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Tool-path effect on the geometric deviations in the machining of UNS A92024 aeronautic skins

I. Del Sol[a,*], A. Rivero[b], J. Salguero[a], S.R. Fernández-Vidal[a], M. Marcos[a]

[a]*University of Cadiz, Dept. of Mech. Eng. and Industrial Design. Av. de la Universidad de Cadiz, 10 E-11519 Puerto Real (Cadiz), Spain*
[b]*Tecnalia Research & Innovation, Paseo Mikeletegi 7, Parque Tecnológico, E-20009, San Sebastian, Spain*

Abstract

Traditionally, aeronautics skins are being machined by chemical milling, a high-pollutant process. An efficient alternative to this technology is conventional machining. However, to ensure the parts machined with this process keeps the industrial quality controls, the effect of tool-path might be characterized, specially analyzing final thickness and roughness.
In this paper, five different tool-paths have been applied under the same machining parameters in the dry milling of Al-Cu UNS A92024 thin plates. Machining time, final thickness and roughness have been evaluated. Most roughness and thickness results are under the industrial quality limits stablished for this type of parts.

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Keywords: metal skin, milling, machining, tool-path, roughness

1. Introduction

The first approximation to high performance in aeronautical industry is reached minimizing the aircrafts' weight. This goal can become a mandatory contractual point possibly punished with 500€/kg to 1000€/kg, depending if the value is related to the Target Weigh or to the Not to Exceed Weight [1]. This reduction of aircraft weight affects to every aircraft's performance component. Particularly, skin panels' weight is reduced machining 21/2 D pockets on

* Corresponding author. Tel.: +34 956483490
E-mail address: irene.delsol@uca.es

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the internal surface, reducing it thickness in non-critical points of the structure. For this purpose, the commonly technology used is Chemical Milling, a non-conventional process that avoid mechanical and clamping troubles. However, it is a slow, high-pollutant technology with many reworking steps and therefore, with a low efficiency.

Factory of the Future and other European Manufacturing Research Programs, as Clean Sky 2 [2], promote the improvement or the look for alternatives in Manufacturing Process in order to reach higher efficiency and competitiveness. The performance of this alternative process have to be evaluated studying five components: economic, environmental and equity (following the Triple Bottom Line perspective [3]), and energetic and functional efficiency (analyzing the integral performance of the process [4]).

4th call for proposal of Clean Sky 2 [5] includes a specific topic, which aim is to change the manufacturing process of specifics parts conventionally manufactured by Chemical Milling. Since the last seven years, the main studied alternative is conventional machining [6] but it requires the use of specific clamping systems in order to ensure no axial deviation of the part -affecting thickness tolerances- or dynamic problems exist. The first ones affect to thickness tolerances, the second one to roughness results. The study of this alternative has previously been focused in the design of specific clamping systems but most of them require expensive machines, in which the solution is related to the use of two heads, one used as a support and the other as a cutting head [7,8], or to the design of a complex and flexible clamping system able to change it shape adapting to the machining part, which are usually double curve [9,10]. Even though the development of this type of systems, the use of conventional machining in this type of slim parts has not been studied directly and the behavior is no characterized.

The most similar experiment carried out in lab-experiences are those related to thin wall or thin floor machining. This type of experiments start from a monolithic block and the final buy-to-fly ratio can arise 30:1 [11], producing a constant change of the system's behavior.

Thin wall and thin floor machining presents two type of problems, dynamics and statics. Both affects geometrics deviation of the part. Therefore, to evaluate the performance of slim structure machining is mandatory to analyze geometrical considerations. Those parameters, especially roughness, can be influenced by the strategy chosen to generate the tool path [12].

For this reason, this study is focused on a small sheet machining, in which the performance of different machining tool path is analyzed in terms of process time, final thickness and surface quality requirements.

Nomenclature

BF	Back and forth strategy	X	X direction for machining in the machine control
InCl	Inward climb strategy	Y	Y direction for machining in the machine control
InCo	Inward climb strategy	D	Diagonal direction for machining refered to X and Y
OutCl	Outward climb strategy	P	total profile measured by the rugosimeter
OutCo	Outward climb strategy	Ra	Average roughness
HSMC	High Speed Machining Center	d	final thickness of the part

2. Materials and methods

Metal skin machining has been commonly developed by Chemical Milling. Consequently, it is very difficult to find a methodology for analyzing the conventional machining of these kinds of materials appearance. The test samples, e.g., are not standardized and the main quality evaluation parameters are not deeply defined. Because all these reasons, a Methodology has been proposed for this preliminary study, see Fig 1. Workpiece designs have been performed and a set of geometrical variables have been selected for the process and samples quality evaluation.

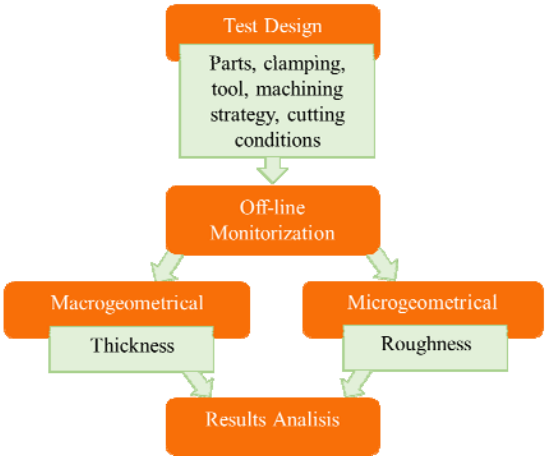

Fig. 1. Experimental methodology scheme.

2.1. Machining test

Aluminium UNS A92024 sheets of 85x85x1.6 mm have been machined in a 5 axis High Speed Machining Centre Kondia Five-400 with a CNC Heidenhain iTNC-530. A 50x50 mm pocket has been dry milled in the middle of the part, using a two teeth torus end-mill Kendu 4400.60, with a diameter of 10 mm, helix angle 30º.

Machining parameters have been fixed to 12000 rev/min, 0.08 mm/teeth and axial deviation of 2.5 mm. Depth of cut is 0.4 mm. Tests were carried out by changing only the machining strategies. At least one test has been performed for each one of the following alternative tool-paths: back and forth (BF), inward climb (InCl), inward conventional (InCo), outward climb (OutCl) and outward conventional (OutCo), al represented in Fig. 2.

In order to reduce possible deflection of the part during the test, a simple clamping system has been designed, consisting in four bolts threaded to a plating sheet. These tests have been performed in order to study the effect of cutting tool-path on the roughness and dimensional deviation.

2.2. Geometrical quality evaluation

The geometrical evaluation of machined test samples has been performed from two point of view:

- Macrogeometrical. Based on dimensional analysis, supported by studying the box final thickness
- Microgeometrical. By acquiring profiles and measuring its roughness. In this paper, only average roughness values are evaluated

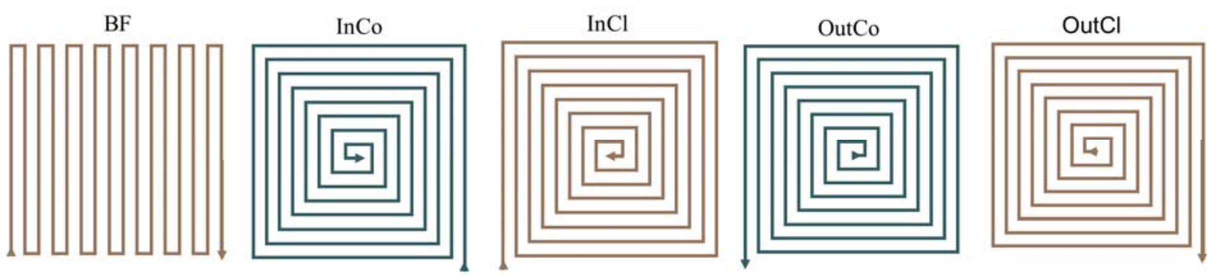

Fig. 2 Machining test strategies.

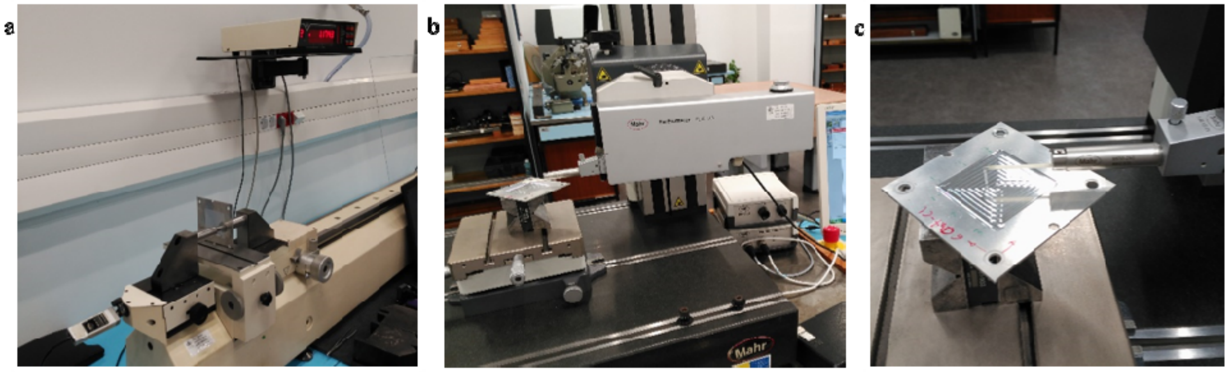

Fig. 3. (a) Helios horizontal coordinate measurer; (b) Marh Perthometer Concept PGK 120 for roughness profiles acquisition; (c) Frame showing the roughness measure process.

Thickness measurements have been taken in 25 points of the each sample equally distributed on the part. Despite in industry quality control, metal skin machining final thickness deviation is usually measured using an ultrasonic thickness-meter, a horizontal coordinate measurer has been used for this purpose, Fig. 3 (a), improving the data precision of the part after the machining process than punctual thickness measures.

Roughness data have been obtained analyzing eight sections of the part with a Marh Parameter Concept PGK 120, Fig. 3(b), following three different directions X, Y and D. Selected cut-off is 2.5 mm and total measure length is 36 mm for X and Y direction and 50 mm for D direction. Total lengths have been chosen in order to cover the maximum distance without register the corner flank, which can distort the results. This methodology also has allowed to study the general behavior of the part in terms of waviness. P profiles can give more macrogeometrical information about the behavior.

3. Results

Machining time has been calculated (theoretical) and registered (actual) during machining operations. Results shown in Table 1 indicates that BF strategy is almost two seconds longer than outward strategies in actual machining time. It was calculated a difference in medium machining time of 1.70 s between helical and BF strategies. This time variation is related with the displacement acceleration which is not enough to achieve the programmed feed in short paths. It is remarkable the difference between theoretical and actual machining time is higher in BF strategy. This difference has been produced for the accumulation of small paths (2.5 mm) in BF repeating the movement 16 times, compared to the helical ones where it only happens twice. Consequently, this difference would be more significant in industrial parts where the pockets are larger and the real machining time can be more similar to the theoretical one in helical strategies.

Machined pockets have been visually checked as shown in Fig. 4. The first part of the evaluation have consisted in the looking for adhesion of foreign particles that could affect quality surface. In this visual analysis, the part machining following an OutCo strategy presents adhesion in flank corners, as marks of the tool in each path, especially in the lowest part. The other part do not present other particularity. It can also be analyze the crossing points of the tool paths, they have been easily identified. It is remarkable the difference between the upper corners in Fig. 4(b) and Fig. 4(c) comparing to the lower ones. This result can be verified in the P profile and is related to the dynamics of the HSMC where accelerations and decelerations are not controlled. An example can be found in Fig. 5, in which the P profile evaluates the diagonal (D1) of the OutCo test. As can be seen, it presents two completely different sections, as it was explained in visual evaluation.

Table 1. Machining time (s).

Strategy	BF	InCl	InCo	OutCl	OutCo
Theoretical	22.50	21.25	21.25	21.25	21.25
Actual	25.17	23.62	23.65	23.32	23.31

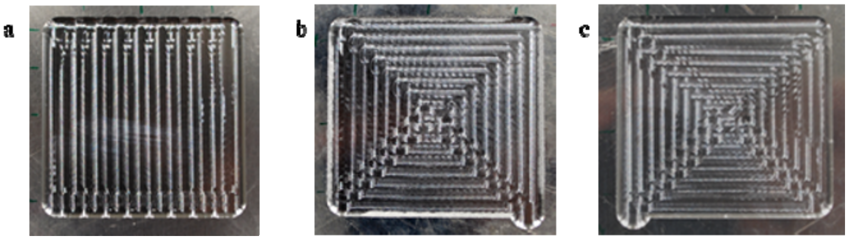

Fig. 4. Pockets visual evaluation for: (a) BF tool-path test; (b) OutCo tool-path test; (c) InCl tool-path test.

Thickness results have been plotted in Fig. 6. BF strategy can be related to a higher variability of the results. It can be relied with the dynamics of the system during the test. Constant acceleration and deceleration take part in the process, making easier the appearance of defection, spatially in the middle of the sheet where the clamping is weaker due to the relative position of the tool with the bolts that anchor the sample test. It also make easier the appearance of unusual vibration.

Inward strategies present lower results than the programed as it was expected. Starting in the outside, more rigid part, and go to the center make easier the deflection reducing the final thickness of the sample. However, variation between results is similar in outward and inward strategies, being this quality parameter more constant in helical strategies.

If assuring a minimum quantity of material were a key factor to maintain final thickness, outward strategy presents better results. Starting in the center of the sample keeps the part more rigid and consequently has kept a value more similar to the main one.

Climb and conventional strategies do not affect considerably the results due to the low cutting depth. This change of strategy only has impact in the peripheral where the tool works in compression or traction. There is no difference in the application of forces in the floor of the part and consequently on the final thickness for low cutting depth.

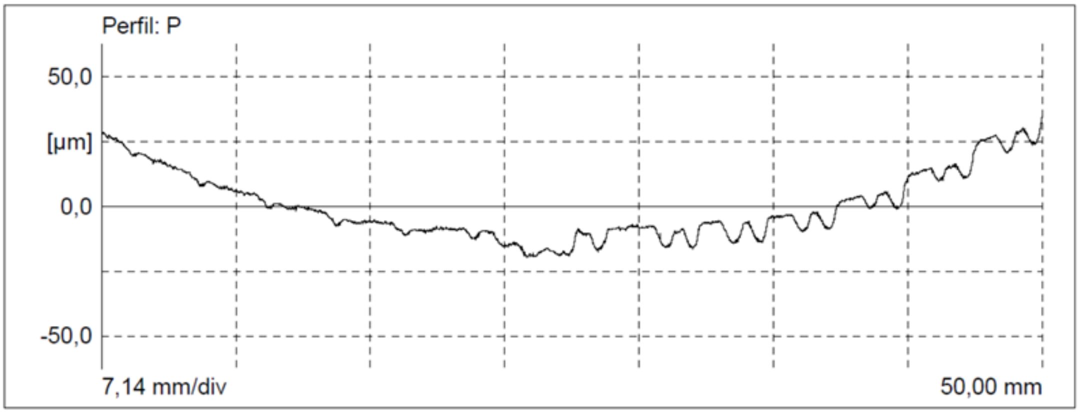

Fig. 5. Example of P profile evaluating a diagonal section.

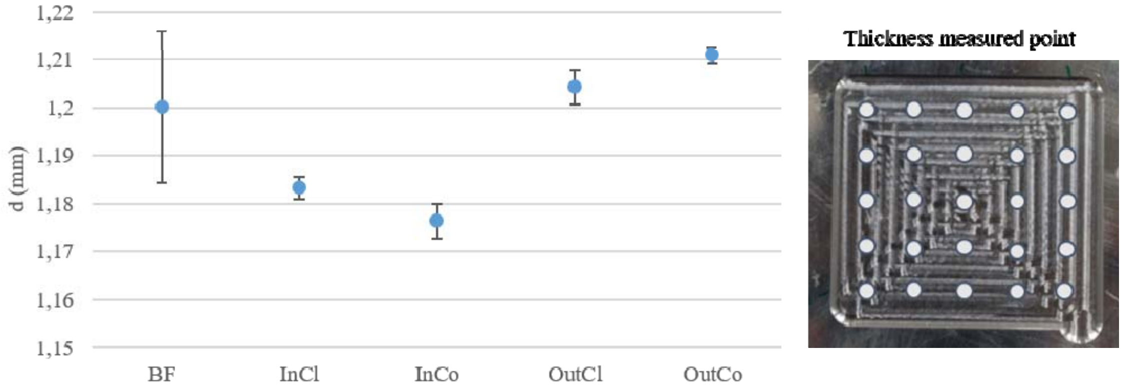

Fig. 6. Thickness average results depending on the toolpath.

Roughness results always have an average roughness (Ra) under 1.6 µm, except for the BF test (Fig. 7). This Ra is the maximum allowed for industrial application and in fine chemical milling processes.

This quality parameter is affected also by climb or conventional milling. The second one seems to present higher results for the same milling path. This difference could be relied to the dynamic stability of the process or it also seems to be affected to the deviation of roughness results. As it was expected, crossing path present the higher Ra. This can be reduced improving the design of the tool-path or including a feed-rate compensation.

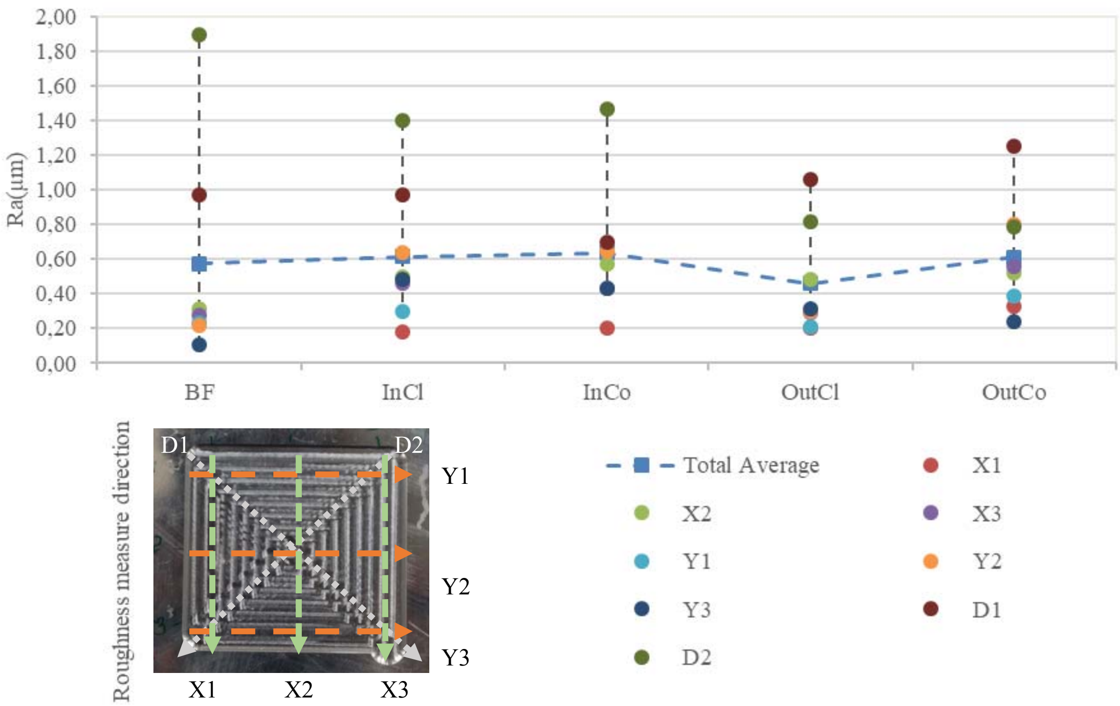

Fig 7. Roughness results depending on the tool-path.

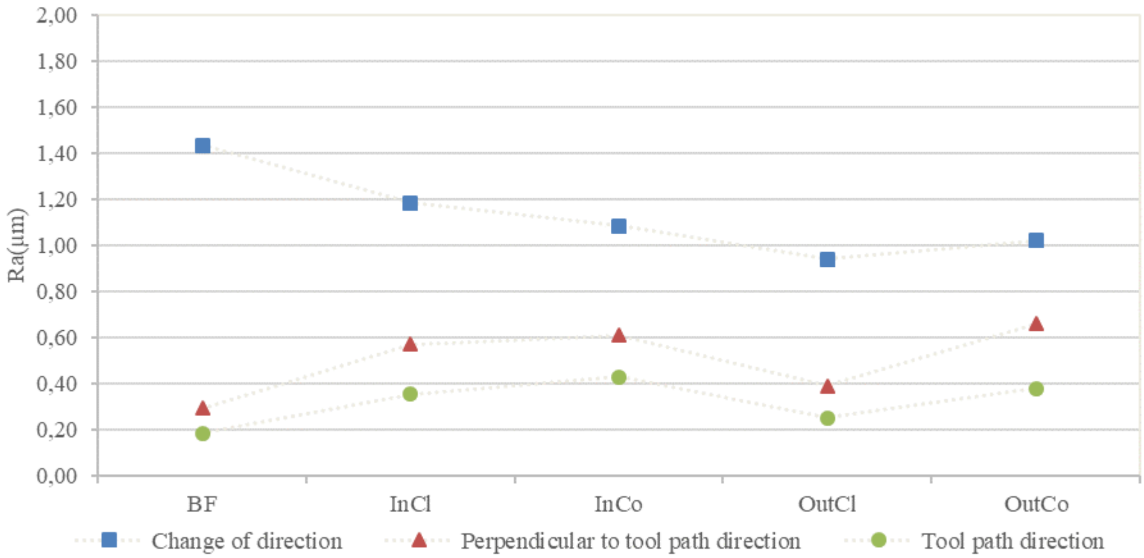

Fig. 8. Roughness results depending on the measuring direction.

Fig. 8 shows the results obtained for each tool-path, depending on the measure direction. It is remarkable that the results of perpendicular tool-path directions are proportional (30-42% higher) to those taken in the tool-path direction. This is related to the pick and valleys appeared in the change between the tool-paths that increase the average value calculated in Ra, as the distance between path and the evaluation length have kept constant, the number of higher irregularities is the same increasing the Ra in a similar proportion in every tool-path strategy. For every direction and roughness measured, OutCl strategy presents the better results.

4. Conclusions

In this work, a preliminary study of aluminium skin conventional machining as industrial alternative to chemical milling has been achieved.

For this reason, a methodology for the geometrical analysis of the parts has been developed to ensure the quality of the machined parts.

Machining time has been analysed presenting the better results in helical strategies, being those closer to the theoretical time. It seems to be related to the tool-path length, the longer it is, the feed rate is closer to the programmed and so to the theoretical machining time, not losing time in acceleration or deceleration in each change of direction.

Final thickness and surface quality are analysed relating them to specific tool path machining. Tool path seems to have an influence in thickness, especially on the variation of the thickness obtained in the same sample depending on the evaluated test. This variation is caused by the deflection on the test sample incurred by it unequal clamping.

Tool path also affects the variability of roughness results probably due to the dynamic stability of the process. This variation appears particularly in the direction of path's change which could be related to the dynamics of the machining centre. This change can induce deflection and vibration in the test sample affecting it microgeometrical properties by increasing the Ra obtained.

However, the Ra results are under the industrial limits. Consequently, it does not became a key factor to choose the tool-path strategy, being thickness and machining time results, in this order, the ones to be principally evaluated. Based on the results obtained Outward strategies are the most suitable for this process. The thickness is closed to the design one, machining time seems to be the shorter and roughness data are under the industrial quality limits.

Nevertheless, further tests must be performed to ensure the capability of the process is enough to industrial applications.

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