Machining of internal corners with a small fillet radius

Obróbka naroży wewnętrznych o małych rozmiarach promienia zaokrąglenia

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The paper presents practical effects of the combined drilling and milling operations to produce blind extensive hollows with small radius fillets.
KEYWORDS: drilling holes, milling, corners

Modern structures used in the aerospace industry tend to rely on thin-walled components with complex geometry pocket. Processing of these elements is difficult due to the presence of elastic and plastic deformation of the structure [3, 6].

In the case of cutting internal corners, a significant change can be made in the angle of belt wrapping with the workpiece due to the sudden change of the motion vector and to the resulting additional pressure on the tool. This can contribute to tool damage and vibration intensification. It is therefore recommended that the treatment proceeded inner corners at high speeds and by an appropriate strategy to reduce the cutting forces and thus the pressure and the deformation of the workpiece [2, 4, 5].

Unstable machining generates object-tool vibrations and deformation and tool life deterioration, which is a problem especially in the case of internal corner corners with a small rounding radius. The instability of the process results in: a decrease in execution accuracy, increased surface roughness, shape inaccuracies or radius of rounding, and damage to the workpiece surface [1, 5, 7].

One of the known ways of making inner corners is the combination of drilling and milling operations. This paper describes the use of this method to provide corners with a small radius of rounding in the flat, flat inner pocket.

Analysis of the state of knowledge confirms that at present, there are no effective methods of treatment of internal corners of small radius curves, thus taking this subject is justified both from a scientific and practical point of view.

Program and research methodology

The study involved the combination of drilling and milling operations to achieve the smallest rounding radius of the blinded corner, the flat inner pocket. First, hole of a small diameter was drilled in place of the sample by drilling and then milled together with the corner pocket cutter of a different or the same diameter as the drill bit used previously.

The aim of the study was to find the optimum ratio of cutting tool diameters (drills and milling cutters), allowing for the execution of an internal corner with a small rounding radius in the thin-walled element to achieve the smallest possible error in the drilling and milling area. Part of the experimental work was performed on a bench equipped with a vertical machining center FV-580A and measurements - laboratory microscope Keyence VHX-500.

Values of processing parameters for each operation are given in the table.

TABLE. Machining parameters values

Type of machining	⌀, mm	a_p, mm	v_c, m/min	f_z, mm/ /ostrze	n, obr/min
Coarse milling	6	5,00	100	0,05	5305
Drilling	2	1,00	15	0,02	2387
	2,5	1,25	15	0,03	1910
	3	1,50	15	0,03	1592
	3,5	1,75	15	0,04	1364
	4	2,00	15	0,04	1194
	4,5	2,25	15	0,05	955
	5	2,50	15	0,05	955
	5,5	2,75	15	0,06	868
Milling corners, milling finishing the walls	2	5,00	50	0,02	7958
	3	5,00	50	0,02	5305
	4	5,00	50	0,02	3979
	5	5,00	50	0,02	3183
	6	5,00	50	0,02	2653

Explanation of symbols: ⌀ – tool diameter, a_p – depth of cut, v_c – cutting speed, f_z – feed on the blade, n – rotation speed

The coarse milling was done with a Ø 6 SGS T8876TB triaxial milling cutter. Borehole drilling operations in the corners were performed using the "Baildon Drill" drill bits with diameters Ø 2 ÷ 5.5 mm (graduated in 0.5 mm increments). Gühring tools were used for the milling of the corners and walls. Double-headed center cutters Din 6627L R-N 3154, carbide-tipped, with diameters in the range of Ø 2 ÷ 6 mm (1 mm). In the experiment, five aluminum alloy AW2024T351 alike samples were used, measuring 80 ×

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27 × 20 mm. Two rectangular pockets with a depth of 5 mm and a wall thickness of 1 mm and eight corners were used in each sample - drill bits and cutters of different diameters were used to find the optimal ratio of the drill bit to the cutter diameter. Fig. 1 shows the geometry of one of the samples after the roughing.

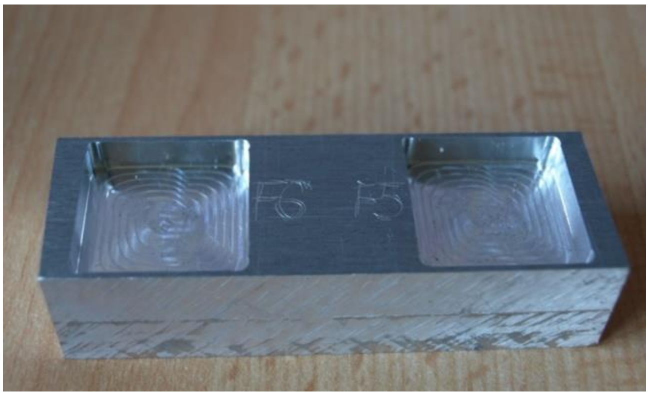


Fig. 1. Sample after roughing - the photo shows different radii of passage in the inner pockets.

Experiment procedure

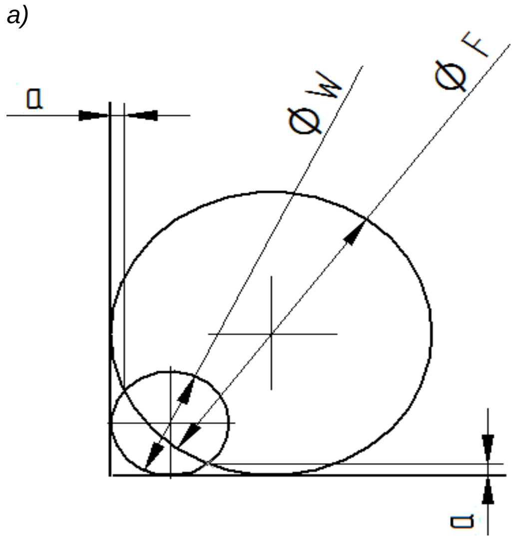
During the experiment, 40 possible relations diameter drills and milling cutters were tested. Given the diameters of the drill bits (Ø 2 ÷ 5.5 mm by 0.5 mm) and the cutters (Ø 2 ÷ 6 mm 1 mm), three cases were considered:

Ø drill bit < Ø milling cutter (fig. 2a) - corner radius here was the radius of the drill bit and the cutter, due to its larger size, cut to the limit of the feed path through the sample walls. This configuration of tools was conducive to the formation on both sides of the corner of the so-called *the tooth* (parameter *a* in fig. 2a) below the maximum cutting range of the drill bit and cutter;

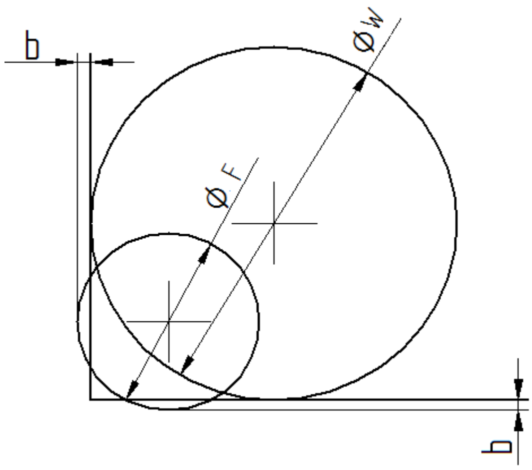
Ø drill > Ø cutter (fig. 2b) - there was a phenomenon of pulling the cutter into the workpiece, resulting in a cavity formed in the wall (parameter *b* in fig 2b);

Ø drill = Ø milling cutter (fig. 2c) - theoretically no tooth or cavity should be formed in the material, but due to the machining errors (drill bit, small stiffness of the milling cutter), depending on the size of the tools in the workpiece, a tooth or cavity was formed.

a)



b)



c)

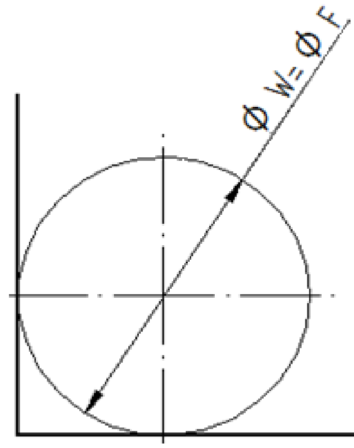


Fig. 2. Tested cases: a) Ø drill bits < Ø milling cutters, b) Ø drill bits > Ø milling cutter, c) Ø drill bits = Ø cutter

The experiment consisted of a machining process and the measurements of each of the corner. Studies were carried out as follows:

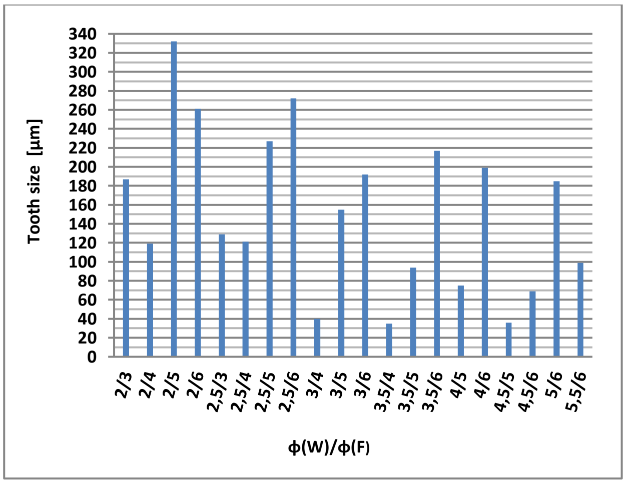
- drilling the holes in the corners with drill bits of diameters Ø 2 ÷ 5.5 mm (0.5 mm in each);
- roughing the rectangular pocket with Ø 6 mm triangular cutter;
- milling in the corners with tools of diameters Ø 2 ÷ 6 mm every 1 mm;
- milling the pocket with the same tool as in the corners;
- making corner measurements with the VHX-500 Keyence microscope - determining the outline of the drill bit and cutter diameter and the highest point of the tooth/cavity, and then guiding the auxiliary dimension lines tangential to the tool contour lines.

Study results

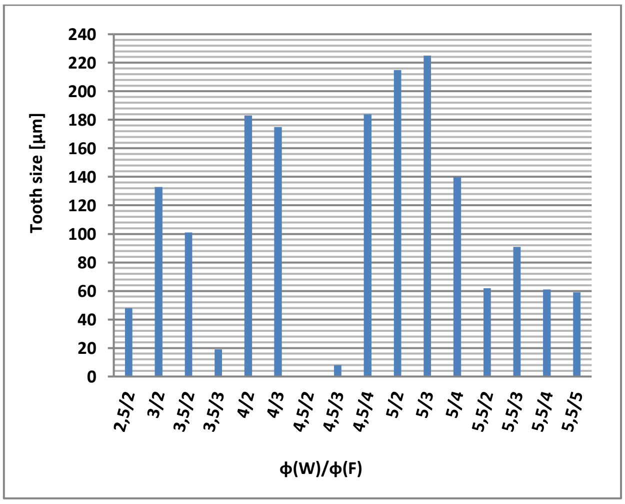
The influence of the diameter ratio of the drill bit and the cutter on the accuracy of corners is shown in fig. 3, and in fig. 4; the corners images after machining, recorded using the VHX-500 Keyence laboratory microscope.

When the diameter of the drill was equal to the diameter of the cutter, the worst quality of the corner was obtained for the ratio Ø 4 / Ø 4, and the most favorable for Ø 3 / Ø 3. When the drill bit diameter was greater than the cutter diameter, the largest recess and thus the lowest precision was obtained for the tool diameter ratio Ø 5 / Ø 3, and the smallest indentation and highest accuracy for Ø 4.5 / Ø 2. In the latter case, when the diameter of the drill was smaller than the cutter's diameter, the optimum ratio was Ø 4.5 / Ø 5 and the least favorable - Ø 2 / Ø 6.

a)



b)



c)

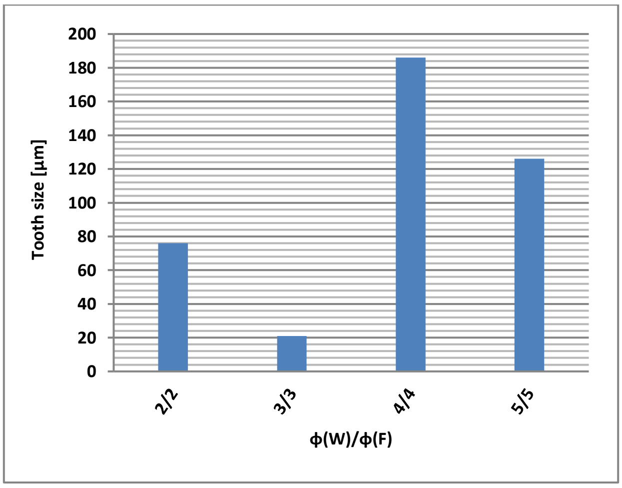
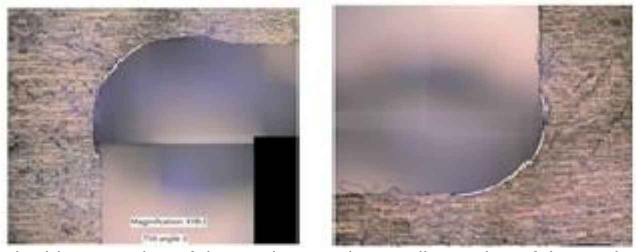


Fig. 3. Effect of the drill bit to cutter diameter on the accuracy of the workpiece: a) Ø drill bit < Ø cutter, b) Ø drill bit > Ø cutter, c) Ø drill bit = Ø cutter

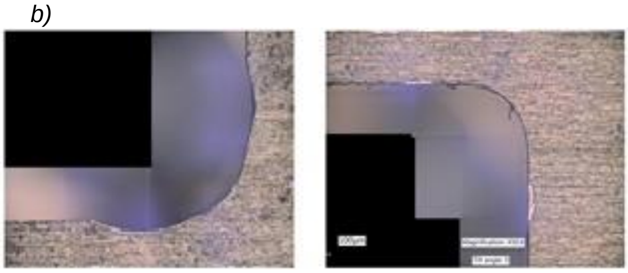
a)



The biggest value of the tooth
Ø drill bit / Ø cutter= Ø4/ Ø4

The smallest value of the tooth
Ø drill bit / Ø cutter= Ø3/ Ø3

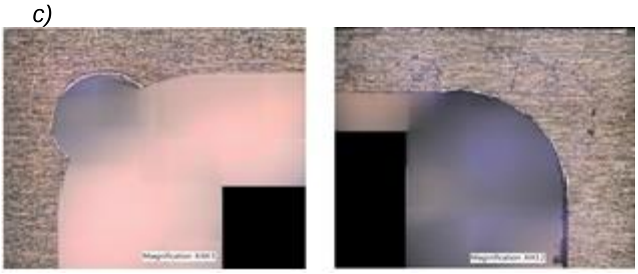
b)



The biggest recess
Ø drill bit / Ø cutter= Ø5/ Ø5

The smallest recess
Ø drill bit / Ø cutter= Ø4,5/ Ø2

c)



The biggest value of the tooth
Ø drill bit / Ø cutter= Ø2/ Ø6

The smallest value of the tooth
Ø drill bit / Ø cutter= Ø4,5/ Ø5

Fig. 4. Effect of chosen tool diameters on the accuracy of the corner: a) Ø drill bit = Ø cutter, b) Ø drill bit > Ø cutter, c) Ø drill bit < Ø cutter

Conclusions

The research has allowed to formulate the following conclusions:

- The method of drilling holes in the corners, and then milling them, makes it possible to make a flat, inner pocket with small radius rounding corners.
- The quality of each corner was determined by the magnitude of errors generated in the drilling and milling process.
- After using a Ø 4.5 mm diameter drill bit and Ø 2 diameter cutter, the best corner quality was obtained. The least accurate corner was obtained when the drill bit diameter to cutter diameter was equal to Ø 2 / Ø 6.
- Relatively the best quality of the corners was obtained for comparable drill bit and cutter diameters.

Results of the study may provide a basis for a deeper analysis of the problem and further improvement of the small cornering strategy. It would also be useful to consider which effects of the presented treatment method are more desirable: high accuracy of the corner design due to the need to change the thickness of the milled wall or poor quality of the corner design without changing the thickness of the workpiece.

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