EVALUATION OF CHIPS FORMATION OF AISI 316L SS USING PRECISION END-MILLING

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ABSTRACT

This paper discusses in detail precision end-milling approach in order to study the chips morphology of AISI 316L stainless steel which affects the machinability to a greater extent. The cutting speed ranges of 80 to 140 m/min while the feed rate ranges from 0.025 mm/tooth to 0.04 mm/tooth were investigated. Scanning electron microscope (SEM) was used for the 3D-view analysis in order to study the top surface, length of chip, width, thickness of chips and shear bands of the chips. Experimental results conclude that the chip length increases with an increase in cutting speed (V_C). Furthermore, the chip width decreases with an increase in feed rate (f). The chips become thicker as the cutting speed is increased. A relationship was built between the surface roughness and surface integrity with the chip morphology.

Keywords: precision end-milling, surface roughness, chip dimensions, AISI 316L stainless steel.

INTRODUCTION

Hard machining refers to the machining of materials whose hardness is above 45 HRC. The complexity related with hard machining especially with the end-milling process from a material deformation and chip formation is yet insufficiently documented. In early research studies the researchers have just focused on the formation of different types of chips such as continuous chip, wavy chips, discontinues chips or serrated chips [1]. AISI 316L stainless steel is in the category of difficult to cut materials with poor machinability. The machinability of a material affects the overall performance of the finished product. Moreover, the surface finish and tool life along with the work piece accuracy is greatly affected by the formation of chips. Slight changes in the chip formation have a damaging effect on the machinability of the workpiece during high speed machining (HSM). A material with good machinability requires less power consumption, less tool wear, high surface finish with no surface damage [2]. Elbestawi *et al.* [3] studied the formation of saw toothed chips that were resulted during machining of hardened steel. The chips were produced as a result of crack imitation at the fee surface which propagated towards the tool end. There are certain types of chips which are produced as a result of machining hardened materials [4]. Furthermore, Alkali *et al*. [5] investigated ASSAB DF-3 material with a cutter made up of wiper coated ceramic and found that the result of poor machinability were cutting speed and feed rate which produce saw toothed chips.

This research work focuses on the formation of various sized chips using variable machining parameters and their influence on the machinability of AISI 316L SS. The whole work is divided into introduction, experimental conditions, experimental setup, results and discussion which include morphology of chips and finally the conclusions of this research study.

EXPERIMENTAL CONDITIONS

Workpiece and cutting tool material

AISI 316L SS rectangular plate was used as the workpiece material. The weight percentage composition of AISI 316L SS consist of: 0.03C, 1.1Mn, 0.5Si, 16.5Cr, 10.02Ni, 2.01Mo, 0.02P, 0.013S and balance Fe (all in wt %). A tungsten carbide tool (WC) with 5mm diameter with four flutes was used for the cutting operation.

EXPERIMENTAL SETUP

The whole experimental procedure was taken place on MAZAK Variaxis 630-5x a 5-axis CNC milling machine whose spindle speed was 20-12000 rpm made by MAC Co. Ltd JAPAN. The workpiece was held tightly in fixture in order to minimize the vibration of the workpiece and the tool.

Different combinations of cutting parameters were used in order to study the chip morphology with respect to their dimensions such as length, width, thickness and shear band. For that dimensional study field emission electron microscopy (FESEM) was used. Four levels of cutting speed ranges from 80-140 m/min and feed rate ranges from 0.025-0.04 mm/tooth were used. A total number of sixteen experimental runs were selected to study the effect of cutting parameters on the chip morphology and properties as shown below in

Table-1. The chips were collected after each run and collected for magnification and the remaining were blown in order to avoid mixing of different chips that were resulted using different cutting parameters. The corresponding chips morphology was studied using FESEM is described below.

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Table-1. Design of experiment for surface roughness

S. No	Cutting speed (Vc) (m/min)	Feed rate (f) (mm/tooth)	Depth of cut (D_C)
1	80	0.025	0.3
2	80	0.03	0.3
3	80	0.035	0.3
4	80	0.04	0.3
5	100	0.025	0.3
6	100	0.03	0.3
7	100	0.035	0.3
8	100	0.04	0.3
9	120	0.025	0.3
10	120	0.03	0.3
11	120	0.035	0.3
12	120	0.04	0.3
13	140	0.025	0.3
14	140	0.03	0.3
15	140	0.035	0.3
16	140	0.04	0.3

Field emission scanning electron microscope

It uses electrons instead of light for the morphology of particles on nanoscale. Those electrons are dispersed from an electron source and scanned the object. Primary electrons are bombarded by the column and a narrow beam is produced on the object. As a result secondary electrons are produced and received by the detector. This signal is amplified and sends to the video scan screen for the view of image.

RESULTS AND DISCUSSIONS

The removed chips from the workpiece during cutting process have an important relationship with the surface finish and surface integrity. End-milling is a complex technique in which the contact of the cutting tool with the AISI 316L SS is involved. In this case a three dimensional geometrical approach is adopted in order to understand the effect of the cutting parameters on the surface roughness and the surface integrity. The morphology of chips was conducted accordingly in which the effect of the cutting speed, feed rate, chip length, chip width and thickness were taken into account.

Chip length

Chip length is one of the important factor which defines the surface roughness and surface integrity as well machinability of AISI 316L SS. It describes the time of contact per tooth with the workpiece. If the contact time with the workpiece is more, lead to tool wear due to abrasion and diffusion and at last the tool life will be short. In case of AISI 316L SS end-milling, when the cutting tool touches the workpiece and penetrate inside it, the shear deformation starts and the primary zone move forward as the cutting proceed. The cutting parameters affect the chip length which replicates the characteristics of chip contact with the tool. The chip length at different cutting speeds is shown in **Error! Reference source not found.**.

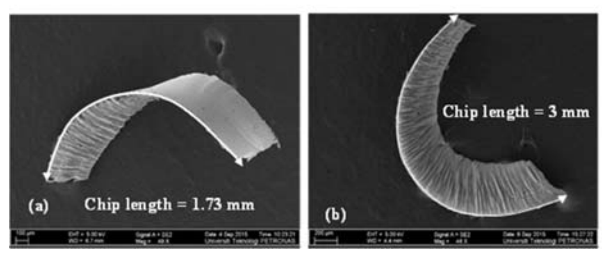

Figure-1. Length of machined chips (a) V_C = 100 m/min (b) V_C = 140 m/min.

The chip length increased with increase in cutting speed as shown in Figure-2. This is due to the thermal action which takes place between the cutter and the material under machining. That resulted in plastic deformation of the material occurred at high cutting speeds.

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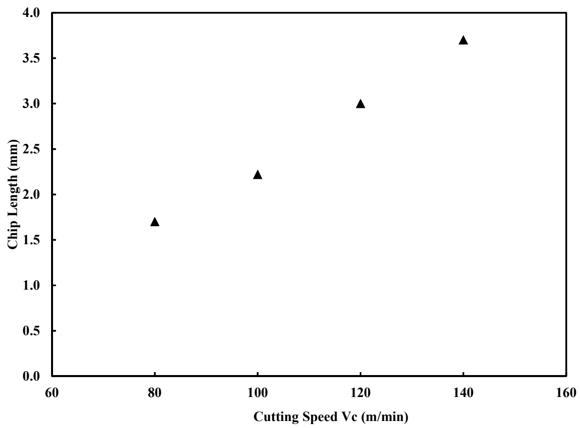

Figure-2. Effect of cutting speed on the chip length.

Moreover, with increase in feed rate (f) the value of the chip length also increased.

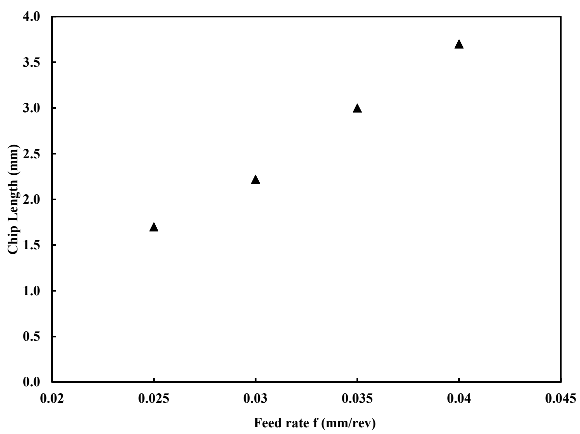

Figure-3. Effect of feed rate (f) on chip length.

Chip width

The contact between cutting tool and the chip is mostly affected by the chip length and the chip width. It also disturbs tool temperature, wear and the tool life. There are various values of chip width resulted at different cutting conditions. Some of these are given in Figure-4. As mentioned earlier that an increase in cutting speed (V_C) and feed rate (f), increases the chip length. For the same volume of the chip, the width of chip decreases. Figure-5 shows the trend of chip width with feed rate (f). It can be seen clearly that at feed rate of 0.025 mm/tooth the chip width has large value as compared to the chip width at feed rate of 0.04 mm/tooth.

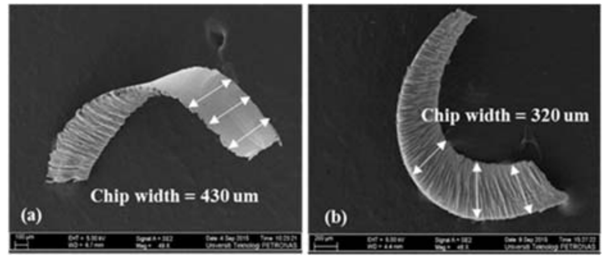

Figure-4. Width of machined chips at (a) f = 0.025 mm/tooth (b) f = 0.04 mm/tooth.

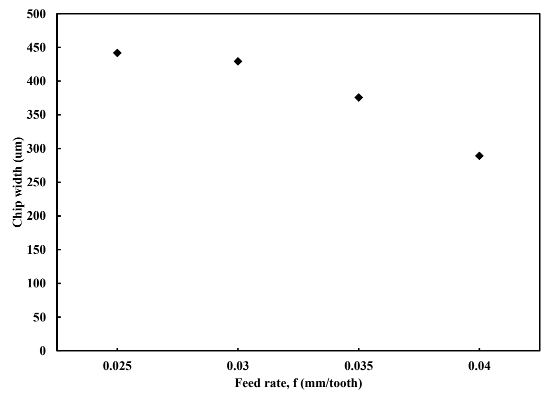

Figure-5. Effect of feed rate (f) on chip width.

Chip thickness

The average chip thickness is effected by the cutting parameters used. Figure-66 shows that an increase in cutting speed from 100 to 140 m/min, the thickness of the chip also increases. Same trend can be seen with the feed rate. As Kalpakjian *et al.* [6] reported that the chip thickness was due to increase in the feed rate and the tangential force was proportional to the undeformed chip thickness. As the feed rate increases that results the increment of the shear plane area.

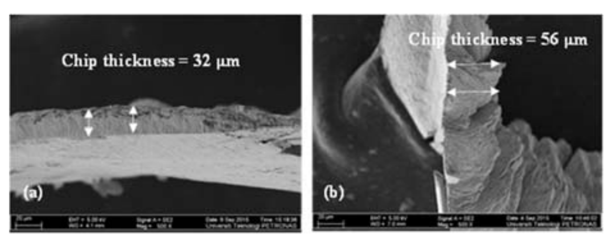

Figure-6. Average chip thickness at (a) V_C = 100 m/min (b) V_C = 140 m/min.

Moreover, Alkali *et al*. [5] concluded that increase in the cutting speed, decreased the cutting forces which ultimately resulted in thicker chip with improved surface finish of the workpiece.

Shear band

The front and back surface of the chips looks different in the micrographs. The front surface which was free and had no contact with the tool was rougher than the back side of the chip. The high contact pressure of the tool and the workpiece, frictional forces, and high temperature make the surface smoother and shiner than the free surface. But this free surface differs according to different cutting parameters. The micrographs of free and back surface of the chips are shown in

Figure-77.

In HSM, the formation of saw tooth or segmentation is obvious as studied by other researchers [7-9]. At low cutting speed the segmentations probability of formation decreased. At high cutting speeds the machining instability occurs which results in tool chattering and poor machinability and low surface finish.

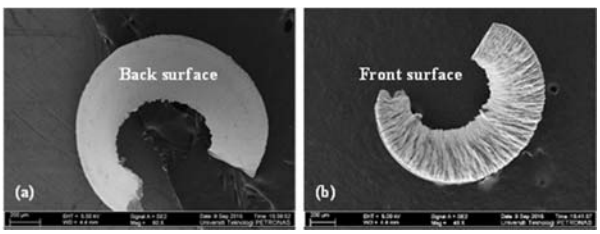

Figure-7. Micrograph of (a) chip back surface (b) chip free surface.

Different cutting speeds produced different Lamella structures; these are formed due to the alternative layers of the material during chip formation in cutting process. The structures with respect to dimension are different for different cutting parameters. With increase in cutting speed the numbers of lamella become less but their height and width becomes prominent. It is due to the cutting edge of the tool which makes the lamella larger and wider as shown in Figure-88.

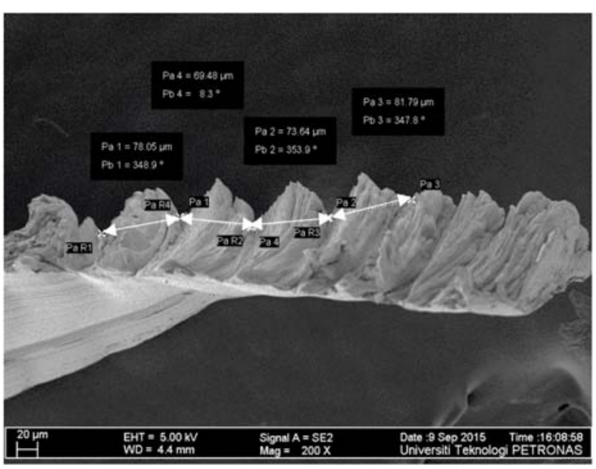

Figure-8. Micrograph of lamella.

CONCLUSIONS

Different types and shape chips were conducted in a series of end milling experiments that was done on AISI 316L SS. Those chips were analyzed in a way to study their microstructural and mechanical behaviors.

- A three dimensional approach was adopted to view the top surface, free surface and back surface of machined chips.
- The length of the chips increases with increase in cutting speed while opposite trend was noticed with increase in feed rate.
- The chip thickness decreases with the increase in cutting speed for all the combination of the feed rates. This study focused on the machinability of the machined surface that is resulted after chips removal. When the cutting speed increase the force component will tend to decrease which will consequently improve the surface roughness.

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