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ROUGHNESS OF METAL SURFACE AFTER FINISHING USING CERAMIC BRUSH TOOLS

ABSTRACT

The paper describes processes of metal parts edges deburring and surface of metal samples polishing with ceramic tools based on fibre aluminium oxide. It presents the construction of basic types of tools and their practical industrial applications, and evaluates the influence of machining parameters on surface roughness. An important advantage of the used tools is the possibility of deburring and machining of external flat and shaped surfaces as well as internal surfaces and even deep drilled holes. These tools can be practically used for machining all construction materials. The results of machining of selected engineering materials, such as aluminium 5052 and 2017A, Inconel 718, non-alloy steel, in various variants of machining parameters are presented. The influence of machining parameters on machined surface roughness was described.

Keywords: *cutting tools; brush ceramic tools; deburring*

PROCESS AND TOOL CHARACTERISTICS

In most cases, machining of metal objects requires their proper finishing. For this purpose, different technologies are used, such as deburring and chamfering, which need expensive individual specialized machines and tools. The solution of this problem is to do final machining on the same machine tool (e.g. a CNC machine tool) on which the operation was done. For that, rotating tools with sets of fibres made of steel, nylon, polypropylene or ceramic material, which is a relatively novel material for such tools, may be used. Surface brushing removes not only fat, dust and other contaminations, but also all absorbed compounds and layers of non-metallic type: oxides, sulphides and other corrosion products [1,2]. Examples of use of steel fibres tools are presented in Fig.1. A serious drawback of steel or polymer tools is permanent deformation of fibres, which causes low quality of machined surfaces and results in low tool durability. A viable alternative are rotating tools consisting of bunches of ceramic fibres or compact hard blocks of tools in the grinding wheel type (Fig. 2). The exact composition of the ceramic material is the know-how of their manufacturers, but the main component is aluminium oxide, Al_2O_3. A single fibre consists of about 1000 microfibres of the diameter of a few micrometers (Fig. 3). The face of every microfibre works as a cutting edge with self-sharpening properties, able to endure a temperature up to 150 °C. The basic properties of ceramic fibres are: high durability, effacement resistance and lack of axial deformation. Contemporarily used brush tools dedicated for, e.g. barb removal, which are made of steel or nylon fibres, typically lose their shape quickly, which leads to a loss of machining capabilities.

Fig. 1. Examples of use of a brush-type tool with steel fibres: a) machining of a weld, b) deburring of gear face [2]

Ceramic tools may be used to improve the surface condition before coating [3-8], for surface honing and roughness improvement [9,10], for brushing and deburring of formed parts [11,12], barb removal after laser cutting, brushing of sintered workpieces, car rims, microfinish machining, edge filleting, surface satinating and cleaning [13], decorative grinding, scum removal, ferrule final machining, steel sheet workpieces after press forging, electro-hollowing, cut out, decorative battens and many others. Like in other machining processes, energy required for machining is delivered in a mechanical way [14,15], so its amount may be easily determined.

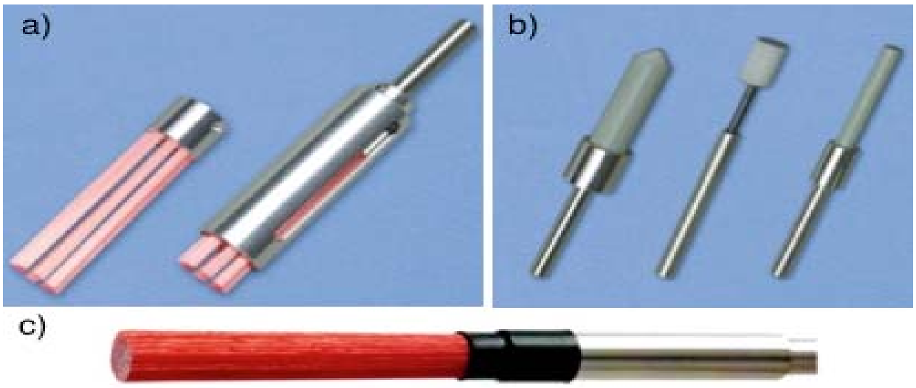

Fig. 2. Basic types of ceramic rotating tools: a) brush-type tool made of bunches of ceramic fibres, b) tool of the grinding wheel type made of compact hard blocks, c) paintbrush-type tool made of bunches of ceramic fibres

In terms of the mechanisation level, ceramic tools are divided into:

- tools for mechanical machining (machine tools, robots, and other numerically controlled machines, and also conventional machine tools and special or dedicated ones),
- tools for manual treatment.

In terms of their purpose, tools may be divided into:

- tools for external surfaces (planes and cylindrical surfaces),
- tools for internal surfaces (including crossing holes).

Another division – based on construction properties – groups bolt tools in three sets:

- brush-type tools,

- paintbrush-type tools,
- tools of the grinding wheel type.

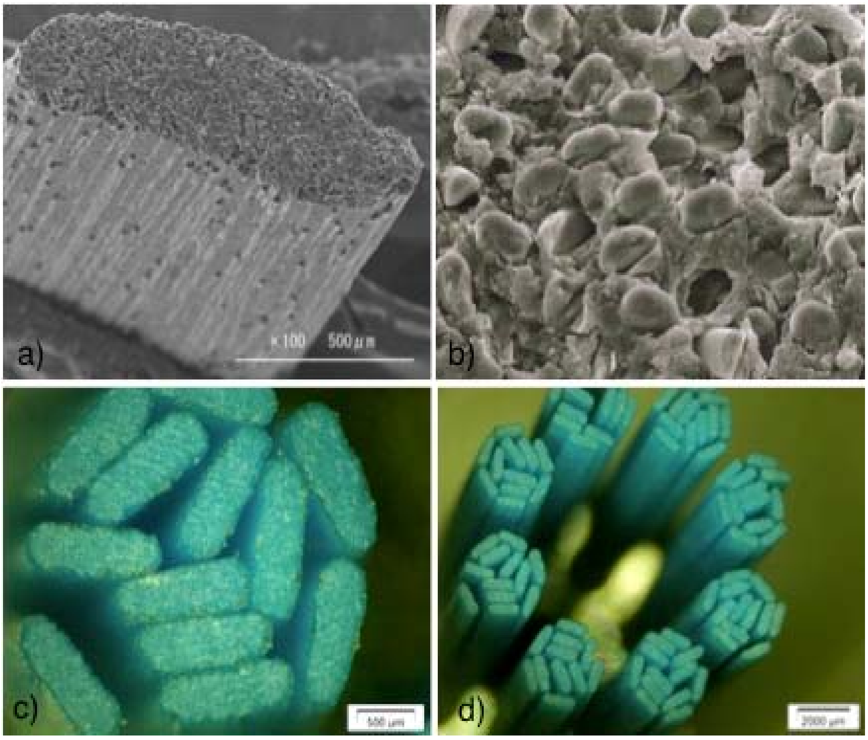

Fig. 3. a) view of a single fibre, b) structure of ceramic fibre, c) bunch of fibres, d) full face view of a tool

Individual tools are marked with different fibre colours (Fig. 4). For example, blue tools used for final machining of workpieces made of very hard metals have respectively thicker fibres than pink brushes, which may be used for polymer workpieces machining. Fig. 4 presents the colours used for tool marking depending on the machined material (vertical axis) and type of machining (horizontal axis).

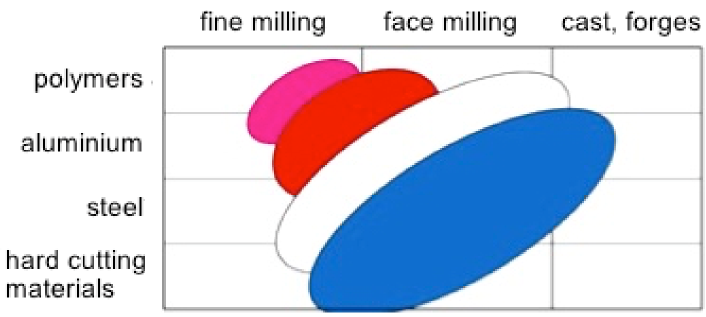

Fig. 4. Colour markings according to tool purpose [2]

To compensate for the workpiece dimension change along the axis of the brush-type tool and to obtain constant press force on the machined surface, a special toolholder with a spring mechanism is used. Thanks to this, tool durability, homogeneity of the obtained roughness and quality of the machined surface texture are increased. A pot brush has fibres located in the range of two circles Dmax and Dmin (Fig. 5), and this results in a slightly different texture of the machined surface in the central belt determined by Dmin and two edge belts implied by peripheral circles of fibre location (Dmax). The brush is a flexible tool (not a stiff monolith); it consists of many fibres the motion of which is not identical for each fibre, and the cutting speed on the external diameter (Dmax) is larger than on the internal diameter (Dmin). A bigger centrifugal force acts on fibres located closer to the external brush diameter Dmax than on the fibres located closer to the axis of rotation, which causes their gaping. In consequence, fibres located closer to the centre go deeper into the machined material than those located externally (they act on the surface with a bigger force than the external fibres located far from the axis of rotation – Fig. 6). That is because fibres under a bigger centrifugal force divert more in relation to their initial position (while spindle rotation is off).

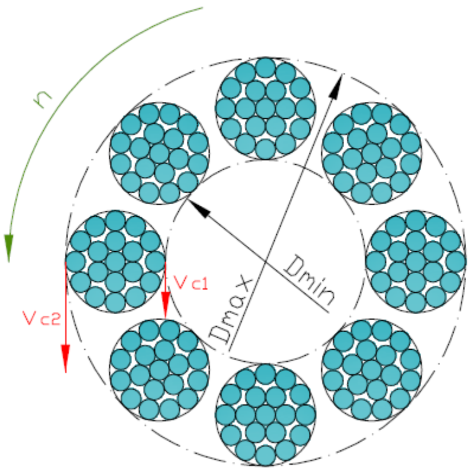

Fig. 5. Cutting velocities: vc1 and vc2 for Dmin and Dmax brush diameters, respectively

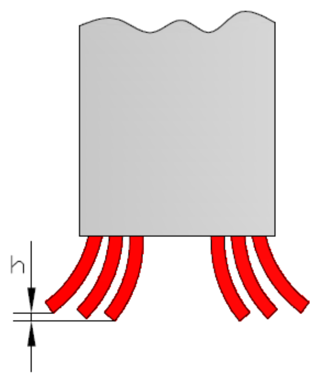

Fig. 6. Fibre gaping phenomenon under the influence of centrifugal force; h – difference of real material plunge depths for peripheral fibres

EXAMPLES OF USE OF CERAMIC TOOLS

In Fig. 7, a typical use of a pot-brush type ceramic tool is presented for deburring, barb removal or surface polishing. The surface presented on the left is before machining, the one on the right – after machining. Positive results of deburring and roughness improvement are clearly visible. In the authors' opinion, this type of machining is strongly recommended for gear face deburring replacing the painful process of milling.

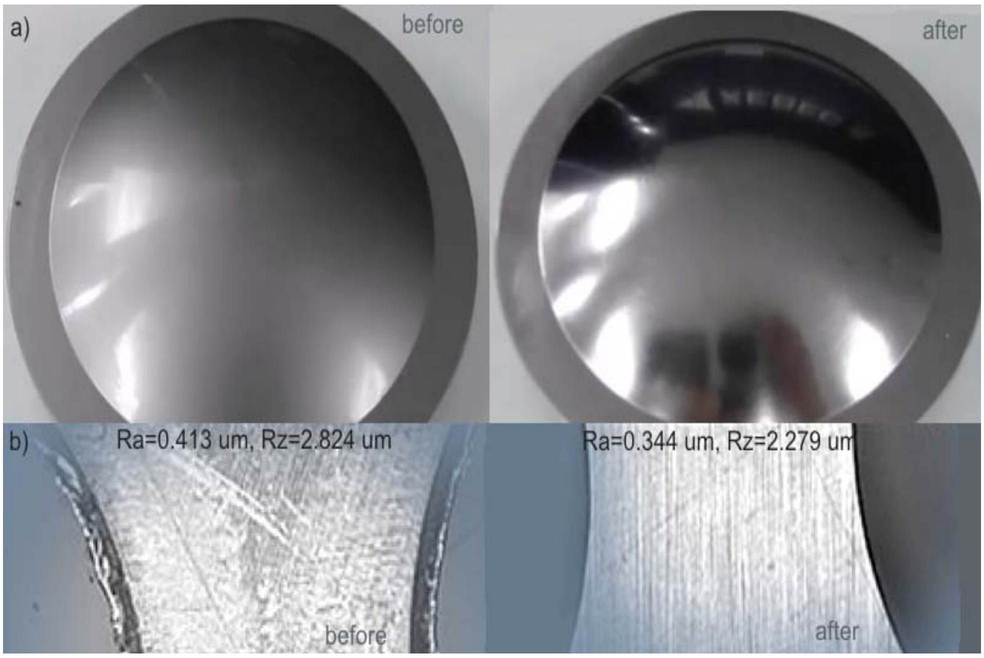

Fig. 7. Example of machining results for tools of the ceramic brush type: a) tool steel spherical surface machining, b) plane and gash edge machining

INFLUENCE OF MACHINING PARAMETERS ON MACHINED SURFACE ROUGHNESS

The tables below present results of tests used for evaluation of the influence of cutting parameters on machined surface roughness Ra. The basic technological parameters were changed: revolution speed, cutting depth and feedrate. The best result Ra=0.354 µm was obtained for rev speed of 4000 rpm, cutting depth 0.5 mm and the smallest feedrate 600 mm/min (Tab. 1).

Table 1. *Influence of machining parameters on machined surface roughness (material: aluminium A5052, raw machining: face milling, cutting tool used: A11-CB40M)*

Process parameters	Rev speed [min^{-1}]	Cutting depth [mm]	Feedrate [mm/min]	Ra before [µm]	Ra after [µm]
Pass 1	4000	0.5	1200	0.880	0.436
Pass 2	5000	0.5	1200	0.875	0.424
Pass 3	4000	1.0	1200	0.864	0.415
Pass 4	4000	0.5	600	0.921	0.354

In case of tool passes, the best result was obtained in the third pass despite two times bigger feedrate value (1200 mm/min) in relation to earlier tests (Tab. 2). Summarizing: of the three technological parameters, feedrate has the biggest influence on roughness improvement. The number of passes is even more significant, but it is connected with an increase of total machining time. The results of research on the influence of cutting parameters on roughness of machined surfaces for machining three different materials (Inconel, steel and aluminium) with brush-type tools are presented below. This is introductory research without prior experiment planning.

Table 2. *Influence of the number of tool passes on machined surface roughness (T1-test 1, T2-test 2)*

	Rev speed [min-1]	Cutting depth [mm]	Feedrate [mm/min]	Pass No	Cycle time [min]	Ra before [µm]	Ra after [µm]		
							Pass 1	Pass 2	Pass 3
T 1	4000	0.5	600	1	1	0.921	0.354	-	-
	4000	0.5	1200	2	1	0.901	0.459	0.325	-
T 2	4000	0.5	400	1	1	0.918	0.327	-	-
	4000	0.5	1200	3	1	0.894	0.467	0.324	0.226

Machining of Inconel 718

Tools marked with white or blue are dedicated for Inconel machining (Fig. 5). The tests were done for g=0.6 mm (brush plunge depth in relation to tool workpiece contact surface), brush diameter D=16 mm, cutting length s=150 mm, sample surface prepared with face mill cutter. The results are summarized in Table

Table 3. *Influence of the number of tool passes on machined surface roughness – Inconel 718*

Process parameters	Rev speed [min^{-1}]	Type of brush	Feedrate [mm/min]	Ra before [µm]	Ra after [µm]
Pass 1	3650	blue	2000	0.5	0.46
Pass 2	3650	blue	1000	0.5	0.39
Pass 3	3650	blue	250	0.5	0.29
Pass 4	3650	white	1000	0.5	0.43
Pass 5	3650	white	250	0.5	0.49

Machining of non-alloy steel

For machining of E295 steel, a white brush was used. The tests were done for a brush with the diameter D=16 mm, g=0.6 mm, cutting length s=100 mm, sample surface prepared with face mill cutter Ra=4.72 µm. Three tool passes were used. The results are summarized in Table

Table 4. *Influence of the number of tool passes on machined surface roughness – non-alloy steel*

Process parameters	Rev speed [min^{-1}]	Type of brush	Feedrate [mm/min]	Ra before [µm]	Ra after [µm]
Pass 1	3650	white	1000	4.72	4.48
Pass 2	4250	white	500	4.72	4.05
Pass 3	4250	white	500	4.72	3.38

Machining of aluminium alloy 2017A (according to EN 573-3)

Tools marked with white or red are dedicated for aluminium machining. The tests were done for 5 values of feedrate with other parameters constant: n=3650 rpm, g=0.6 mm, brush diameter D=16 mm, cutting length s=100 mm, sample surface prepared with face mill cutter. The obtained roughness values are presented in Tab. 5. Test results show small influence of feedrate on Ra in case of the white brush and meaningful impact in case of the red brush. In

Fig. 8, a sample of the machined surface is presented with specific marks of tool fibres passes, as well as surface geometrical structure for the following machining parameters: white brush with diameter D=16 mm, fibre extension 10 mm, plunge fibre depth ap = 0.5 mm, feedrate 4000 mm/min, revolution speed n=4000 rpm.

Table 5. *Values of surface roughness Ra obtained depending on brush type and feedrate [μm]*

Process parameters	Rev speed [min^{-1}]	Type of brush	Feedrate [mm/min]	Ra before [μm]	Ra after [μm]
Pass 1	3650	Red/white	4000	1	0.53/0.75
Pass 2	3650	Red/white	2000	1	0.45/0.82
Pass 3	3650	Red/white	1000	1	0.40/0.96
Pass 4	3650	Red/white	500	1	0.50/0.95
Pass 5	3650	Red/white	250	1	0.65/0.95

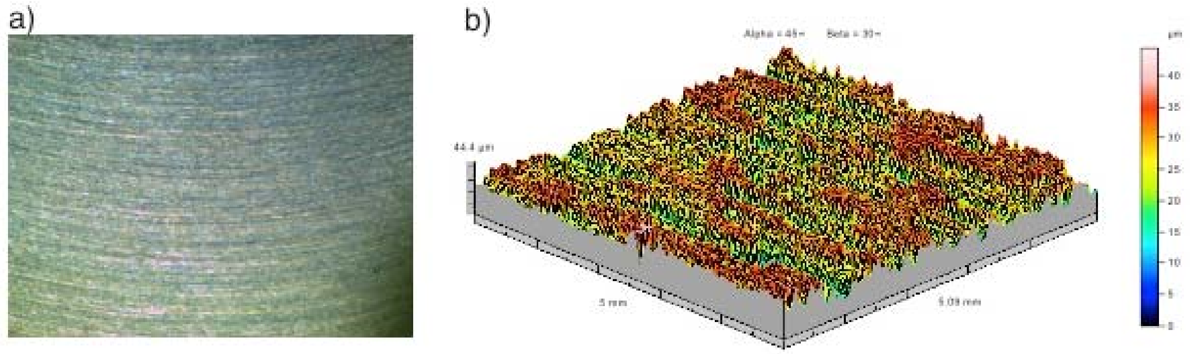

Fig. 8. a) View of a surface machined with a brush ceramic tool (magnification 15x); b) measured and visualized surface geometrical structure

CONCLUSIONS

The conducted research basically confirmed the results of tool tests done by manufacturers. Both a decrease of feedrate and an increase of the number of passes decreased the roughness value, and the influence of the number of passes was less meaningful. Both the tool producer's and the authors' tests confirmed that these tools should not be used in too many passes (up to 3), because in certain cutting conditions there is a specific threshold number of passes above which the roughness value does not improve. Ceramic brush tools may be very significant in hard materials and hard-cutting materials machining such as Inconel, especially in case of fine machining of workpieces of complex shapes. High technological parameters of cuts with ceramic tools significantly reduce machining time, which makes them competitive in comparison to conventional cutting tools. The use of such tools in technological processes may allow to totally eliminate manual treatment, as well as workstations dedicated to manual work. Research on this subject is currently conducted at the Institute of Manufacturing Technologies of Warsaw University of Technology.

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