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Performance of Tialn Coated Carbide Tool in Peck Drilling Stainless Steel SS316L with Pressurized Minimum Quantity Lubrication (PMQL)

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ABSTRACT

Austenitic stainless steel, SS316L is vastly being used in food and medical applications instead of titanium alloys especially in the third world countries. The presence of chromium in SS316L improves its scratch-resistance and corrosion resistance while the nickel content provides a smooth and polished finish. The molybdenum element's enhances the hardness of the SS316L and ensure the sharpness of the cutting edge whereby these properties are very crucial in orthopedic devices. Machining of austenite stainless steel is considered difficult due its unfavorable properties such as gummy, high strength, high modulus of elasticity, low thermal conductivity and high work hardening. The contradiction between policy maker and industrialist in reducing pollution during machining can be compromised by using the Pressure Minimum Quantity Lubrication (PMQL). This technique of cooling and lubricating is applied and evaluated during peck drilling of SS316L with the combination of pressurized lubrication oil spray to the tool and work piece interface. This paper presents an experimental investigation on the performance of CVD-TiAlN coated carbide drills when drilling austenite stainless steel SS316L at various cutting speeds of 110, 130 and 150 m/min with feed rates of 0.05, 0.1 and 0.15 mm/rev, at customized point angles 110, 122.5 and 135 degree on fixed 12 degree rake angle and 30 degree helix angle. Surface finish, tool failure modes and tool life were evaluated at various conditions to determine the optimum condition of the process. It was found that point angle and the interaction of cutting speed and feed rate are the pronounced effect on the tool performance. Result also showed that feed rate was the dominant factor affecting the surface roughness.

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INTRODUCTION

In metal cutting, drilling plays a very important role since more than 40% of material removal processes are drilling operation (Brinksmeier, E., 1990). Since the development of corrosive resistant and superior surface finish materials, stainless steel have been adopted widely mainly due to its characteristics of high toughness, low thermal conductivity, high work hardening coefficient and good physical appearance. Its applications for medical devices and implants require not only corrosion resistant but also burr free edges (Mori Seiki Co. Ltd. 2010 Vol.1). An implant used in medicine for bone osteosynthesis has to satisfy functional demands defined by the working environment of human body. Geometry, roughness and other characteristics of the implant surface also significantly influence the surface-tissue interaction. Currently commercially pure (CP-Ti), titanium alloys TiAl6V4 and stainless steel AISI 316L are the most popular alloys used for the trauma and orthopedic medical implants (David Bombač, *et al*, 2007). SS316L stainless steel possesses reasonable corrosion resistance, biocompatibility, tensile strength, fatigue resistance and suitable density for load-bearing purposes thus qualifying this material for a desirable surgical-implant material. SS316L is a specific type of stainless steel and extensively used in medical applications. The presence of chromium in AISI 316L enhances the scratch and corrosion resistant of the metal. Nickel element provides a smooth and polished finish of the metal. Figure 1 shows the percentage range of chromium and nickel in austenite stainless steel. The presence of molybdenum provides greater hardness, and helps to maintain the sharpness of the edges, therefore well-suited for making surgical instruments. SS316L is easy to clean and sterilize, strong and corrosion-resistant. The nickel/chrome/molybdenum alloys are also used for orthopedic implants as aids in bone repair, as structural part

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of artificial heart valves, and other implants. High accuracy of the drilled hole is vital to precisely locate the surgical fasteners (U Kamachi Mudali, T M Sridhar and Baldev Raj, 2003).

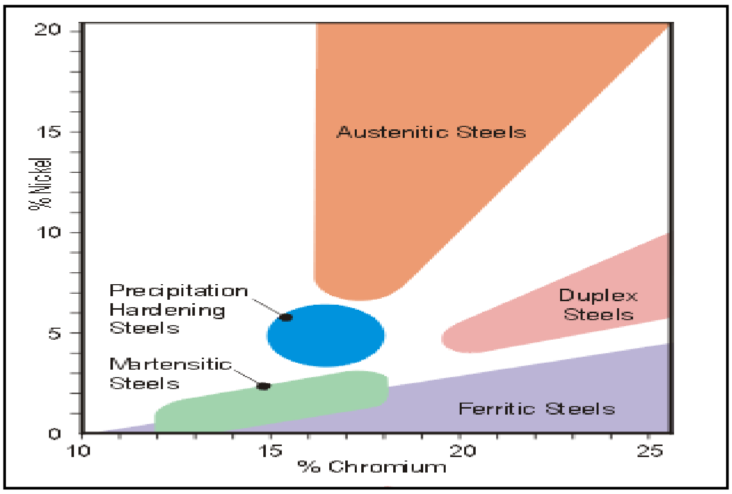

Fig. 1: Percentage of Chromium and Nickel in stainless steel

2. Machining Austenite Stainless Steel:

Machining of austenite stainless steel is considered difficult due its unfavourable properties when subjected to machining such as gummy, high strength, high modulus of elasticity, low thermal conductivity and high tendency to adhere to the cutting tool(Susanne Eva Cordes, 2012). These properties were responsible for the rapid wear on the cutting tool hence resulting in short tool life and rapid tool failure. During machining, particular in drilling operation, the optimization of the cutting parameters is essential in order to minimize the effect on the tool life and surface integrity of the work piece. The assistance of coolant in drilling is important to overcome the rapid tool wear. Cooling lubrication performs several functions such as reduce the friction, heat dissipation, cleaning of tool and work piece and provides uniform temperature field at the tool and work piece interface area. An increase of environmental awareness and an establishment of laws and regulation related to environmental pollution of the consumption of conventional cooling lubricant, has attracted many researchers to focus on the exploration of new tools and coatings as well as minimum quantity lubrication (MQL) and dry cutting towards green machining of metals. On the other hand, to the industry, use of excessive coolant tends to increase the cost and reduce the profit. The primary functions of cooling lubricant are to cool, to lubricate and to remove the chips (A.Shokrani, V. Dokia, S.T. Newman, 2012). MQL technique is applied with the ratio of 10 - 110l ml/h to the cutting edge towards environmentally concern (S.Bhowmick, A.T. Alpas, 2011). These elements may significantly reduce the cutting performance of a twist drill. Therefore the pressurized minimum quantity lubrication (PMQL) as shown in Fig. 2 is an option which compromises both requirements. The spray of oil mist and pressurized air supply alternately applied to the working area acts as a coolant and pressurized air flushes away the chips and debris from the working area.

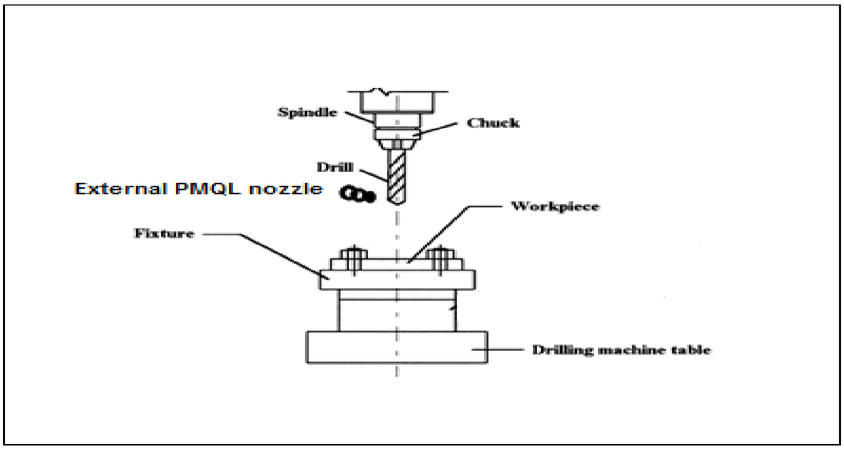

Fig. 2: PMQL set up in Drilling

3. Material Properties:

SS316L posses the properties of higher creep resistance, excellent formability, rupture and tensile strength at high temperatures and corrosion and pitting resistance. Table 1, shows the properties of SS316L.

Table 1: Chemical composition, mechanical and physical properties of SS316L.

Chemical composition (mass fraction)(wt.%)

Elements	C	Si	Mn	Pb	S	Cr	Ni	Mo	N
Max. (<)	0.03	1	2	0.045	0.035	18	14	3	0.1

Mechanical Properties

Tensile Strength	Yield strength	Elongation	HRC
474 -335 MPa	806 MPa	36 %	30

Physical Properties

Thermal Expansion	Thermal Conductivity	Specific Heat	Melting Temperature	Density	Resistivity
55-95 e-6/K	85-47 W/m. K	450-460 J/kg.K	5215-9622 ^{0}C	2920 kg/m^3	0.5-0.6 Ohm.mm^2/m

From the metallurgical microstructure point of view, stainless steels can be divided into three groups: austenitic, ferritic and martensitic (Serope Kalpakjian & Steven R. Schmid,2010). Amongst them, the austenitic stainless steels (e.g., 316) are the most difficult to machine than other alloy steels because of their high work-hardening rate and low thermal conductivity.

4. Research Objective:

It was found that little attention has been paid on the machinability studies of SS316L during peck drilling using TiAlN single layer coated tool. The study is aimed to investigate experimentally the optimum conditions when peck drilling SS316L austenitic stainless steel using TiAlN coated carbide drills. The performance of TiAlN coated carbide tool when SS316L was evaluated based on the tool wear, tool life and surface roughness. In addition a mathematical model for predicted tool life was established using Design of Experiment (DOE) approach.

Experimental Set- Up:

The objective of the design of experiment (DOE) is to provide an efficient means of experimentation and analysis of experimental results. The statistical design of experiments has been used by several researchers in the analysis of machining processes (Alauddin, M. and El-Baradie, 1997, Choudhury, I. A., and El-Baradie, M. A, 1999). Using diameter 6mm curve cutting edge Tungsten Carbide coated TiAIN twist drill. The test will be conducted using a 6 mm TiAlN coated carbide drill under different cutting conditions of cutting speeds of 110, 130 and 150 m/min with feed rate of 0.05, 0.10 and 0.15 mm/rev. The point angle of he drill was set at 110,122.5 and135 degree with fixed rake and helix angle of 12 and 30 degrees respectively as shown in Figure 3. Table 2 shows the experimental planning and results based on partially factorial and Response Surface Method (RSM) approach will be applied when sign of curvature exist to characterize the relationship between the predicted responses and the independent variables. The optimum cutting conditions of drilling austenite stainless steel 316L was derived accordingly based on the ANOVA results.

Table 2: Experimental design and results

Std	Run	Block	A:Vc	B:Fz	C:P. Angle	Tool life	Ra
			m/min	mm/tooth	Degree	Sec	um
1	12	Block 1	110	0.05	110	226.9	1.26
2	8	Block 1	150	0.05	110	283.3	1.16
3	4	Block 1	110	0.15	110	366.6	0.92
4	3	Block 1	150	0.15	110	267.9	0.89
5	10	Block 1	110	0.05	135	380.7	1.02
6	7	Block 1	150	0.05	135	412.5	0.86
7	6	Block 1	110	0.15	135	422.7	0.87
8	11	Block 1	150	0.15	135	384.6	0.63
9	5	Block 1	130	0.1	122.5	350.4	0.96
10	2	Block 1	130	0.1	122.5	370	0.95
11	9	Block 1	130	0.1	122.5	330	0.91
12	1	Block 1	130	0.1	122.5	325	0.98

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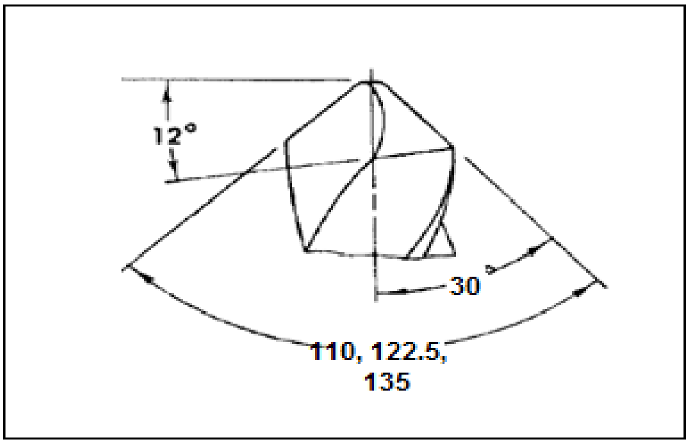


Fig. 3: Customized point angle

RESULTS AND DISCUSSION

Tool Life:

The analysis of variance (ANOVA) technique was employed for evaluating the significant level of cutting speed, feed rate and point angle on tool life are given in Table 2. The criterion for a confidence level of 95% or P-value less than 0.05 is used to determine which factor is significant. Result shows that the point angle and the interaction between cutting speed and feed rate have significant influences on the tool life. Low cutting speed with high feed rate and larger point angle resulted in highest tool life and low cutting speed with low feed rate and low point angle produced shortest tool life, as shown in Table 3.

Table 3: ANOVA results generated from the experimental data

Respose:Tool life						
ANOVA for Selected Factorial Model						
Analysis of variance table [Partial sum of squares]						
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**	
Model	37574.28	7	5367.75	12.64	0.0307	significant
A	*295.25*	*1*	*295.25*	*0.7*	*0.4655*	
B	*2394.32*	*1*	*2394.32*	*5.64*	*0.0981*	
C	*25969.2*	*1*	*25969.2*	*61.16*	*0.0044*	
AB	*6328.12*	*1*	*6328.12*	*14.9*	*0.0307*	
AC	*162*	*1*	*162*	*0.38*	*0.5805*	
BC	*1518*	*1*	*1518*	*3.57*	*0.155*	
ABC	*907.38*	*1*	*907.38*	*2.14*	*0.24*	
Curvature	1.31	1	1.31	3.08E-03	0.9592	not significant
Pure Error	1273.87	3	424.62			
Cor Total	38849.46	11				

The increase of point angle corresponds with the maximum lip movement at the earliest possible time to avoid work hardening (V.N. Gaitonde, et. Al, Taguchi, 2008). The customized CNC programmed peck drilling approach, shows no significant contribution to tool life compared to through drilling. It was observed that most of the wear progressed towards the centre of the drill as shown in Fig. 4. This phenomenon occurred because of peck drilling approach required continuous impact force to penetrate the new surface of work piece which is similar to intermittent cutting condition.

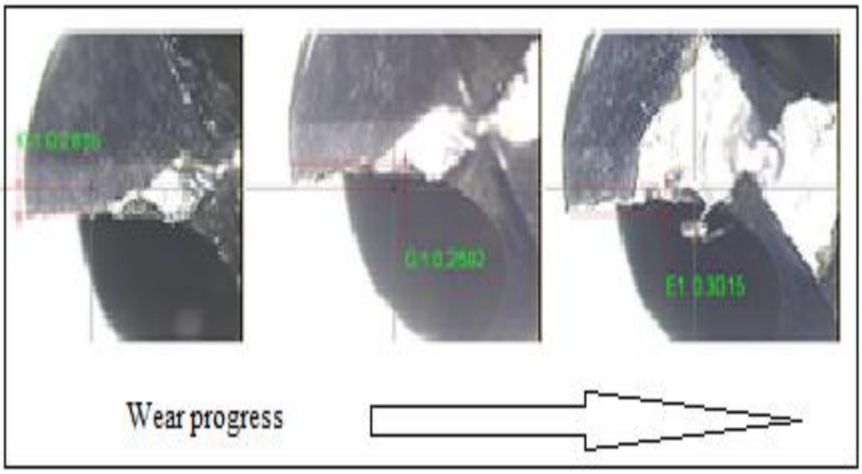


Fig. 4: Wear progress toward drilled centre

The combination of cutting speed and feed obviously increase the temperature rapidly. The low thermal conductivity of SS316L will initiated more severe wear condition at the chip-tool interface. Therefore, the generated heat is concentrated at the chisel edge and produced high cutting temperature that accelerates thermally induced tool wear such as diffusion and chemical reaction between the tool and work piece material. In addition, SS316L has high tendency to adhere to the cutting tool and forms BUE, as shown in Fig. 5.

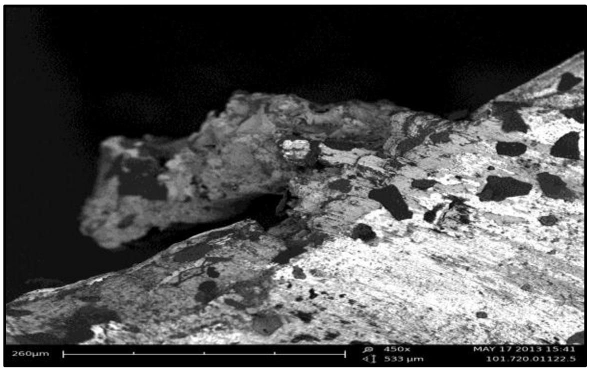


Fig. 5: SEM shows the Build Up Edge (BUE) on tool edge

Based on the experimental results, the final mathematical model to predict the tool life during peck drilling of SS316L austenite stainless steel with TiAlN coated drill is given as.

Tool life = - 1916.09250 + 10.74075* Vc + 20270.25000*Fz + 15.49800 * P. Angle -132.49500 * Vc * Fz – 0.067200* Vc * P. Angle –132.80000* Fz *P.Angle + 0.85200 * Vc * Fz * P.Angle

Surface Roughness:

As shown in Table 4, feed rate seems to be the dominant factor affecting the surface finish, although the point angle and cutting speed are also significant. The greater the number of drilled holes the higher the surface temperature of the drills that attributed to the coarser surface roughness of the drilled holes as a result of adhesion the work piece to the tool (12). An increase of temperature also contributes to welding effect at tool tip – work piece interface which causes ploughing at the drill center (Fig. 6). This phenomenon tends to accelerate the wear towards catastrophic failure of the drill.

Table 4: ANOVA results for surface roughness

Response:	Ra					
ANOVA for Selected Factorial Model						
Analysis of variance table [Partial sum of squares]						
Source	**Sum of Squares**	**DF**	**Mean Squa**	**F Value**	**Prob>F**	
Model	0.27	7	0.038	43.93	0.0051	significant
A	*0.035*	*1*	*0.035*	*40.51*	*0.0078*	
B	*0.12*	*1*	*0.12*	*141.36*	*0.0013*	
C	*0.09*	*1*	*0.09*	*104.21*	*0.002*	
AB	*1.25E-05*	*1*	1.25E-05	*0.014*	*0.912*	
AC	*9.11E-03*	*1*	9.11E-03	*10.51*	*0.0478*	
BC	*6.61E-03*	*1*	6.61E-03	*7.63*	*0.07*	
ABC	*2.81E-03*	*1*	2.81E-03	*3.25*	*0.1694*	
Curvature	4.17E-06	1	4.17E-06	4.81E-03	0.9491	not significant
Pure Error	2.60E-03	3	8.67E-04			
Cor Total	0.27	11				

Fig. 6: An increase of heat because of tribology effect that caused the ploughing action on tool tip.

The final mathematical model to predict the surface roughness during peck drilling of AISI 316L austenite stainless steel workpieces is given as.

Ra = + 3.45675 - 5.02500E-003* Vc -31.83500* Fz - 0.015050* P. Angle + 0.18250 * Vc * Fz + 1.50000E-005*Vc*P. Angle + 0.24100* Fz * P. Angle - 1.50000E-003*Vc*Fz*P.Angle

Optimization:

Tool life:

ANOVA results shows that the optimum condition for tool life is 422.7 seconds when peck drilling at cutting speed of 110m/min and feed rate of 0.15mm/rev at 135 degree point angle**.** Validation of the prediction model an actual machining was conducted using the recommended factors. The result actual drilling for tool life is 419.7 seconds as in Table 4.

Table 4: Tool life prediction versus actual experiments

Number	Vc	Fz	P. Angle	Tool life	Desirability	
1	110.00	0.15	135.00	422.699	1.000	Selected
Actual drilling = 419.7 seconds						

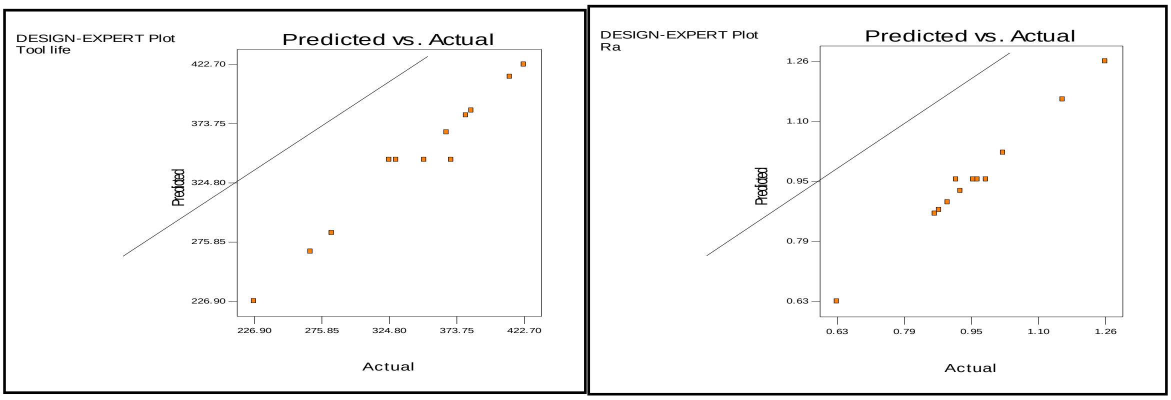
Surface roughness:

As for surface roughness the optimum condition is 0.76 um when peck drilling at cutting speed of 150m/min, feed rate 0.15mm/rev and the point angle of 135 degree. It shows that less than 15% from the predicted value as shown in table 5.

Table 5: Predicted surface roughness versus actual result generated by DOE software.

No.	Vc	Fz	P. Angle	Tool life	Ra	Desirability	
1	150.00	0.15	135.00	384.625	0.633	0.897	Selected
Actual Drilling = 0.76							

The condition of machine, clamping force, temperature control and some other factors also will affect the actual result of tool life and surface roughness as shown in Fig. 7.



(a) (b)

Fig. 7: Tool life (a) and Surface roughness (b) prediction and actual result

Conclusion:

Experimental results showed that point angle significantly affect the tool life. The combination of cutting speed and feed plays important roles in controlling the tool life. It was obvious that the temperature has a tendency to increase with simultaneous increase of cutting speed and feed. Higher drill point angle is required to maximize tool life, whereby increase in point angle tends to ensure maximum lip movement in the earliest possible time to avoid work hardening. In machining stainless steel the generated heat cannot effectively be transferred into the work piece and chips due to low thermal conductivity of material. The generated heat was concentrated at the cutting zone and produced high cutting temperature resulting in the occurrence of thermally induced tool wear such as diffusion and chemical reaction between the tool and work piece material. In addition AISI 316L tends to adhere to the cutting tool and forms BUE which corresponds to severe tool wear and low surface quality. The BUE is one of the cause of cutting resistance and higher level of cutting resistance could be observed at the chisel edge of the drill.

Future Works:

Further investigation is on progress to verify the result especially related to forces and case hardening in future article. Here some on-going experiments conducted:

i) Measurement of thrust and torque forces.
ii) Microhardness measurement near to drilled surface.
iii) Chips morphology

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