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EFFECTS OF TOOL TYPE AND ADAPTIVE MILLING ON THE SURFACE TOPOGRAPHY AND THE DIMENSIONAL ACCURACY OF THIN-WALLED COMPONENTS FROM TI6AL4V

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Abstract: *The aerospace industry is seeking to reduce the weight of the constructions. This is the reason for the increase in the use of thin-walled elements. One of the main problems in the machining of thin-walled components is the elastic deformation of the wall, which leads to deformations and thus to geometric errors and a deterioration in the quality of the workpiece. In the work, the influence of the adaptive milling and tool type on the surface topography and the dimensional accuracy of thin-walled components was determined. The samples for constant cutting parameters were prepared from titanium alloy Ti6Al4V using conventional, HSM and HPM tools. Based on the experiment results, waviness and roughness and dimensional deviations (using optical scanner GOM) were determined.*
Key words: *adaptive milling, surface topography, dimensional accuracy, GOM measurement, roughness, waviness, titanium alloy, aerospace industry.*

1. INTRODUCTION

Some branches of the industry, as aerospace industry, are striving to reduce weight, so there is an interest in this sector in the use of thin-walled components. In the aircraft constructions there are thin-walled elements in the fuselage, chassis, body, etc [1].

Despite the advanced level of machining, there are still many limitations that are being analysed by the researchers.

One of the main problems in the machining of thin-walled components are the elastic deformation of the wall during machining, which leads to deformations and thus to geometric errors and vibrations as well as a deterioration of the quality of the workpiece [2-7]. This is due to the low stiffness of the workpiece due to the small cross-sectional area.

The deformations are a serious problem as the manufacturers of the aerospace constructions want to improve the quality of their products in order to remain competitive. This results in increasingly the tight dimensional tolerances [8-10].

There are the several ways to reduce the deformations when machining thin-walled components.

The main methods include the simultaneous machining of the component walls from both sides, optimization of the tool geometry, the technological parameters and the tool path, the use of a special mounting bracket [3,5].

Zębala [2] in his work showed that improving the quality of execution of thin-walled components can be achieved by applying right manufacturing strategy. During his work, he checked the surface roughness of the aluminium alloy 7075.

Authors of the study [3] analysed the effects of the methods and the tools when milling thin-walled components from aluminium alloy 2024. They showed that these parameters have an influence on the deformation of thin-walled components.

The work [7] investigated the deformation of vertical thin-walled components by means of a calculation and experimental method. The experiment was carried out on a one type of end mill.

Among the broad spectrum of titanium alloys, Ti6Al4V is commonly used for thin-walled aerospace elements [11,12]. This material is used for both the aircraft construction and the engine or the turbines [13]. Ti6Al4V is a highly machinable alloy and ensures a high stiffness of the construction [14].

The main problem encountered during milling is the tendency of the chip to flood the cutting edge [12]. Hindering factors are low thermal conductivity and diffusion capability, high material stiffness and low modulus of elasticity, high chemical reactivity at elevated temperatures [15].

2. MATERIALS AND METHODS

A series of six samples was prepared using *Mikron VCE 600 Pro* milling center manufactured by *GF Machining Solutions* with *iTNC 530* control software developed by *Heidenhain*. Experimental setup was shown in figure 1. The tools were mounted in a holder *ER32* and all samples were set in a special adapter.

Fig. 1. Experimental setup.

The samples were machined using three different coated monolith end mills, manufactured by *SECO Tools*, intended for machining titanium alloys. In this study the samples were prepared under controlled conditions, with constant process parameters such as feed rate *f*, cutting speed V_c, rotating speed *n*.

The values of those parameters for the sample are included in table 1 and the tools applied to the experiment in table 2.

Table 1

The process parameters using in experiment.

f [mm/min]	V_c [m/min]	*n* [rpm]
255	100	3183

Table 2

The tools using in the experiment.

Indica-tor	Tool 1	Tool 2	Tool 3
Tool designation	JSE514100 D2C.0Z4 SIRA	JHP770100E2 R040.0Z4A-SIRA	JH730100D2 R100.0Z7-HXT
Tool description	General Purpose Solid Carbide End Mills	High Performance Machining Solid Carbide End Mills	High Speed Machining Solid Carbide End Mills
Cutting diameter	10 mm	10 mm	10 mm
Cutting item coating	SIRON-A	SIRON-A	HXT
Face cutting edge count	4	4	7
Flute helix angle	35°	42°	34°

Table 3

The description of the samples with their strategies and tools.

Sample	Strategy	Tool	a_p [mm] and number of passes	a_e [mm] and number of passes
T1	adaptive milling with increased radial depth a_e	Tool 1	2 mm 3 passes	4 mm 1 passe
T2		Tool 2		
T3		Tool 3		
T4	adaptive milling with increased cutting depth a_p	Tool 1	6 mm 1 passe	0.5 mm 8 passes
T5		Tool 2		
T6		Tool 3		

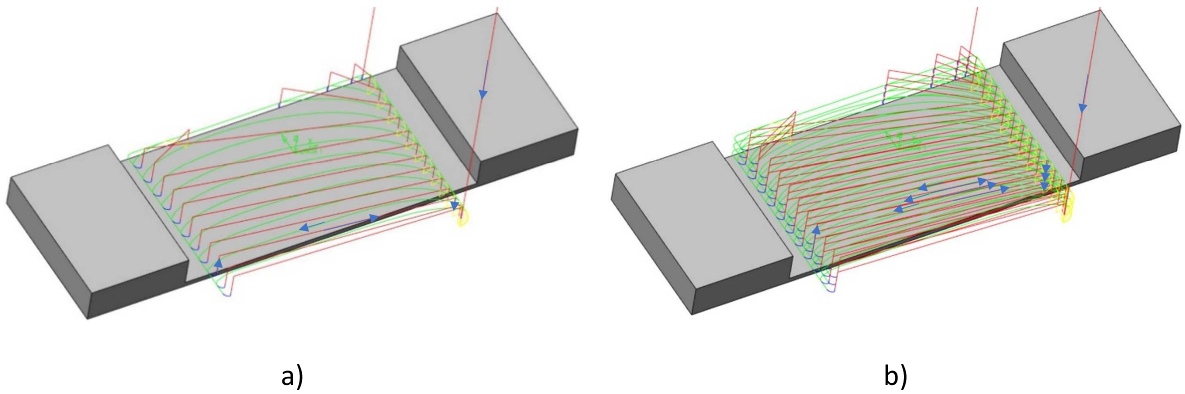


Fig. 2. The tool paths of adaptive milling:
a) with increased radial depth a_e, b) with increased cutting depth a_p

The samples were prepared with three different tools and various depth of cut a_p, radial depth a_e with adaptive milling strategies. Table 3 gives a description of the samples with their strategies and tools.

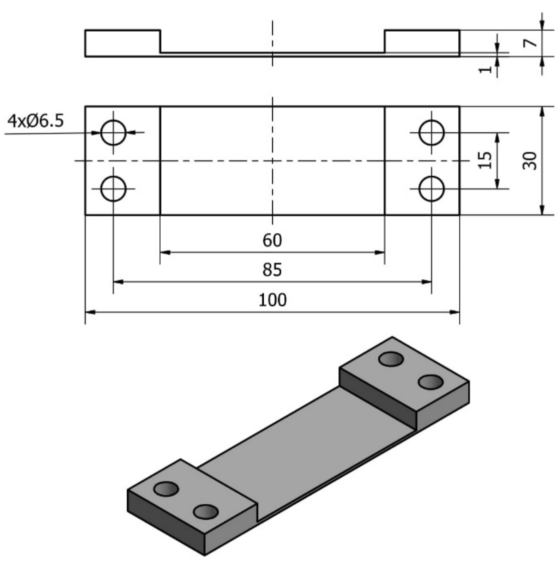


Fig. 3. The documentation and 3D projection of the sample with horizontal thin wall.

Two strategies were used for the adaptive milling - with increased radial depth a_e (Fig. 2.a) and with increased cutting depth a_p (Fig. 2.b). The tool paths are shown in figure 2 and were generated in *NX Unigraphics*.

The results of experiment are comparable by applying a constant material removal rate (MRR = 2.03 cm^3/min).

The machining of the samples was carried out with using emulsion cooling. The samples were machined according to the documentation shown in figure 3.

A semi-finished products had been a blank of sized 7 x 30 x 100 mm with mounting holes for screw adapter M6.

The dimension of thin-walled wall of the sample was 1 mm and machined on the 30 x 60 area.

The material used in this research was titanium alloy Ti6Al4V (grade 5), which a chemical composition is shown in table 4. This material was chosen because of its widespread application and the difficulty of processing in the aerospace industry.

Table 4

The chemical composition of Ti6Al4V.

Element	Al	Fe	O	V	Ti
Percentage [%]	6	0.25	0.2	4	the rest

The surface quality, included parameters such as waviness (W_a) and roughness (R_a), were measured using the contact profilometer *TOPO 01P* in accordance with *ISO 25178-2*.

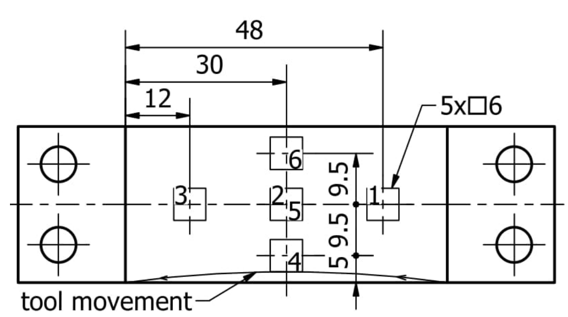


Fig. 4. The measuring points and their position on the machined surface.

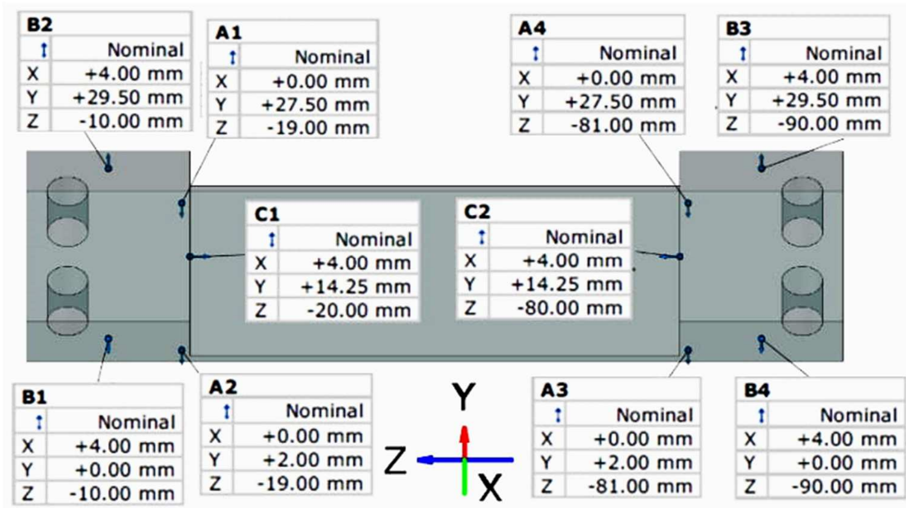


Fig. 5. The reference point of the measurement of shape deviations.

The five measuring area (in Fig. 4. marked with 1-6, where the areas 2 and 5 are common) and their position on the machined surface are shown in figure 4.

For each selected area, 13 profiles with a distance of 500 µm of 6 mm length were measured with off-set 1 µm and a measuring speed equal 0.5 mm/s.

The dimensional and shape accuracy was tested using the optical measuring machine *ATOS ScanBox 6130*. On the basis of the report, diagrams of the deflection arrows after milling were drawn up.

The reference points of the measurement of the shape deviations by the optical method are shown in figure 5.

3. RESULTS AND DISCUSSIONS

3.1 Surface topography analysis

The results of the topography measurement are waviness and roughness diagrams in the individual areas (see Fig. 4).

The results of measurements are graphically presented in figure 6 and figure 7.

The waviness/roughness values at the individual measuring points are given (see Fig. 4). Each of the diagrams shown, as described in table 3.

Based on the values of waviness and roughness in the selected areas, the average values of the sample (see marking in Table 3.) were determined (Fig. 8.).

It is striking that the most advantageous roughness was achieved for the high-performance machining solid carbide end mill.

The adaptive milling with a lower cutting depth has also had a positive effect on the surface topography.

The lowest average roughness was achieved for the adaptive milling with increased cutting depth of the machining tool at 0.37 µm, and the highest average roughness was achieved for the adaptive milling with increased radial depth with the universal machining tool and it is assumed 0.89 µm.

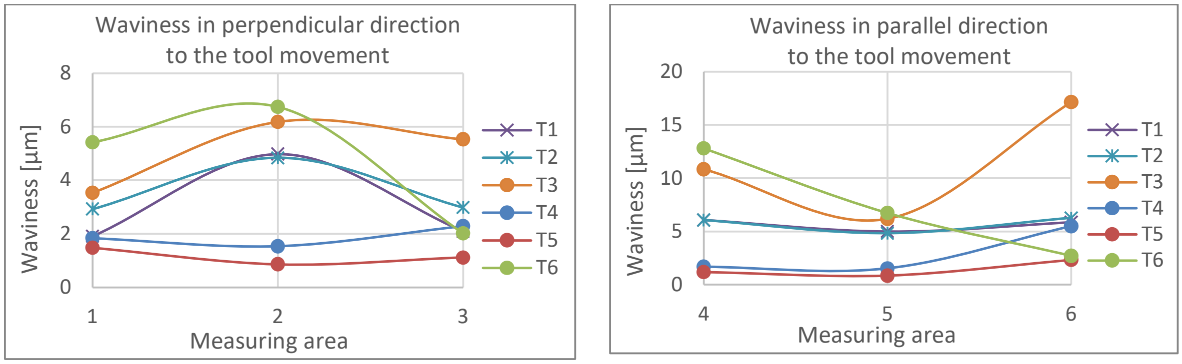
3.2 Dimensional and shape accuracy analysis

The deflection arrows were determined in 2 cross-sections with *GOM Inspect 2021* software – perpendicular and parallel to the main direction of the end mill.

The deflection arrows were measured in ½ - length and width of the machined area. A description of surfaces of the sample is shown in figure 9.

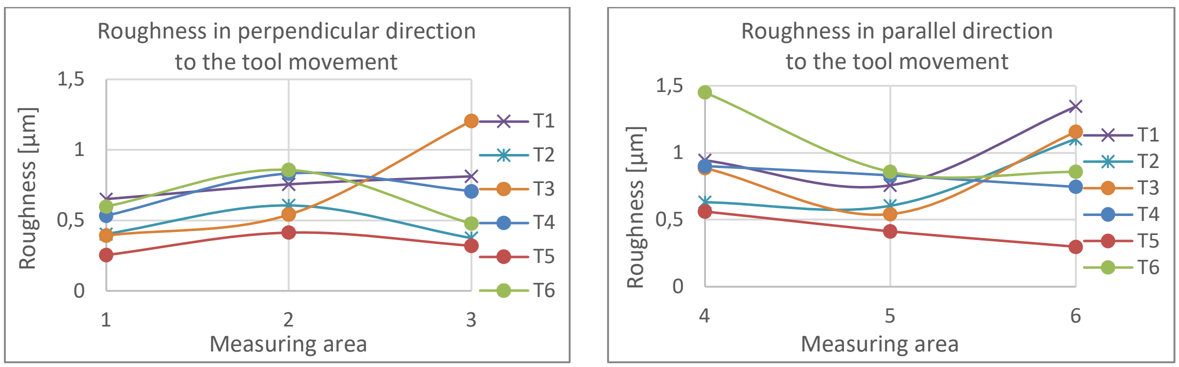
On the basis of the report, the diagrams of the deflection arrows were created (Figure 10). Designation of diagrams in accordance with Table 3.

The use of tools for universal and performance machining do not significantly affect shape deviations.



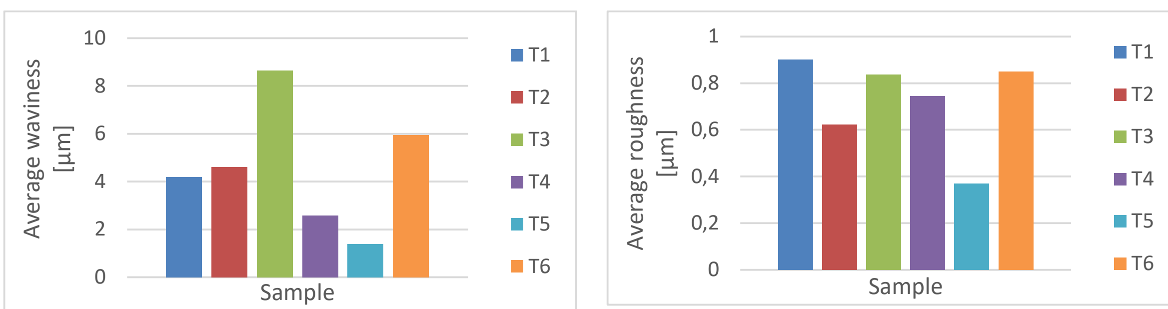
a) b)

Fig. 6. The comparison of experimental results for waviness W_a: a) in perpendicular direction to the tool movement, b) in parallel direction to the tool movement.



a) b)

Fig. 7. The comparison of experimental results for roughness R_a: a) in perpendicular direction to the tool movement, b) in parallel direction to the tool movement



a) b)

Fig. 8. The average values of the samples: a) waviness, b) roughness.

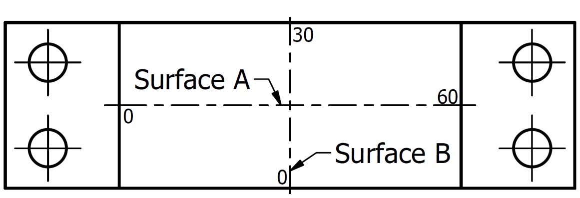
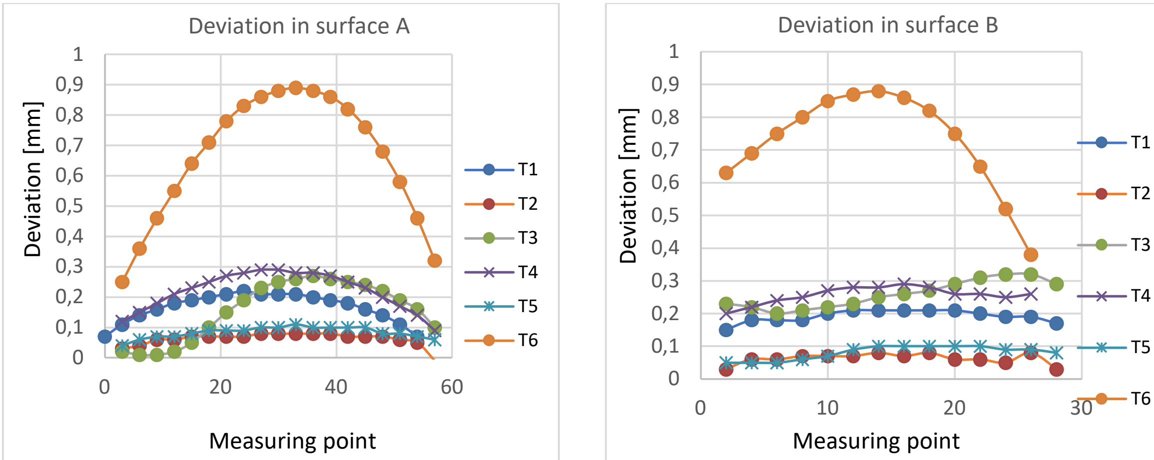


Fig. 9. The surface description used to determine the deflection arrows.

The situation is different with end mill for high-speed machining, where the strategy (despite the constant material removal rate) has a significant influence on the accuracy of the surface to be machined.



a) b)

Fig. 10. The deflection arrows: a) surface A, b) surface B.

The higher cutting depth led to up to $3x$ larger shape deviations.

For reasons of a tolerance, the maximum deviations for the individual samples are presented in figure 11. The smallest dimensional deviations were achieved, similar to the surface topography for milling tool for performance machining.

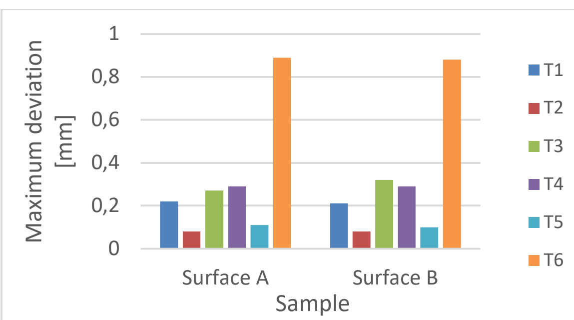


Fig. 11. The maximum deviations for the individual samples.

4. CONCLUSION

In this study, a series of samples with constant process parameters and various cases of adaptive milling was prepared and measured with respect to the surface topography and dimensional deviations from a reference model. The experiment led to a few of conclusions, which are listed below.

Based on the surface quality, it is possible to give following conclusions:

- Waviness and roughness depend on the cutting depth. The parameters of the surface topography are higher for larger radial depth.
- The choice of tool has a significant impact on the surface topography. The most favourable topography has been achieved for the high-performance machining solid carbide end mill.
- The parameters of the surface topography are variable depending on the test area – they are not constant over the entire surface processed.

The deviation measurements using GOM have shown that the lowest deformation was achieved for high performance machining solid carbide end mill (0.1 mm) and the highest deformation for high-speed machining solid carbide end mill (0.89 mm).

It can be concluded that the geometry of the cutting tool has a significant influence on the dimensional accuracy of the workpiece.

The results of the surface topography and the deflection arrows do not show a clear correlation between these parameters.

On the one hand, the lowest roughness and dimensional deviation are observed for the both adaptive milling strategies using high performance machining end mill, on the other hand, the roughness is highest for using tool for general purpose.

According to the deviation diagrams, it might appear that the highest roughness should be for high-speed machining end mill.

More measurements would have to be made in order to draw a clear conclusion on the correlation.

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EFECTELE UNOR CARACTERISTICI ALE SCULEI ȘI ALE FREZĂRII ADAPTIVE ASUPRA TOPOGRAFIEI SUPRAFEȚEI ȘI PRECIZIEI DIMENSIONALE A PIESELOR CU PEREȚI SUBȚIRI DIN TI6AL4V

Industria aerospațială caută modalități de a reduce greutatea elementelor constructive. Acesta este motivul pentru care s-a extins utilizarea pieselor cu pereți subțiri. Una dintre principalele probleme în prelucrarea componentelor cu pereți subțiri este deformarea elastică a peretelui, care conduce la deformații și, astfel, la abateri geometrice și la o înrăutățire a calității piesei obținute. În lucrare, a fost determinată influența frezării adaptive și a unor caracteristici ale sculei asupra topografiei suprafeței și asupra preciziei dimensionale a componentelor cu pereți subțiri. Epruvetele pentru încercările cu valori constante ale parametrilor de așchiere au fost realizate dintr-un aliaj de titan Ti6Al4V, folosind freze convenționale, respectiv freze speciale pentru așchiere cu viteze mari și pentru prelucrări de înaltă performanță. Pe baza rezultatelor experimentale, au fost determinate mărimile ondulațiilor, ale rugozității și ale abaterilor dimensionale (folosind un scaner optic GOM) ale suprafețelor prelucrate.

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