VOL. 9, NO. 5, MAY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

INFLUENCE OF PERIPHERAL MILLING ON MACHINING OF AIRCRAFT GRADE ALUMINUM ALLOY

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ABSTRACT

Peripheral milling is a metal cutting operation in which the cutter produces a machined surface parallel to the axis of rotation of cutting. This is approached either by upmilling or downmilling methods. The fundamental difference among these modes of milling shows a marked variation in the magnitude of cutting forces during the process, chip formation and the quality of metal cutting. This work examines the difference brought out on the resultant component/part in terms of surface finish and hardness on aircraft grade precipitation hardenable Aluminum 2124 T851 alloy. Other cutting parameters like feeedrate, depth of cut, spindle speed, tool over hang length, tool diameter, number of flutes etc., are maintained identical on both types of milling. This study is examined on finishing operation of Aluminum plates of the considered aspect ratio in attaining a defined thickness on all the specimens. Metal cutting is carried using three different types of cutters for both upmilling and down milling strategies. The surface texture, surface finish and hardness are evaluated and the results are presented. The results indicate that hardness values are relatively high in down milling strategy for the same machining variables as against the case of upmilling and the surface roughness is higher in case of down milling compared to upmilling operations**.**

Keywords: peripheral milling, up milling, down milling, surface finish, hardness.

INTRODUCTION

Peripheral milling is the process in which a cutter produces a machined surface parallel to the axis of rotation of cutter. The direction of rotation of the tool/cutter with respect to the feed direction contributes to two types viz., Upmilling and Downmilling. Upmilling is referred to conventional milling wherein the cutter rotation opposes the feed motion.

The cutting force acts in upward direction and the magnitude is minimum at start and maximum at the end of the cut [1]. Due to the cutting forces, the bodies (tool and wall) tend to move towards each other in the radial force direction and therefore the relative displacement will be the sum of the displacements of each component. Downmilling is also referred to as climb milling. The cutting force acts downwards and is maximum at the start of cutting action and minimum at the end of cut. With this technique, the relative movement of tool and wall are the addition of displacements in the radial direction but the bodies tend to move away from each other due to action of cutting force [2].

Depending on the cutting variables and the attention in manufacturing the part to desired nominal dimensions, the metal cutting is classified into roughing and finishing operations. The roughing operation aims in removal of maximum material utilizing the maximum efficiency of the machine and variables involved in it. This is usually imparted by high magnitude of depth of cut, feed rate, spindle speed, more ramping angle, and bigger diameter cutters etc., The results are accompanied by high magnitude of cutting forces in the system.

The process of peripheral milling under varied machining parameters is subjected to both horizontal and vertical loading. However the magnitude of vertical forces is dominant in peripheral milling which was tested using dynamometer [3]. The cutting speed, radial depth of cut and feed rate are influential upon roughness of work piece's end surface, followed by feed rate in the next place. In order to minimize the work piece surface roughness, the machining was carried at lower rates for all the three cutting parameters [4]. High surface roughness was observed when the feed rate was high in combination with the highest depth of cut and the lowest spindle speed. The feed rate is highly responsible for surface roughness in milling. Best surface finish was obtained by the use of high spindle speed and high depth of cut, while a low feedrate provided a better surface finish [5]. The relationship between contact area during end milling and the subsequent chips generated were studied. When the feed rate is increased, the instantaneous chip thickness is also increased. It was observed that radial and axial depth of cut affected the width and length of the contact area. As the radial depth of cut increased the contact area, the forces also increased [6]. The effects of spindle speed, cutting feed rate and the depth of cut on the surface roughness was brought out using a predictive model for end milling operation [7]. The tool activity during the chip formation process is important considering the machining impact on the work piece surface integrity. Situations of low chip ratio and undesirable plastic flow, such as ploughing effect or side flow can cause significant damages to the surface finish and the hardness of the work piece [8]. A mathematical model was proposed using Response Surface Methodology to predict cutting forces on aluminum Al 6063 by high speed steel end mill cutter [9].

In finishing operation, the focus shall be on the removal of left over stock after roughing operations, towards achieving the dimensions and surface finish as required by the designer / function / application. The significant cutting variables like depth of cut and feed rate are reduced to a level wherein the chatter of the tool is avoided and the surface finish is achieved to the optimum. Many studies have been done on this segment to address the optimum cutting conditions with maximum efficiency. All variables contribute both individually and also with interactions/ association, during metal cutting. Besides, it is the realized part that becomes accounted for the application / functionality. The properties with which the part is realized shall bear the tag of product specification. These properties include the stress imparted during machining, surface roughness, surface hardness and residual stresses. There are lots of metal cutting residual stresses imposed during the finishing operations depending upon the complexity of the part. The dimensions on a part shall be achieved after meeting certain threshold of the parameters like depth of cut, feed rate and spindle speed whereas properties like surface roughness and hardness are dependent on the aspect ratio of the tool, chatter, cutting angle of the tool, number of flutes, type of cutter, work holding devices etc., This paper presents the work carried out from the data generated and analyses the properties of the part differentiating the machining process during Upmilling and Downmilling operations. Further, the results are also mapped with three different types of cutters viz., insert type, flat end mill and ball end mill cutters.

MATERIALS AND METHODS

Tool

The following tools were used to carry out the research activities viz., Ø 8mm Flat end mill cutter, Ø 10mm Ball nose end mill cutter and Ø 20mm Insert type flat end mill cutter. All tools are carbide tipped or carbide cutters as shown in Figure-1.

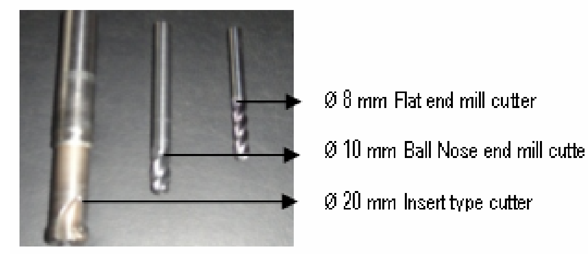

Figure-1. Types of cutters used.

MATERIAL

Aircraft Aluminum alloy 2124 T851 Grade of dimensions 110mm x 55mm (2:1aspect ratio) x 5mm (thickness) and supported by lugs of 30mm x 30mm at the ends for holding during machining are used as specimens as shown in Figure-2.

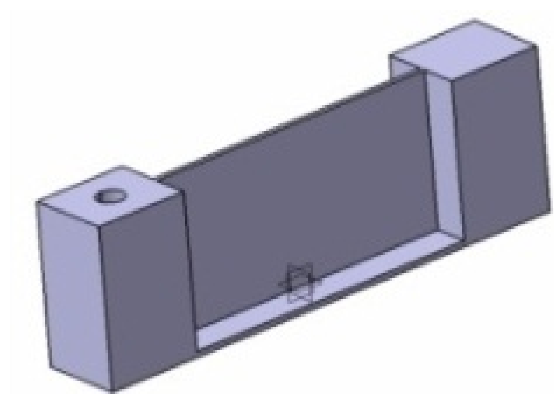

Figure-2. Model of the specimen.

Figure-3. Part with clamps on the CNC machine.

METHODOLOGY

The experiments are designed in such a way that the three types of cutters mentioned earlier perform both types of milling i.e., Upmilling and Downmilling with corresponding Feed rate (F), Spindle speed (S) and Depth of Cut (DoC). Six samples are subjected to the mentioned cutting parameters as detailed in Table-1.

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-1. Plan of experiments to study Upmilling and Downmilling variations by different types of cutters.

S. No.	Milling type	Tool specification	Machining parameters			
			F (mm/min)	S (RPM)	AxialDoC,mm	Radial DoC, mm
1	Up (U)	Ø 8mm Flat end mill	1000	2400	1	0.5
2	Down (D)	Ø 8mm Flat end mill	1000	2400	1	0.5
3	Up (U)	Ø 20mm Insert type	5000	6000	1	1
4	Down (D)	Ø 20mm Insert type	5000	6000	1	1
5	Up (U)	Ø 10mm Ball Nose end mill	1500	2000	1	0.5
6	Down (D)	Ø 10mm Ball Nose end mill	1500	2000	1	0.5

On machine

The center rib of thickness 5mm is reduced to 2mm thickness by end milling operation with different type of cutters on a CNC machining Centre. The part is held on the Table with proper clamping devices as shown in Figure-3 so as to withstand the cutting forces. With tool overhang length of 60mm, the profile contouring program is executed with one-way pass ensuring the required Upmilling and Downmilling operations, respectively as cited in Table-1 on Specimens 1 to 6. Every pass of the tool has axial depth of cut, radial depth of cut, feed rate, spindle speed, number of flutes and type of contact to the part (line contact in flat end mill, point contact in ball nose and varying contact with insert type of cutter). Flush type oil-based synthetic cutting fluid and water are used in the proportion of 1:20. The regions of the specimen are so divided that the reactive force region are classified as Region 1, where the centre vibrations shall be relatively more than Region 2, the regions near the clamping zone.

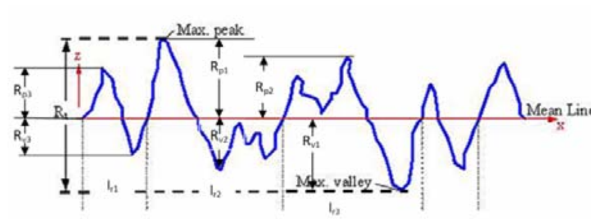
Surface morphology

Machining performed by Ø 20mm Insert type cutters, are photographed with 6X zoom to present the surface morphology. This is done using a commercial camera. Machining performed by Ø 10mm Ball Nose type cutters, Ø 8mm Flat end mill cutters are etched and the micrographs of the surface are captured.

Surface roughness

Surface roughness is measured for the surface texture examining the R_z for a sample length of (minimum) 10mm using Taylor Hobson Surface Roughness Testing Instrument as in Figure-4. R_z is the average of five highest peaks and lowest valleys over the entire sampling length. Surface roughness measurement involves parameters which can be obtained using empirical relation as depicted in Figure-5.

Figure-4. Surface roughness tester.



$$R_z = \sum_{i=1}^{5} \frac{R_{pi} + R_{vi}}{5}$$

Figure-5. Representation of R_z surface roughness.

where, y_i is the vertical distance from the mean line to the i^{th} data point. R_{pi}, R_{vi} is the i^{th} highest peak, and lowest valley respectively.

Hardness measurement

The hardness of Aluminum Al 2124-T851 is measured in HRE scale using Rockwell Hardness measurement for the Ø 20mm Insert type flat cutter. Micro-hardness tests are performed for testing hardness of coatings, surface hardness or hardness of different phases in the multi-phase material. Small diamond pyramid is used as indenter, loaded by a small force of 0.5 kg. Machined surface obtained by tools of Ø 8mm Flat end cutter and Ø10mm Ball nose cutter are measured by Micro-hardness test.

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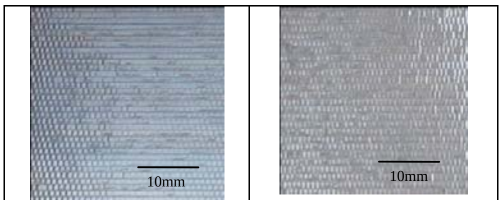
RESULTS AND DISCUSSIONS

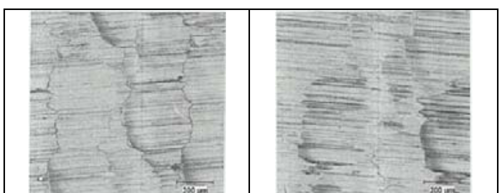
Surface morphology

The differences in surface texture of Ø 20mm insert type flat by upmilling and downmilling are distinct, different and visible by close examination by naked eye as in Figure-6. The impression/ marks left over by the cutter during upmilling have irregularities and are exhibiting matte finish with more spacing. In the case of downmilling, the matte-like finish irregularities are closely spaced presenting more roughness. This can be attributed to the uniformly varying radial force available during downmilling; whereas the radial force is higher during the initial cut of every flute and reduces slowly at as the chip is being ploughed out during upmilling [10].



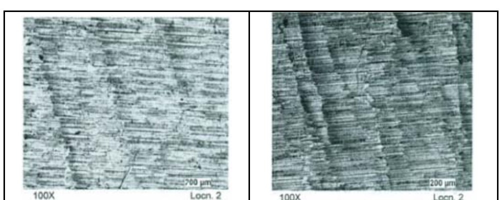
a. Up Milling b. Down Milling

Figure-6. Machined surface of Ø20mm Insert Flat.



a. Up Milling b. Down Milling

Figure-7. Machined surface of Ø10mm Ball Nose.



a. Up Milling b. Down Milling

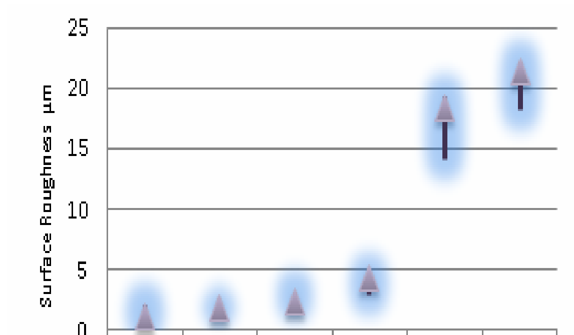
Figure-8. Machined surface of Ø8mm Flat end mill.

The machined surface of both specimens by Ø 10mm Ball Nose type cutters and Ø 8mm Flat end mill cutters showed very smooth surface texture when viewed by naked eyes. The surface was subjected to micrograph to zoom 200µm length in 1cm distance as presented in Figure-7 and Figure-8. In both the cases, the down milling strategy showed distinctly more tool cut marks per unit length compared to the upmilling operation. Further, the surface texture is quantified by measuring the surface roughness.

Surface roughness

The surface roughness is measured on the top, middle and bottom regions of the part surface. It is observed that for the same cutter type, the surface roughness achieved by down milling is more compared to that of surface roughness achieved by upmilling. In the case of Ø 20mm Insert Flat end-mill cutter, R_z = 21.2835 is observed in downmilling case against R_z = 18.3548 in case of upmilling at the middle region of the plate. Ø 10mm Ball Nose results in R_z = 4.1943 during downmilling case and R_z = 2.3793 during upmilling. Ø 8mm Flat end mill imparts surface finish of R_z = 1.1396 by upmilling and R_z = 1.8057 by downmilling respectively. Similar results of surface roughness are measured at top and bottom regions of the plate shown in Figure-9.

The surface roughness attained by Ø20mm Insert Flat end-mill cutter is in higher magnitude because the radial depth of cut being 1mm. In case of lesser diameter cutters, the radial depth of cut was only 0.5mm. It can be quantified that the better surface finish is achieved by upmilling condition for the same cutter and other metal cutting parameters and conditions.



	8 U	8D	10 U	10 D	20 U	20 D
Top	1.9749	1.8234	3.0066	4.4888	19.1467	22.1242
Bottom	0.8907	1.477	2.1856	2.8494	14.1071	18.0958
Mid	1.1396	1.8057	2.3793	4.1943	18.3548	21.2835

Tool Diameter and Milling type

U - Upmilling, D - Downmilling

Figure-9. Graph of surface roughness obtained by different tool diameters through upmilling and downmilling.

Hardness measurement

Rockwell hardness (scale E for Aluminum) has been measured for the surface being cut by Ø 20mm Insert type Flat end-mill cutter and is tabulated in Table-2. It is observed that the hardness values obtained by downmilling operation are higher than the upmilling. Since the radial depth of cut was 0.5mm in case of surface machined by Ø 10mm Ball Nose and Ø8mm Flat end mill, Micro hardness value are reported and presented in Figure-10.

VOL. 9, NO. 5, MAY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Table-2. Hardness value by Ø20mm Insert Flat end-mill.

	Up milling	Down milling
Trial 1	77	85
Trial 2	64	71
Trial 3	70	81

It is observed that the hardness values of downmilling in both the case of the tools are also higher while compared to that of the upmilling conditions.

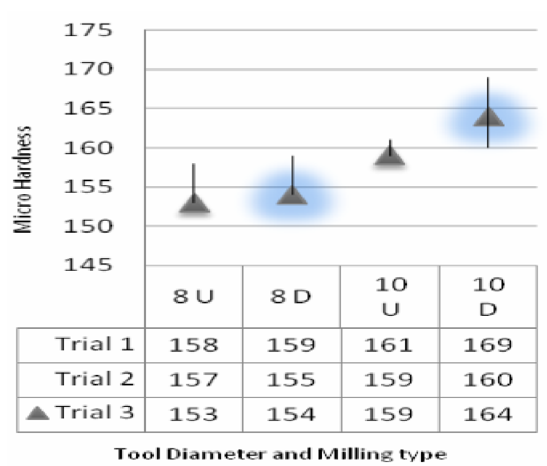


Figure-10. Graph of micro hardness obtained by different tool diameters through upmilling and downmilling.

CONCLUSIONS

Milling operations were carried out for specimens using different cutters. Surface roughness and hardness tests were conducted and the conclusions are given below.

a) Significant difference is brought out between up milling and down milling operations and their relation with respect to hardness and surface finish.
b) Finishing operations demand good surface finish and is realized to a high degree by up milling for the specific cutter type.
c) The hardness values are relatively high in down milling for the same machining variables as against the case of up milling.
d) The advantage of down milling operation contributing to increase in hardness can be utilized in finishing pass of metal cutting operation.
e) The down milling imparts hardness on the surface of the machined component. Down milling operation in the finishing pass (depth of cut < 0.5mm) can be utilized in enhancing the surface hardness of the machined component.
f) Prominent differences in up milling and down milling are seen by the different cutters used.

Future scope of work

a) Results shall be utilized to predict the optimum machining characteristics in terms of part realization.
b) Characterization of the material with the influence of deformation patterns, thermal/friction effects, residual stresses and bowing effect during machining shall be ongoing contribution in extension of this work.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to Director, Council of Scientific and Industrial Research-National Aerospace Laboratories (CSIR-NAL), Head, Centre for Civil Aircraft Design and Development, CSIR-NAL for their consistent support for this research work. The staff and facilities at Aircraft Prototype Manufacturing Facility are acknowledged.

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