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# INFLUENCE OF END MILL HELIX ANGLE ON SURFACE QUALITY OF ALUMINIUM THIN-WALLED PARTS

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## Abstract

*This paper deals with the influence of the end mill helix angle on the flatness and surface quality of aluminium (EN AW 6082) thin-walled parts. The three teeth solid end mills of 12 mm diameter with same and different helix angle of third tooth were designed. The tests were performed using the HSC 105 linear CNC machine and following cutting parameters: cutting speeds (800, 100 and 1200 m.min$^{-1}$), feed per tooth (0.12 mm), cutting depth (for roughing 10 mm and for finishing 5 mm). Evaluation of surface quality of the processed thin-walled parts shows that the helix angle of the end mills has a significant influence on the surface quality of the thin-walled parts. The best results were obtained in the case of end mill with different 35° helix angle of third tooth and cutting speed 1000 m.min-1.*

## Key words

*Milling, helix angle, aluminium thin-walled parts, 3D scanning, colour deviation map, flatness*

## INTRODUCTION

Thin-walled parts are widely used in the aviation, aeronautics, automotive and energetic industry. Due to the shape and low rigidity the thin-walled parts can be easily deformed during the milling process (1). The feature of a thin-walled part is to change the workpiece dynamic structure due the change in its geometrical shape. The challenge is in the creation of thin-walled sections. During the machining process, the workpiece undergoes deflection due the application of external forces caused by milling process (2).

For milling of thin walled parts, High Speed Cutting (HSC) is the most widened technology. A thin-walled part has lower thickness than height (3). During milling of thin-walled parts regenerative chatter vibrations are generated. The chatter is one of the major limitations in milling operations causing poor quality, reduced productivity (4). The regenerative chatter vibrations can be eliminated in several ways. The first way is the use of

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stability lobes diagrams to predict the regenerative chatter in milling (5, 6). The second way is the appropriate machining strategy (material removal way) of the thin-walled parts. An effective machining strategy has a significant impact on the surface quality of the thin-walled parts (7, 8). The third way is the use of end mills with variable pitch (9, 14, 15) and variable helix angle (4). The fourth method is the use of the sandwich elements (10, 13) or the use workpiece or tool support (11). In this paper, the effect of the end mill helix angle on the flatness and surface quality of aluminium (EN AW 6082) thin-walled parts was studied.

## MATERIALS AND METHODOLOGY OF EXPERIMENTS

Three solid end mills with regular pitch were designed using Numrotoplus software. Table 1 shows designed parameters of end mills and Fig. 1 shows CAD model of designed mill. The difference between each designed end mill was that the third tooth of each end mills has different helix angle. So that the one end mill of 30° helix angle for all three teeth was designed and further two end mills were designed where helix angle of third tooth was 25° and 35°, respectively. By variation of the third teeth helix angle the position of third cutting edge varies in regard of the distance from the tip of end mill (Fig. 2). For keeping same cutting edges width and clearance land width the parameters of flutes and reliefs were adjusted based on 2D and 3D simulation of Numrotoplus software. The end mills were made of cemented carbide of K20 grade and they were manufactured using WZS 60 Reinecker CNC grinding machine.

**Table 1:** Parameters of designed end mills

| **Parameter of end mill** | **Value** |
|---|---|
| Diameter - $dm_m$ | 12 h6 mm |
| Diameter - $D_c$ | 11.95 mm |
| Diameter- $D_n$ | 11 mm |
| Length - $l_2$ | 82.5 mm |
| Length - $l_3$ | 45 mm |
| Max. depth of cut - $a_{pmax}$ | 20 mm |
| Pitch and division angle | 120 – 120 – 120° |
| Teeth number - z | 3 |
| Helix angle | 30° – 30° – 30° |
| | 30° – 30° – 25° |
| | 30° – 30° – 35° |
| Rake angle | 10° |
| Relief angle | 10° |

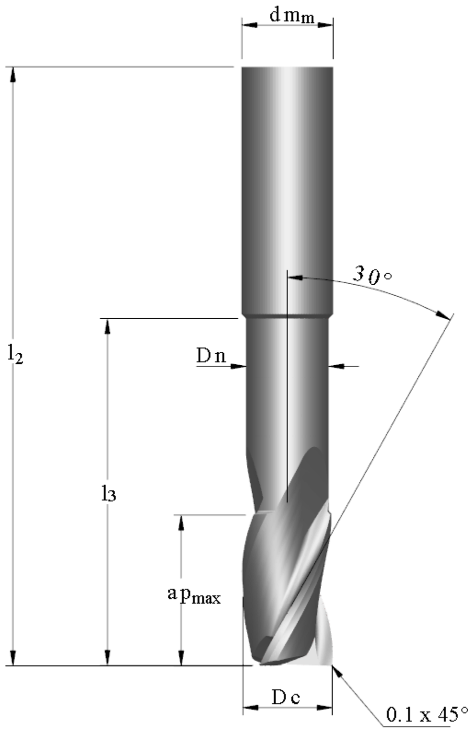


***Fig. 1*** *CAD model of designed end mill*

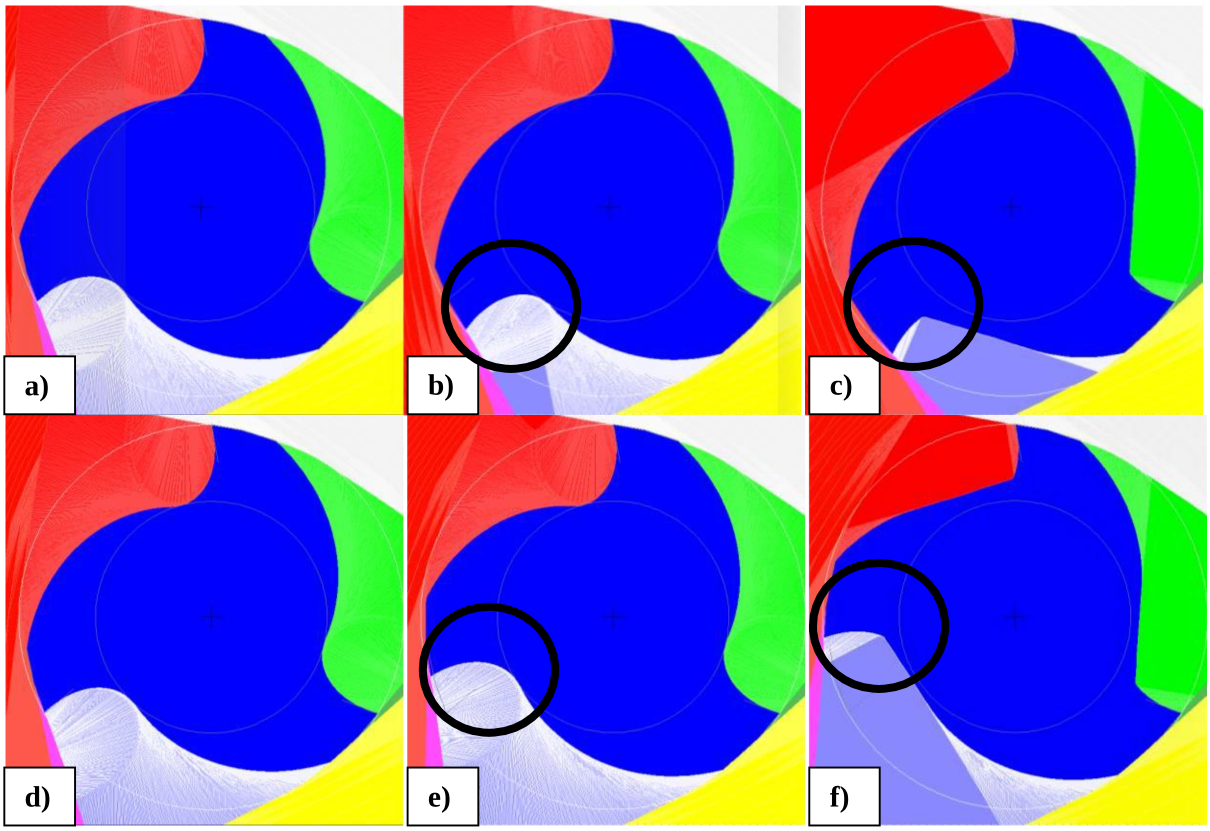


***Fig. 2*** *Cross sections of end mill with 25° helix angle of third tooth in 2D simulation 0.1 mm (a), 10 mm (b) and 20 mm (c) from the tip; cross sections of end mill with 35° helix angle of third tooth in 2D simulation 0.1 mm (d), 10 mm (e) and 20 mm (f) from the tip*

The workpiece material was EN AW 6082 aluminium alloy. Tables 2 and 3 show the chemical composition and physical-mechanical properties of EN AW 6082 alloy. It is known that the machinability of the material is good. The blank dimensions were 80 x 80 x 10 mm. Fig. 3 shows clamping of the blank in the machining vice. The overhang of the blank was 56 mm.

**Table 2:** Chemical composition of EN AW 6082

| Chemical Element | % Present |
|---|---|
| Manganese (Mn) | 0.40 - 1.00 |
| Iron (Fe) | 0.0 - 0.50 |
| Magnesium (Mg) | 0.60 - 1.20 |
| Silicon (Si) | 0.70 - 1.30 |
| Copper (Cu) | 0.0 - 0.10 |
| Zinc (Zn) | 0.0 - 0.20 |
| Titanium (Ti) | 0.0 - 0.10 |
| Chromium (Cr) | 0.0 - 0.25 |
| Other (Each) | 0.0 - 0.05 |
| Other (Total) | 0.0 - 0.15 |
| Aluminium | Balance |

**Table 3**: Physical and mechanical properties of AW 6082

| Property | Value |
|---|---|
| Density | 2.70 g/cm³ |
| Melting Point | 555 °C |
| Thermal Expansion | 24 x10^-6 /K |
| Modulus of Elasticity | 70 GPa |
| Thermal Conductivity | 180 W/m. K |
| Electrical Resistivity | 0.038 x10^-6 Ω .m |
| Density | 2.70 g/cm³ |
| Melting Point | 555 °C |
| Thermal Expansion | 24 x10^-6 /K |
| Proof Stress | 255 Min MPa |
| Tensile Strength | 300 Min MPa |
| Elongation A50 mm | 9 Min % |
| Hardness Brinell | 91 HB |

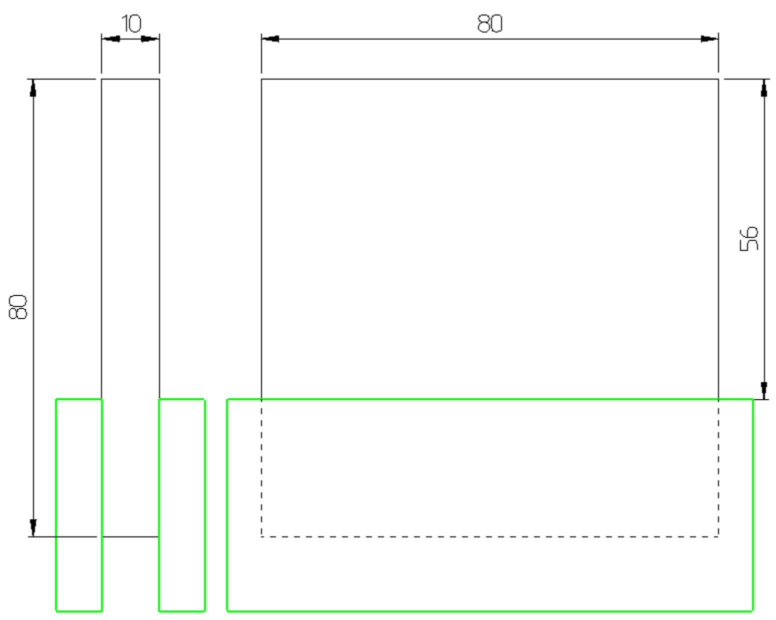


***Fig. 3*** *Drawing of the blank (black colour) and the clamping jaws (green colour)*

The thin-walled parts were milled only from one side. Figure 4 shows the final shape of the thin-walled part after milling.

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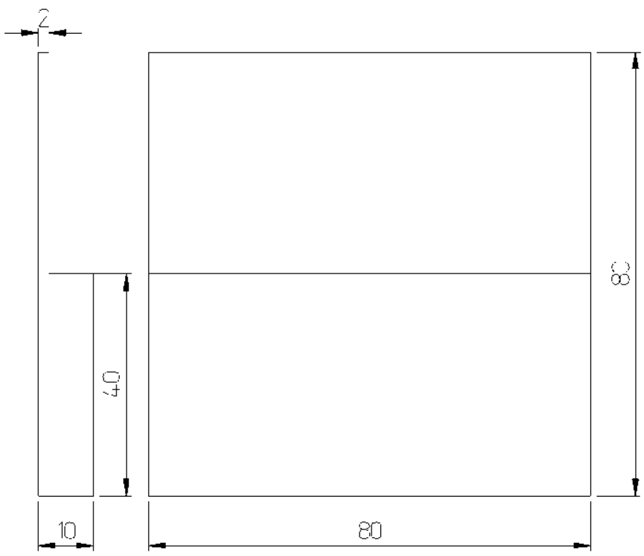


***Fig. 4*** *Final shape and dimensions of thin-walled parts after milling*

The experiment was carried out using HSC 105 linear CNC 5-axis machine. Table 1 shows the machining parameters used in the experiment. The cutting zone was cooled by cold compressed air.

**Table 4**: Machining parameters

| **Parameters** | **Value** |
|---|---|
| Cutting speed – $v_c$ | 800, 1000, 1200 $m.min^{-1}$ |
| Frequency - n | 21221, 26526, 31831 $min^{-1}$ |
| Feed per tooth - $f_z$ | 0.12 mm |
| Deep of cut, roughing - $a_p$ | 10 mm |
| Deep of cut, finishing - $a_p$ | 5 mm |
| Width of cut, roughing - $a_e$ | 3, 2.5, 1.5 mm |
| Width of cut, finishing - $a_e$ | 0.5, 0.5 mm |

The progressive radial depth of cut (RDOC) strategy was used (Fig. 5). The method of material removal according to RDOC is usually used for milling of parts with medium height and thickness ratio <30:1. For the studied samples, the ratio was 20:1. Toolpaths and NC programs were generated using Autodesk PowerMILL software.

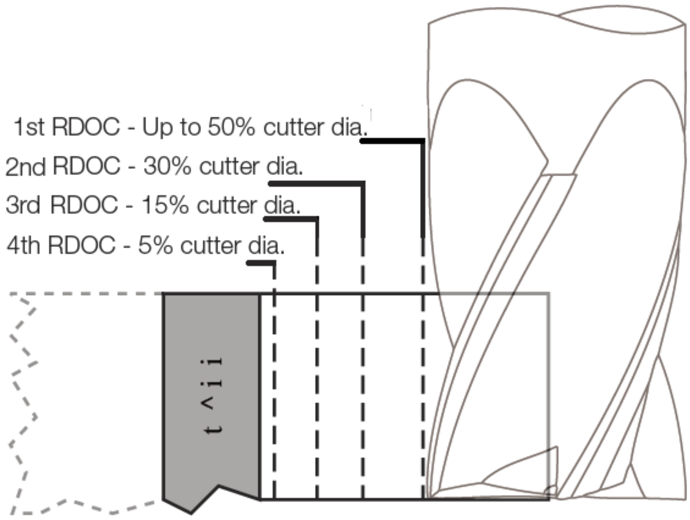


***Fig. 5** RDOC milling strategy (12)*

The surface quality and flatness were measured by GOM Atos II TripleScan optical 3D scanner. The measuring volume MV 170 (170 x 130 x 130) was used for scanning the aluminium thin-walled parts. The chalk spray was applied to eliminate shiny surface. Surface quality was evaluated by the colour deviation maps and flatness. Fig. 6 shows the method of evaluation of the surface quality, which is based on surface comparison (CAD model vs. 3D Scan). That method was completely described in the following paper (8).

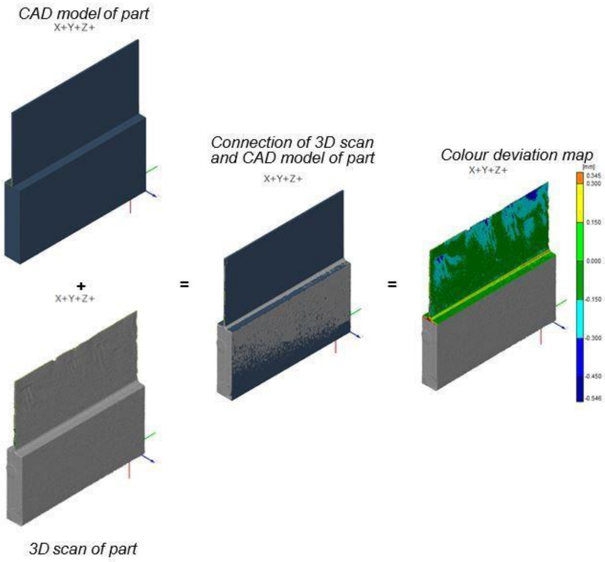


***Fig. 6** Scheme of colour deviation map development (8)*

## RESULTS AND DISCUSSION

The machined surface of thin-walled parts can be seen in Fig. 7. In the case of workpieces, which were milled using end mill with constant 30° helix angle for all three teeth (Fig. 7a-c) the tool marks are visible. The significant tool marks can be seen mainly when the higher cutting speeds were used, specifically1000 and 1200 m.min$^{-1}$.

The thin walled workpieces which were machined using end mills with adjusted helix angle of third tooth, the finer surface and smaller tool marks are visible (Fig. 7 d-i) in compared with surface milled by end mill with constant helix angle. In this case the using of cutting speeds 1000 and 1200 m.min$^{-1}$ do not affected size of tool marks after milling, so that it is possible to use higher cutting speed in milling using end mill with different helix angle without decrease of the surface quality of aluminium thin walled parts.

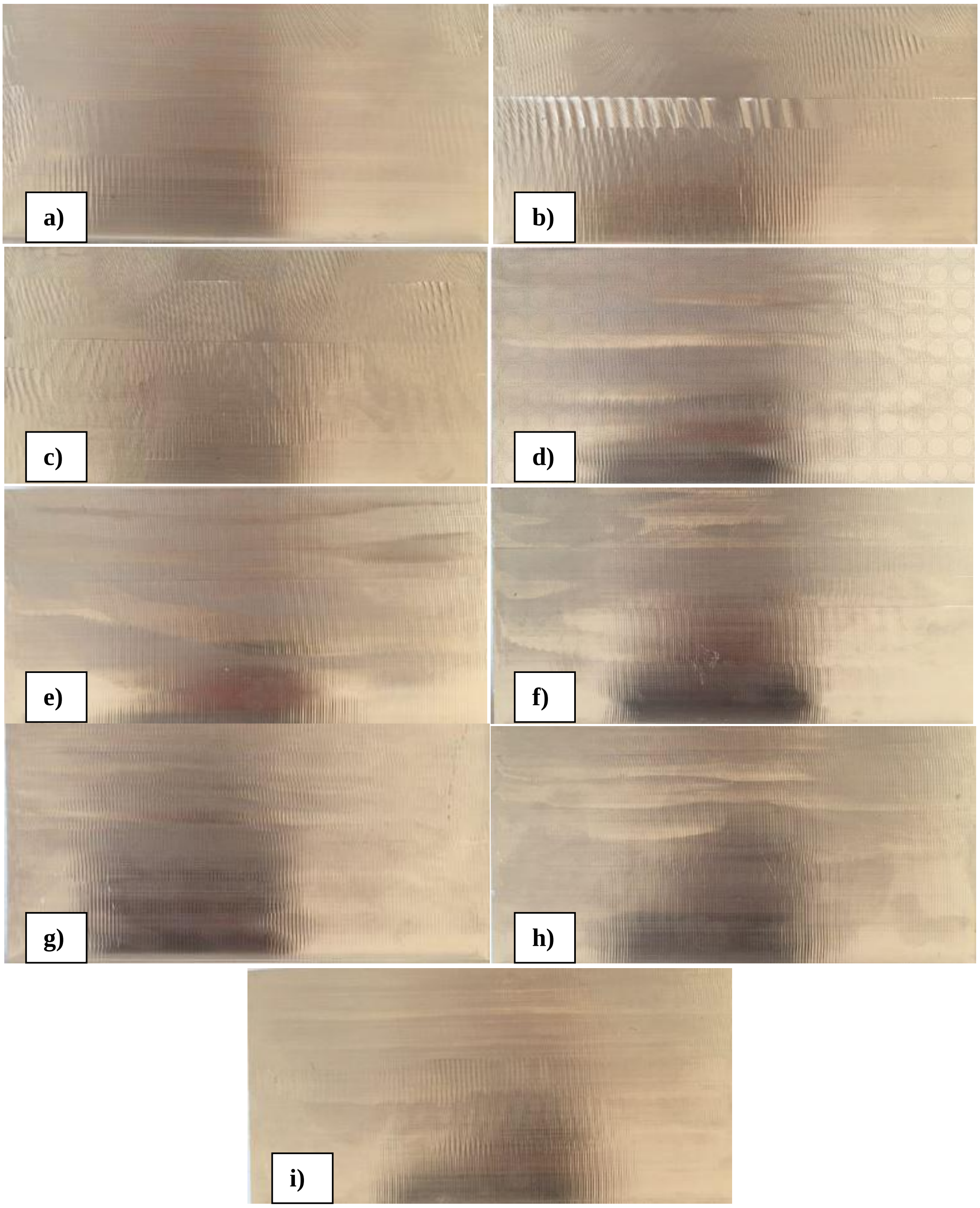


***Fig. 7*** *Machined surface of thin walled part after milling using end mill 30° and cutting speed 800 m.min$^{-1}$ (a), 1000 m.min$^{-1}$ (b) 1200 m.min$^{-1}$ (c); using end mill with 25° helix angle of third tooth and cutting speed 800 m.min$^{-1}$ (d), 1000 m.min$^{-1}$ (e) 1200 m.min$^{-1}$ (f); using end mill with 35° helix angle of third tooth and cutting speed 800 m.min$^{-1}$ (g), 1000 m.min$^{-1}$ (h) 1200 m.min$^{-1}$ (i)*

Figs. 8-16 show colour deviations maps between a 3D scan of the machined thin walled parts and a 3D CAD model. The surface quality was evaluated by colour deviations maps and flatness of thin wall. Table 5 shows flatness of thin-walled parts. Colour deviations maps in Figs. 8-10 show that the use of end mill with constant 30° helix angle in the milling of thin walled parts causes significant surface deviations which are even larger using higher cutting speeds 1000 and 1200 m.min$^{-1}$.In the case of using end mill with constant helix angle, the deviations and flatness were the smallest at cutting speed 800 m.min$^{-1}$, which is in accordance with well-known theory that in the milling of thin walled parts it is suitable to use lower cutting speed.

The colour deviations maps when end mills with different helix angle was used is showed in Fig. 7-12 and it shows significant decrease of surface deviations and flatness in compared with use end mill with constant helix angle, what can be even 50% in some cases. Simultaneously, the increase of cutting speed causes only minor increase of surface deviations and even using end mill with 35° helix angle of third tooth and cutting speed 1000m.min$^{-1}$ the best result were obtained, which means the deviations between 3D scan of machined parts and 3D CAD model were the smallest and the flatness was 0.06 mm. It follows that the use of end mills with different helix angle can significantly improves surface quality of thin walled part even at use of the higher cutting speed.

**Table 5:** Flatness of thin-walled parts

| **Cutting speed and Helix angle** | **Flatness** |
|---|---|
| 800 m.min$^{-1}$ – 30° | 0.,20 |
| 1000 m.min$^{-1}$ – 30° | 0.28 |
| 1200 m.min$^{-1}$ – 30° | 0.24 |
| 800 m.min$^{-1}$ – 25° | 0.10 |
| 1000 m.min$^{-1}$ – 25° | 0.15 |
| 1200 m.min$^{-1}$ – 25° | 0.16 |
| 800 m.min$^{-1}$ – 35° | 0.10 |
| 1000 m.min$^{-1}$ – 35° | 0.08 |
| 1200 m.min$^{-1}$ – 35° | 0.13 |

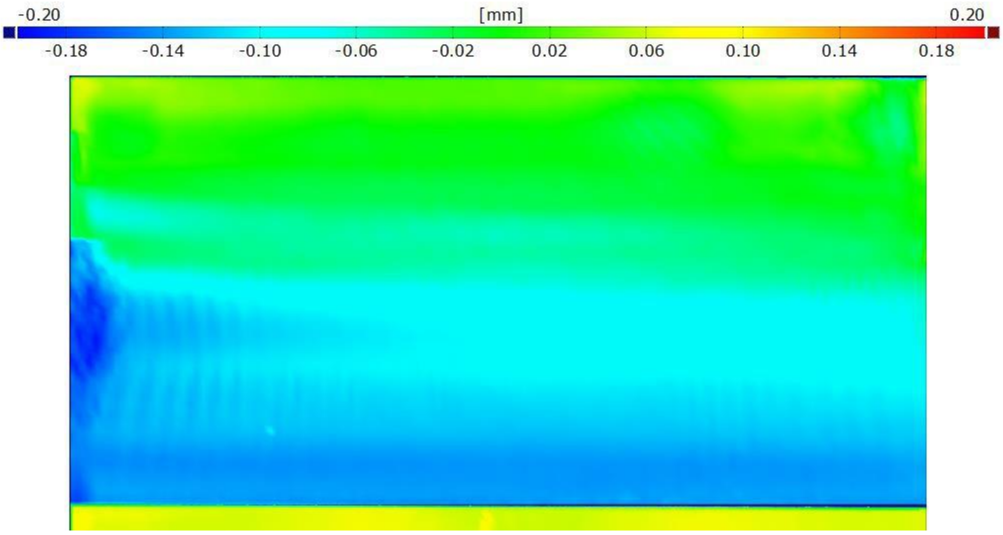


***Fig. 8*** *Colour deviation map for D12-30°, $v_c$ = 800 m.min$^{-1}$*

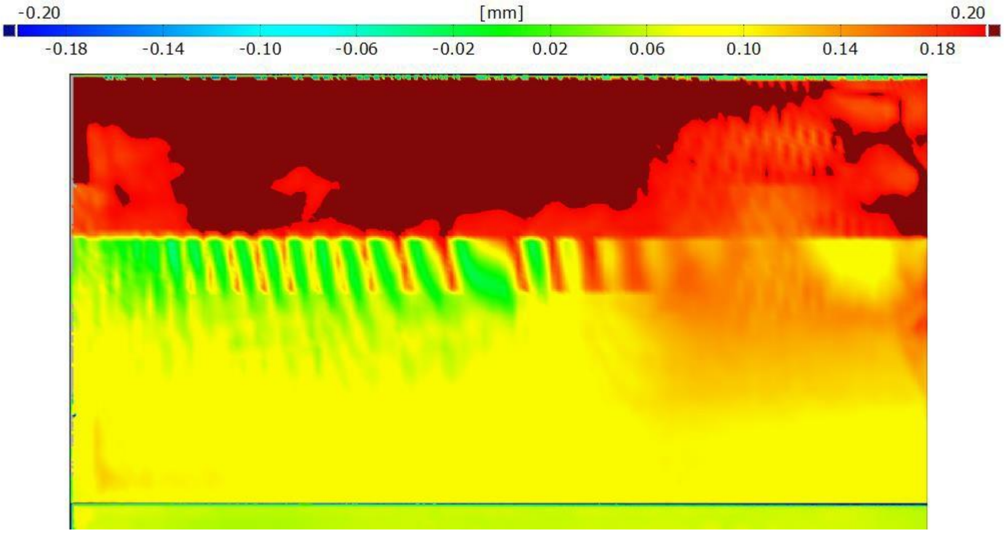


***Fig. 9*** *Colour deviation map for D12-30°,* $v_c$ *= 1000 m.min*$^{-1}$

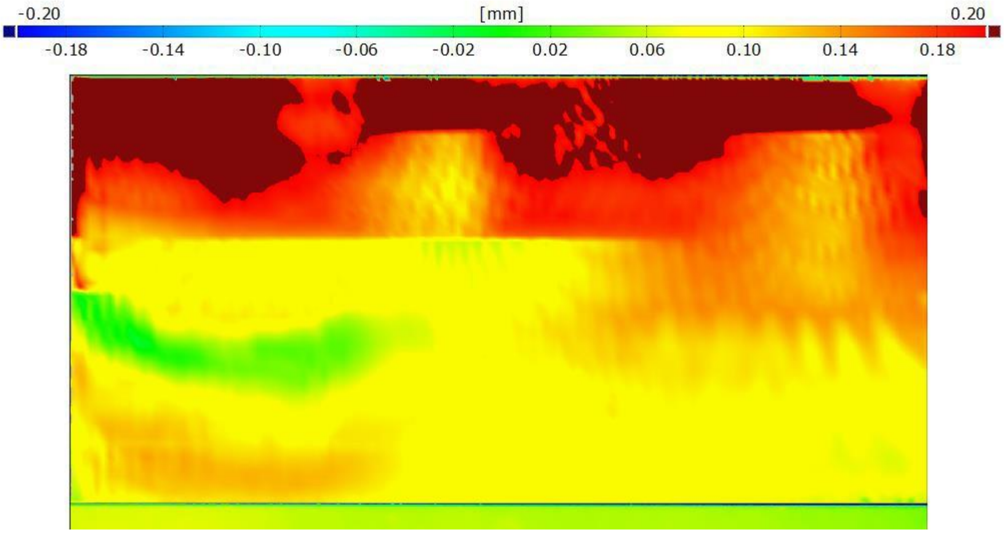


***Fig. 10*** *Colour deviation map for D12-30°,* $v_c$ *= 1200 m.min*$^{-1}$

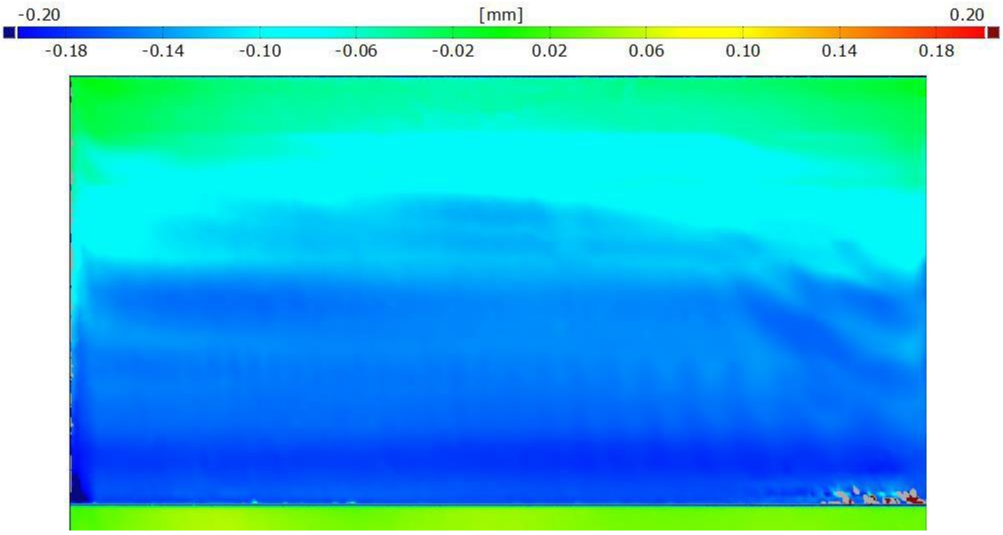


***Fig. 11*** *Colour deviation map for D12-25°,* $v_c$ *= 800 m.min*$^{-1}$

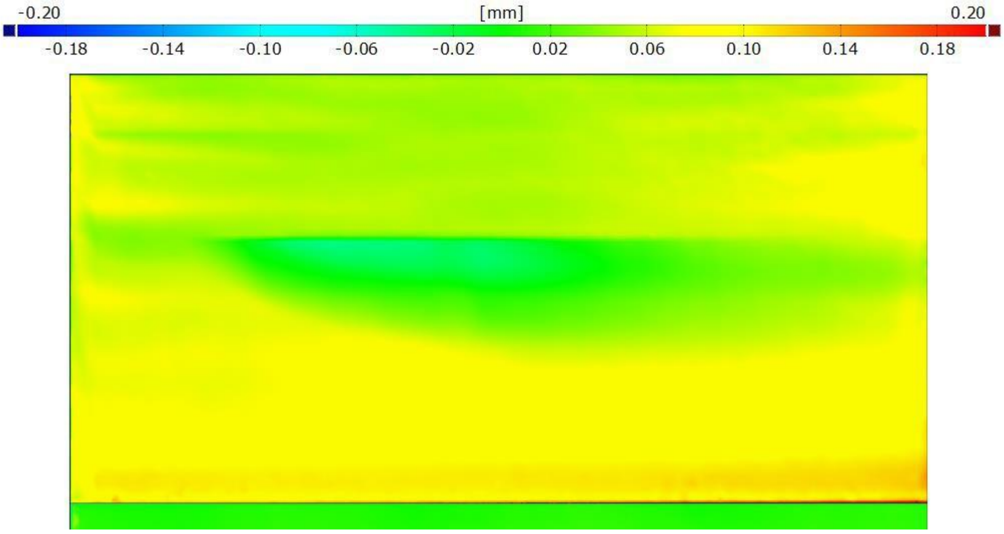


***Fig. 12** Colour deviation map for D12-25°, $v_c$ = 1000 m.min$^{-1}$*

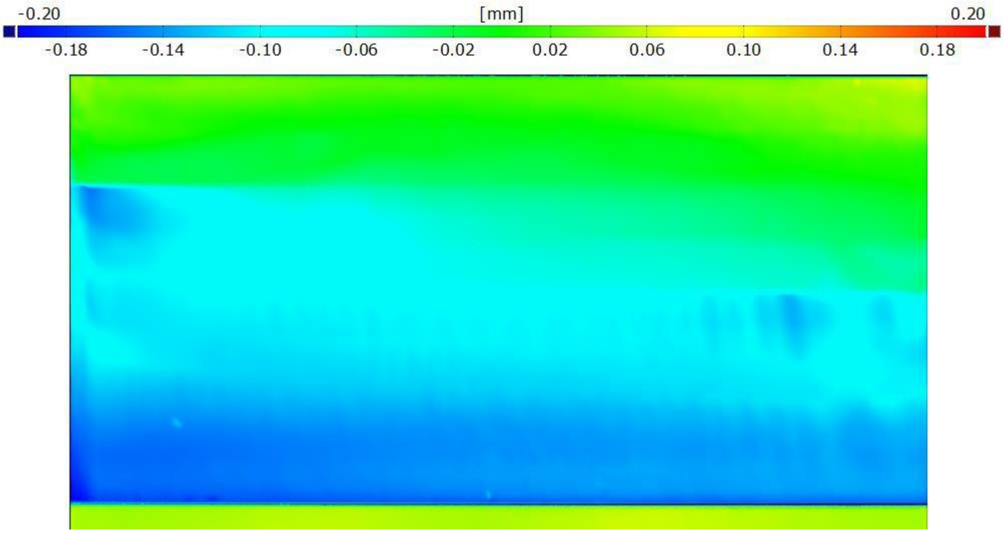


***Fig. 13** Colour deviation map for D12-25°, $v_c$ = 1200 m.min$^{-1}$*

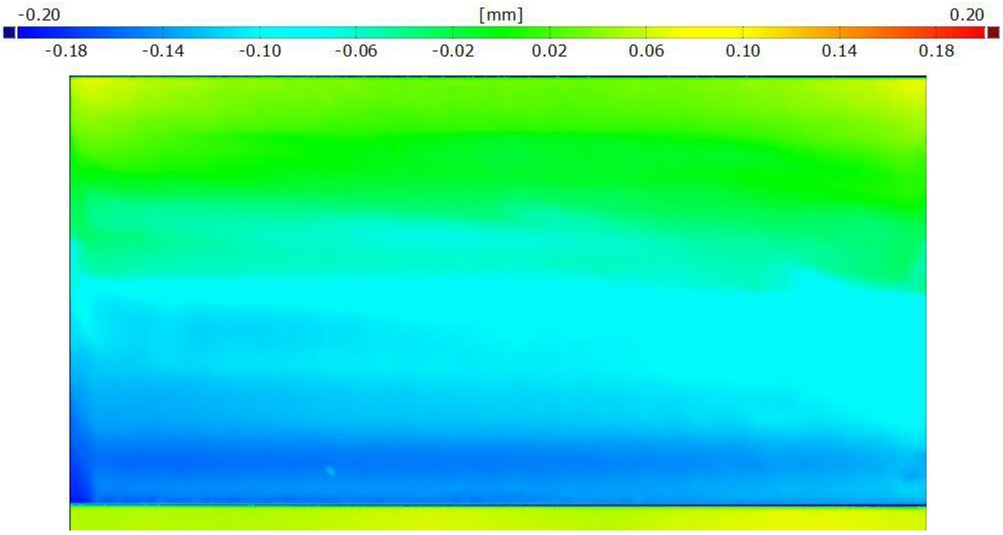


***Fig. 14** Colour deviation map for D12-35°, $v_c$ = 800 m.min$^{-1}$*

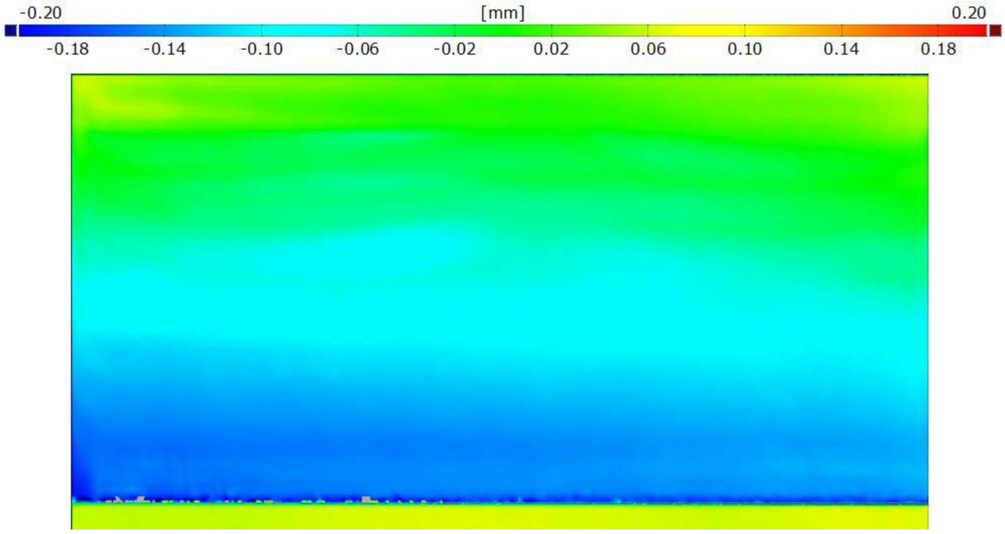


***Fig. 15*** *Colour deviation map for D12-35°,* $v_c$ *= 1000 m.min*$^{-1}$

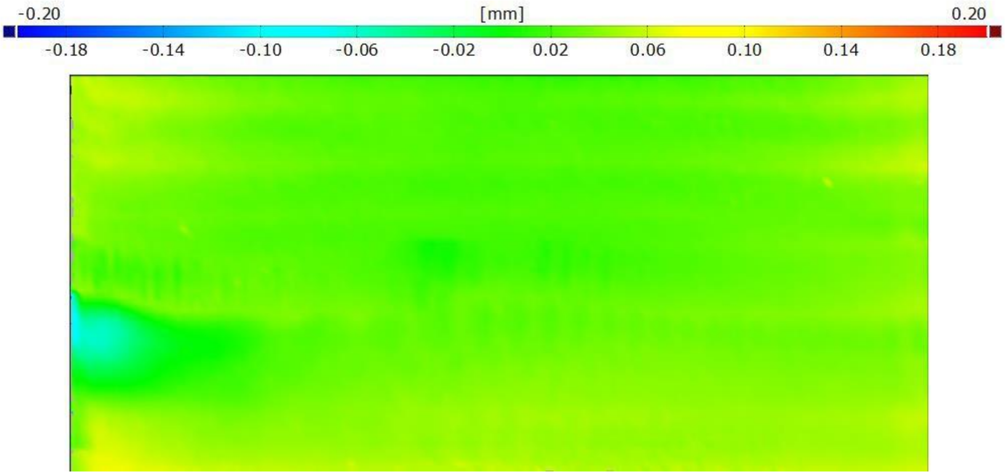


***Fig. 16*** *Colour deviation map for D12-35°,* $v_c$ *= 1200 m.min*$^{-1}$

## CONCLUSION

The present paper describes the influence of helix angle of the end mills on surface quality and flatness of the processed aluminium thin-walled parts. It was shown that the different helix angle of third tooth of end mill has significant influence on surface quality and flatness. Use of the end mills with previous mentioned design reduces the chatter during milling process of the thin-walled parts. The experiment proved that the use of lower cutting speeds during the machining led to the surface quality improvement of the thin-walled parts. However, the best results of flatness and surface deviations were obtained after milling by end mills of 35° helix angle of third tooth at higher cutting speed 1000 m.min$^{-1}$, so that based on the results in the case of end mills of different helix angle it is possible to increase cutting speed.


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