.

![Feed Rate vs. Surface Roughness](image)

**Figure 12.** Effect of feed rate (mm/rev) on Surface roughness (µm)

Based on the result illustrated, stated that the low feed rate produces fine surface finish for drilling AISI 316L austenite stainless steel. The best feed rate is 0.05 (mm/rev) that produced the best surface finish (Ra 0.61 µm).

3.6. Feed rate vs. Hole accuracy.
The result was obtained as shown at Figure 13 to show the influenced of feed rate on hole accuracy.

![Feed Rate vs. Hole accuracy](image)

**Figure 13.** Effect of feed rate (mm/rev) on hole accuracy (mm)
Based on figure 13, stated that drilling with low feed rate increased hole accuracy. The best feed rate for accurate hole dimensional accuracy 0.05mm/rev.

3.7 Point Angle vs Tool Life
Refer to Figure 14, the point angles give less significant effect on tool life. It can be justified from the result that the tool angle with combination of low cutting speed and feed rate will produced longer tool life.

![Point Angle vs. Tool Life](image)

**Figure 14.** Effect of point angle (degree) on tool life (minutes)

3.8 Point angle vs. Surface roughness
Based on result in Figure 15, low point angle solid carbide twist drill (110°) produced fine surface finish 0.61µm.

![Point Angle vs. Surface Roughness](image)

**Figure 15.** Effect of point angle (degree) on surface roughness(µm)
3.9. Point Angle vs. Hole Accuracy

Refer to the result illustrated on Figure 16, the point angle of solid carbide drill not give a significant effect on hole accuracy. The result shows the fluctuation value of hole dimensional accuracy reflect to drill point angles.

![Point Angle vs. Hole Accuracy](image_url)

**Figure 16.** Effect of point angle (degree) on hole accuracy (mm)

According to the results obtained from the drilling holes experiment, its reveal that higher cutting speeds reduce tool life and surface roughness, vice versa to feed rate because low feed rate increased the tool life and resulting fine surface finish. The value of the lowest surface roughness is the result of the best surface finish. It is shows that the parameters that have been used during carried out the experiment have the influence on the surface roughness and the performance of the cutting tools. This is also been concluded by the previous researcher and studies that they found that cutting speed increases surface roughness decrease, whereas feed rate increase, surface roughness increase. The feed rate was main influencing factor on the surface roughness; it increased with increasing the feed rate but decreased with increasing the cutting speed and the depth of cut, respectively [9]. Point angle of drill is the one main role in this study. The angle that has been modified were evaluated by the effectiveness of its operations through the measurement of tool life, surface roughness and hole accuracy (the size of drill compare to the actual drills hole). Based on the result, the right combination of cutting speed and feed rate significantly affect the performance of drilling 316L austenite stainless steel with less influence of tool point angle. This is shows by the proven of the study that have been carried out in this experiment.

4. Optimization

The optimization is run using design expert to find the optimum value for all variables toward responses. The method is based on factor weight, which determined the weights of dependent parameters according to the degree of influence of the cutting process. The degree of influence parameter can be determined from evaluation of the parameter effect based on their contribution [10]. The ANOVA analysis shows that the tool life is stated as the most importance because considering the tool consumption that reflect to tool cost. The term weight and importance of factors are the ranked based on relationship and contribution toward objectives.
Table 3. Solution for optimization

| NAME | Goal | LOWER | UPPER | LOWER | UPPER | Weight | Weight | Importance |
|------|------|-------|-------|-------|-------|--------|--------|------------|
| VC   | is in range | 110   | 150   | 1     | 1     | 3      |        |
| FR   | is in range | 0.05  | 0.15  | 1     | 1     | 3      |        |
| P    | is in range | 110   | 130   | 1     | 1     | 3      |        |
| TL   | maximize    | 23    | 33.7  | 1     | 1     | 4      |        |
| RA   | minimize    | 0.61  | 2.45  | 1     | 1     | 3      |        |
| HE   | minimize    | 6.027 | 6.063 | 1     | 1     | 3      |        |

5. Validation
The conformation run was done based on 1.0 desirability index as in Table 4.

Table 4. Desirability Index

| SOLUTIONS | VC  | FR  | P   | TL   | RA   | HE   | DESIRABILITY |
|-----------|-----|-----|-----|------|------|------|--------------|
| NUM       |     |     |     |      |      |      |              |
| 1         | 110 | 0.05| 110 | 33.7 | 0.61 | 6.027| 1.000        |
| 2         | 110 | 0.05| 110 | 33.634| 0.612883 | 6.02708 | 0.998        |
| 3         | 110 | 0.05| 110 | 33.6247| 0.615929 | 6.02716 | 0.995        |

Based on confirmation trial it can be suggested that the empirical models in drilling AISI 316L Austenite Stainless steel using coated carbide tool for surface roughness (Ra), tool life (TL), and hole accuracy (Diameter Error,( He)) that were developed are reasonably accurate. This conclusion is drawn by the value of percentage error for all responses are shown to be in between 0.02 to 5.6 percent as seen in Table 5.

Table 5. Result of confirmation run

| PARAMETER               | PREDICTED | ACTUAL | RESIDUAL | % ERROR |
|-------------------------|-----------|--------|----------|---------|
| Surface Roughness (Mm)  | 0.610     | 0.638  | 0.028    | 4.59    |
| Tool Life (Min)         | 33.7      | 35.590 | 1.890    | 5.60    |
| Hole Accuracy (Mm)      | 6.027     | 6.039  | 0.012    | 0.02    |

6. Conclusion
The following conclusions were drawn based on the result and analysis done throughout this study, drilling AISI 316 L Austenite stainless steel with Ø6mm Solid Carbide Drill. Drill bit with point angle of 110° with 0.05mm/rev and 110m/min provides the best overall performance in terms of tool life, surface roughness and hole accuracy for AISI 316 L Austenite Stainless Steel. Feed rate cause a significant affect the performance of Solid Carbide drill followed by cutting speed and point angle. The increase of this parameters have led to increased temperature, as a result, tool life decreased, worsen the surface finish as a result reduced the hole accuracy.

7. References
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