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Effect of Machining Parameters on Tool Wear and Hole Quality of AISI 316L Stainless Steel in Conventional Drilling

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Abstract

This paper focuses on the effect of drilling parameters on tool wear and hole quality in terms of diameter error, roundness, cylindricity, and surface roughness. In this work, the drilling was conducted using uncoated carbide tool with diameter of 4 ± 0.01 mm with point angle of 135º and helix angle of 30º. The drilling was done at different levels of spindle speed (18 and 30 mmin-1) and feed rate (0.03, 0.045 and 0.06 mmrev-1). Austenitic stainless steel AISI 316L was the workpiece material. Comparatives analysis was done on hole diameter, roundness, cylindricity, and surface roughness of the drilled holes by experimentation. From the result, the hole quality characteristics are mostly influenced by cutting speed and feed rate. An exception was for circularity error where a two tail t-test for circularity error indicates that cutting speed and feed rate give no significant influence on circularity error. As the cutting speed increases, the surface roughness decreases (1.09 µm). Contrary, when the feed rate increases, the surface roughness value increases as well. For cylindricity error, lower cutting speed and lower feed rate will give better result. In terms of diameter error, feed rate influences more than cutting speed. Minimum diameter error was achieved when low cutting speed and low feed rate were employed.

Keywords: Surface roughness; Roundness; Cylindricity; Drilling Austenitic Stainless Steel

1. Introduction

Although metal cutting methods have improved in the manufacturing industry, conventional drilling process still remains one of the most common processes. Drilling can be applied to various workpiece materials. The surface

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quality is important for the functional behavior of the mechanical parts [1]. The most obvious factors influencing the accuracy of drilled holes are cutting speed and feed rate [2]. 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 [3]. In material removal processes, an improper selection of cutting conditions will result in rough surfaces and dimensional errors. Therefore, it is necessary to understand the relationship among the various controllable parameters and to identify the important parameters that influence the quality of drilling.

Austenitic stainless steel especially AISI 316L is used widely in aeronautical, biomedical, and food industries. However, the poor machinability makes it a typical difficult-to-cut material, often resulting low hole quality when drilling process is conducted on this material. They bond very strongly to the tool, and chips often remain stuck to the tool after cutting [4]. These properties were responsible for the rapid wear on the cutting tool hence resulting in short tool life and rapid tool failure [4]. Researches regarding the machinability of the austenitic stainless steels have highlighted the insufficiency of the data for establishing of the optimum cutting conditions. Considering this, this study investigates the machinability of austenitic stainless steel AISI 316L during conventional drilling process using uncoated carbide tools, by varying the cutting parameters of cutting speed and feed rate.

2. Experimental

2.1 Material.

In this study, AISI 316L austenitic stainless steel was used as the workpiece material. This steel are generally used in the production of exhaust manifolds, furnace parts, heat exchangers, jet engine parts, pharmaceutical and photographic equipment, valve and pump trim, chemical/pharmaceuticals equipment, digesters, tanks, evaporators, pulp, paper and textile processing equipment, food preparation equipment particularly in chloride environments, and medical implants (including pins, screws, and orthopedic implants like total hip and knee replacements). The chemical composition of the workpiece materials was determined with EDS (Energy Dispersive Spectroscopy) analysis and given in Table 1.

Table 1. Chemical compositions of 316L austenitic stainless steel

Fe	Cr	N	Ni	Mo	Mn	Si	S	C	P
Bal	16.5	0.1	10.23	2.6	2.0	0.6	0.03	0.03	0.03

Samples with dimension of 102 x 60 x 10 mm^3 and hardness of 179.4 HV was used in the drilling trials. The samples were prepared using milling and surface grinding in order to meet above dimension and to prepare surface references for both drilling trials and measurement process. The samples were clamped on precision jig.

2.2 Drilling experiments.

Drilling tests were performed on DECKEL MAHO DMC835V CNC machining center using uncoated carbide drill bits with diameter of 4 ± 0.01 mm, point angle of 135°, and helix angle of 30°. Previous study recommended the cutting tool to have point angle between 118º and 135º and helix angle of 24º to 32º [5], hence the selected tool geometry. To guarantee the consistency of each test, a new drill tool was used for each trial. Holes were drilled at each trial until average flank wear on the tool reached 0.3 mm. The experiments were performed at two cutting speeds (18 and 30 mm/min) and three feed rates (0.03, 0.045 and 0.06 mm/rev) while the hole depth was kept constant at 10 mm. Tool overhang was set at 30 mm. All drilling experiments were conducted under 18.3 l/min flood drilling with 6% commercial FUCHS Ecocool 68CF2 as cutting fluid. Surface roughness (Ra) was measured by an Accretech Handysurf surface profilometer. The cut–off and sampling lengths for each measurement were taken as 0.8 and 4 mm, respectively. For each hole, the surface roughness was measured parallel to the drilled axis at four radial positions at 0°, 90°, 180° and 270° using the surface profilometer. The surface roughness was an average taken from twelve measurements from three repetitions on each position.

In these experiments, the final shape of the hole was determined using Renishaw cyclone coordinate measurement machine (CMM). The diameters of the holes were calculated using the standard built-in software package of the CMM. Twenty points were probed to determine the diameter in the horizontal plane, and the diameter of each hole was checked at 0.5 mm (i.e., near the top of the produced hole), 5.5 mm (i.e., near the middle of the produced hole), and 9.5 mm (i.e., near the bottom of the produced hole) along the hole axis height. All diameters were checked thoroughly. The difference between the measured diameter and the drill diameter was the diameter error. After drilling each hole, wear was measured at d/6 mm located at chisel edge [6] by a Raxvision microscope at 40X magnification.

Cylindricity is a tolerance of form that checks cylindrical features only. All circular and longitudinal elements on the surface of the cylinder must lie within two concentric cylinders separated by the value of the cylindricity tolerance which is measured on radius. Circularity is a tolerance of form and measured from a cross-section perpendicular to the axis of a hole or a cylinder to ensure that all elements are within a two concentric circle tolerance zones. Twenty points were probed for each hole cross-section, and the circularity was calculated using the built-in software package of the CMM. The circularity of each hole was also checked at three different heights along the hole axis.

3. Results and analysis

3.1. Effect of drilling parameters on tool wear.

Tool wear is an important issue since wear on drill affects the hole quality and tool life of the drill. As shown in Fig. 1, the feed rate was found to be more significant compare to cutting speed, impacting the tool life, due to the large feed rate, material must be scratch at each revolution will also be greater. Lower feed rate and cutting speed results in higher tool life.

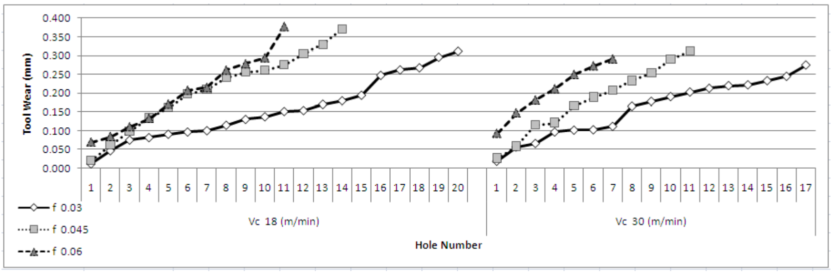

Fig.1. Average flank wear progress at different cutting speed and feed rate

With the tool life criterion that the average flank wear reached 0.3 mm, the number of holes that can be drilled at cutting speed of 18 m/min is 20 holes, 14 holes, and 11 holes at a feed rate of 0.03, 0.045, and 0.06 mm/rev, respectively . In conditions of higher cutting speed is 30 m/min, the number of holes that can be drilled before tool wear of 0.3 mm was 17, 11, and 7 holes at the same level of feed rate, i.e. 0.03, 0.045, and 0.06 mm/rev, respectively. Higher feed rate will cause the material volume that must be removed also higher in the same revolution.

During drilling, flank wear observed increase rapidly in all cutting speeds and feed rate applied. Drill experienced similar modes of failure during the experiment trial. These were non uniform flank wear, chipping, and catastrophic failure. Chipping of the cutting edges was common at most cutting speeds, perhaps due to the immediate loss of sharp cutting edge. Attrition wear was observed to be the prominent wear mechanism operating at all cutting speeds and feed rates. At the same time, the ability of the AISI 316L to retain its strength at elevated temperature during drilling also contributes to the resulting wear pattern of the drill.

Another contributing factor to the brittle failure of the cutting edge could be due to the low modulus of AISI 316L which can cause vibration and chatter during drilling. Chipping was the dominant mode of failure at most cutting speeds. However, close observation of the worn drills showed that under the same cutting speed, tool with lower feed rate suffered less damage when compared to the higher feed rate tool.

3.2. Effect of drilling parameters on diameter error.

Generally, as the cutting speed increases, the diameter of the hole drilled errors also increase (Fig. 2). This is because as the spindle rotation speed is higher, the vibration caused by the spindle also gets higher. In addition, the worsening hole profile was caused by multiple changes of direction during drill bit movement along the hole axis.

Diameter error showed a tendency to decrease in the next drill holes. This is because the tool wear rate increase so although the spindle vibrates the same as the previous hole, but due to the existing wear, the diameter irregularities do not occur too large to exceed the previous diameter. Minimum diameter error (7.417 µm) was achieved when the lowest cutting speed (18 m/min) and lowest feed rate (0.03 mm/rev) were applied.

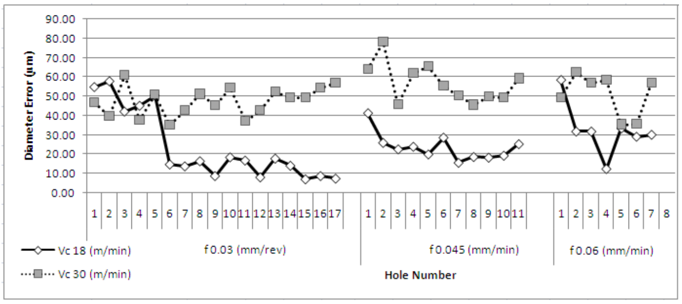

Fig. 2. Variation in diameter error for different cutting speed and feed rate.

3.3. Effect of drilling parameters on circularity.

For drilled holes, circularity or roundness is another important quality characteristic. Based on feed rate groups, the variation in average circularity error for different holes is given in Fig. 3. No clear trend was apparent; however there was a slight increase in circularity error values with an increase in cutting speed. wo tail t-test for circularity error gives $s_{tat} = 0.143 < c_{ritical} = 2.228$ for different cutting speed and $s_{tat} = 0.593 < c_{ritical} = 2.228$ for different feed rate. Based on the t-test result, null hypothesis accepted where no significant difference between the two cutting speeds and two feed rates applied on circularity error.

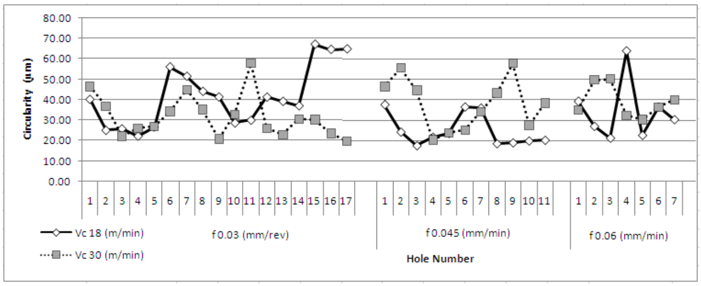

Fig. 3.Variation in circularity error for different cutting speed and feed rate.

3.4. Effect of drilling parameters on cylindricity.

Fig. 4 shows error of cylindricity at different level of feed rate and cutting speed. In terms of cylindricity error, it can be seen that lower cutting speed (18 m/min) and lower feed rate (0.03 mm/rev) will gives better result (0.035 mm). This can be mainly attributed to that the lower cutting speed leads to a minimal vibration in drilling, thus lower cylindricity error was obtained. While lower feed rate means the drill bit moving slowly with lower material removal rate along hole axis. As a result, hole axis tends to be consistent in constant position.

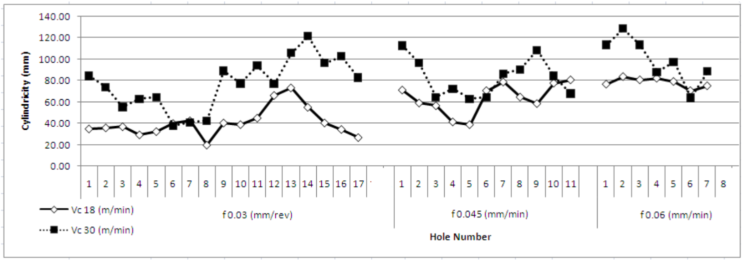

Fig. 4.Variation in cylindricity error for different cutting speed and feed rate.

3.5. *Effect of drilling parameters on surface roughness.*

Cutting speed has a significant influence on the surface roughness produced. When cutting speed increases, the surface roughness values of the holes produced decrease (from 1.34 µm to 1.09 µm). The decrease in surface roughness with increasing cutting speed can be explained by decreasing built up edge (BUE) formation tendency. Due to the highly ductile structure of austenitic stainless steels, they have tendency to form a large and unstable BUE. The presence of the large and unstable BUE causes poor surface finish. The trend lines in Fig. 5 shown that when number of holes drilled is increased, the surface roughness values gradually increase due to the increase of the tool wear.

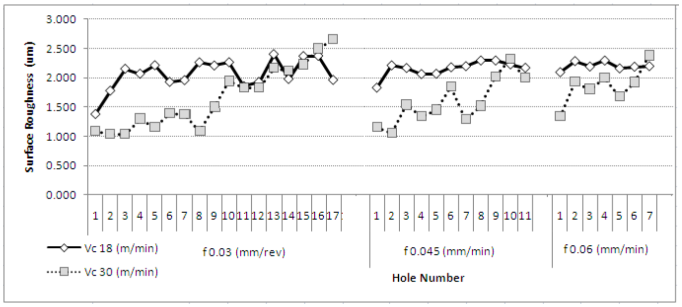

Fig. 5. Variation in surface roughness for different cutting speed and feed rate.

4. Concluding remarks

In drilling AISI 316L stainless steel using uncoated carbide tool with diameter of 4 ± 0.01 mm with point angle of 135º and helix angle of 30º at spindle speed of 18 and 30 mmin-1 and feed rate of 0.03, 0.045, and 0.06 mmrev-1, diameter error, cylindricity, and surface roughness are mostly influenced by the cutting speed and feed rate. The feed rate and cutting speed give no significant influence on value of the circularity error. As the cutting speed increases, the surface roughness decreases. In contrary when the feed rate increases, surface roughness value increases as well. At the same time, tool wear influences surface roughness. For cylindricity error, lower cutting speed and lower feed rate will give better result. In terms of diameter error, feed rate influenced more than cutting speed. During drilling austenitic stainless steel, drill experienced similar modes of failure at all cutting speeds and feed rates employed, i.e. non uniform flank wear, chipping, and catastrophic failure.

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