SURFACE FINISHING USING CERAMIC FIBRE BRUSH TOOLS

SALACINSKI Tadeusz, WINIARSKI Maciej, CHMIELEWSKI Tomasz, SWIERCZ Rafal

Warsaw University of Technology, Institute of Manufacturing Technologies,Warsaw, Poland, EU

Abstract

The paper describes processes of edge deburring and surface polishing with ceramic tools based on 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.

Keywords: Cutting tools; brush ceramic tools; deburring

1. 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. The solution to 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 dirt, 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 **Figure 1**.

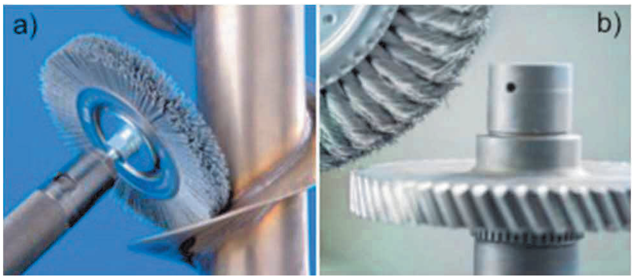

Figure 1 Examples of use of a brush-type tool with steel fibres: a) machining of a weld, b) deburring of gear face [2]

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 of the grinding wheel type (**Figure 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 (**Figure 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. Ceramic tools may be used to improve the surface condition before coating, for surface honing and roughness improvement, for brushing and deburring of formed parts, barb removal after laser cutting, brushing of sintered workpieces, car rims, microfinish machining, edge filleting, surface satinating and cleaning, 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 [3-14], so its amount may be easily determined.

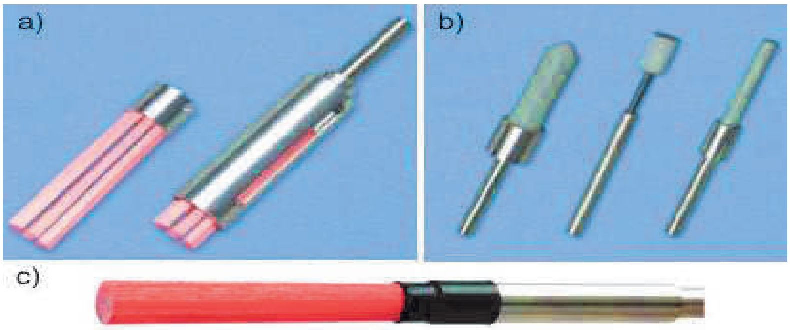

Figure 2 Basic types of ceramic rotating tools: a) brush-type tool made of bunches of ceramic fibres, b) tool of the grinding wheel type made of compact hard blocks, c) paintbrush-type tool made of bunches of ceramic fibres

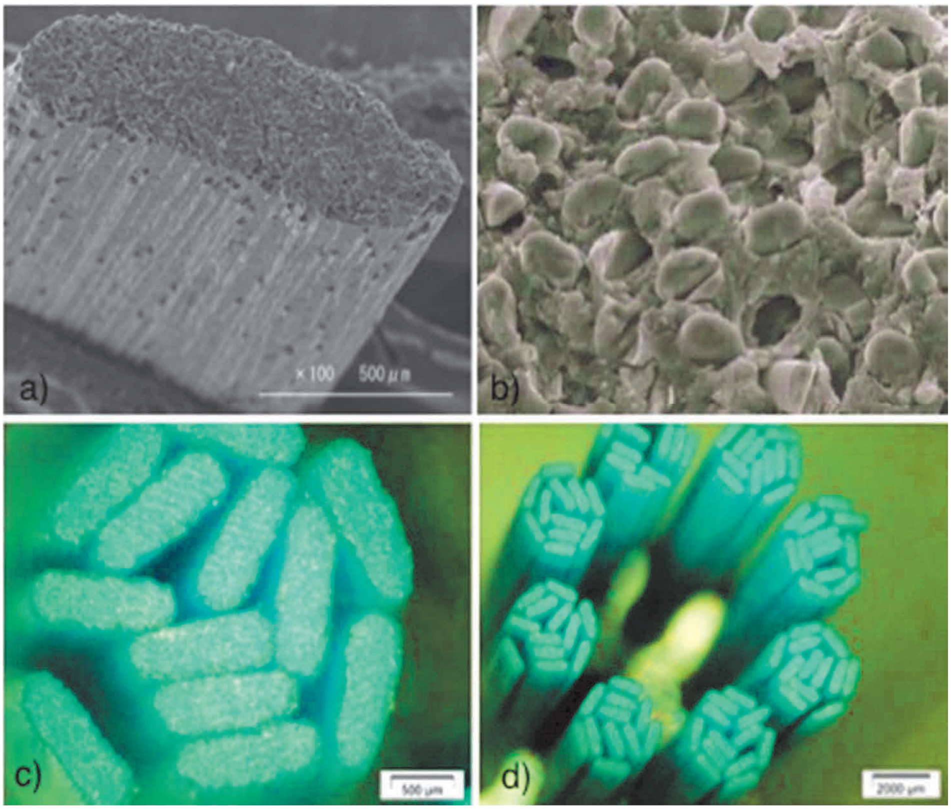

Figure 3 a) view of a single fibre, b) structure of ceramic fibre, c) bunch of fibres, d) full face view of a tool

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.

Individual tools are marked with different fibre colours (**Figure 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. **Figure 4** presents the colours used for tool marking depending on the machined material (vertical axis) and type of machining (horizontal axis).

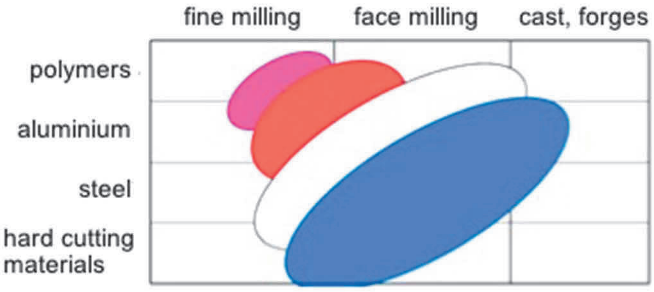

Figure 4 Colour markings according to tool purpose

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 D_{max} and D_{min} (**Figure 5**), and this results in a slightly different texture of the machined surface in the central belt determined by D_{min} and two edge belts implied by peripheral circles of fibre location (D_{max}). 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 (D_{max}) is larger than on the internal diameter (D_{min}). A bigger centrifugal force acts on fibres located closer to the external brush diameter D_{max} 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 - **Figure 6**). That is because fibres under a bigger centrifugal force divert more in relation to their initial position (while spindle rotation is off).

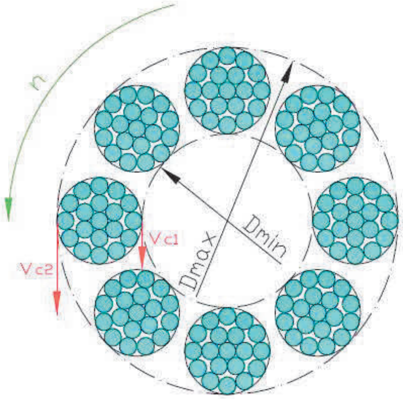

Figure 5 Cutting velocities: vc1 and vc2 for Dmin and Dmax brush diameters, respectively

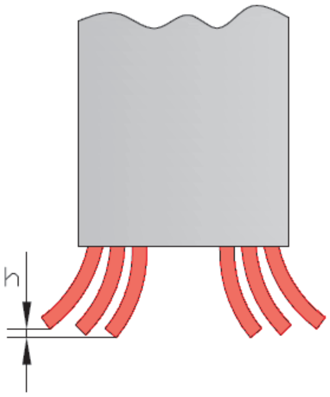

Figure 6 Fibre gaping phenomenon under the influence of centrifugal force; h - difference of real material plunge depths for peripheral fibres

2. EXAMPLES OF USE OF CERAMIC TOOLS

In **Figure 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.

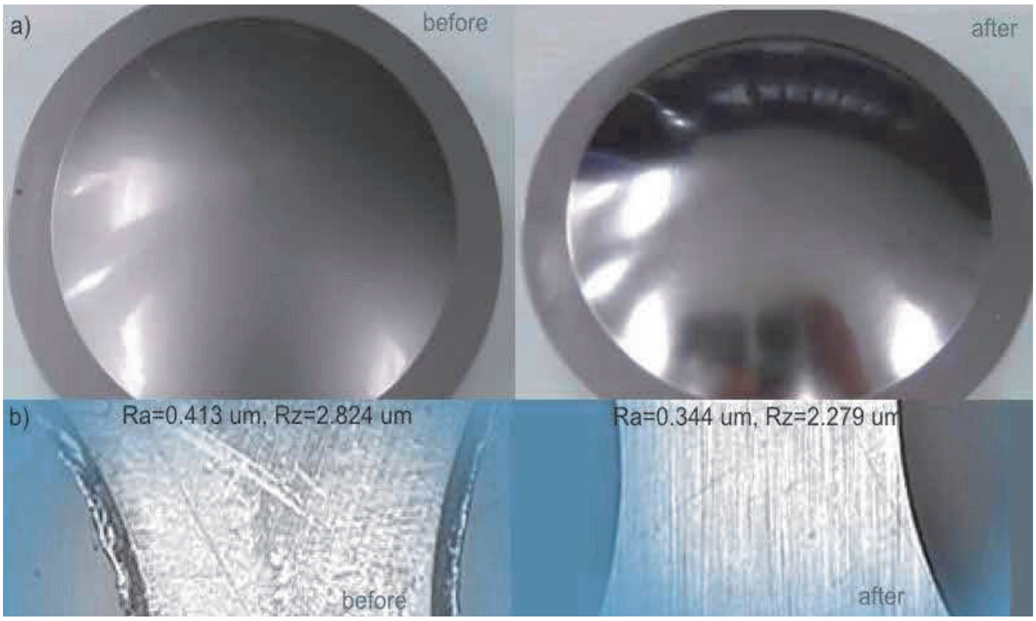

Figure 7 Example of machining results for tools of the ceramic brush type: a) tool steel spherical surface machining, b) plane and gash edge machining

3. 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 0.5mm and the smallest feedrate 600 mm/min (**Table 1**). 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 (**Table 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.

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]
Case 1	4000	0.5	1200	0.880	0.436
Case 2	5000	0.5	1200	0.875	0.424
Case 3	4000	1.0	1200	0.864	0.415
Case 3	4000	0.5	600	0.921	0.354

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

	Rev speed [min-1]	Cutting depth [mm]	Feedrate [mm/min]	N of pass	Cycle time [min]	Ra before [µm]	Ra after [µm]		
							Pass 1	Pass 2	Pass 3
T1	4000	0.5	600	1	1	0.921	0.354	-	-
	4000	0.5	1200	2	1	0.901	0.459	0.325	-
T2	4000	0.5	400	1	1	0.918	0.327	-	-
	4000	0.5	1200	3	1	0.894	0.467	0.324	0.226

4. OWN RESEARCH

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. Full research is planned as part of a doctoral dissertation at Warsaw University of Technology.

4.1. Inconel 718 machining

Tools marked with white or blue are dedicated for Inconel machining (**Figure 5**). The tests were done for g=0.6mm (brush plunge depth in relation to tool workpiece contact surface), brush diameter D=16mm, cutting length s=150mm, sample surface prepared with face mill cutter Ra=0.5 µm.

Test I: (blue brush): n=3650 rpm, v_f=2000 mm/min, three tool passes used gave consecutively Ra_1=0.46 µm, Ra_2=0.44 µm, Ra_3=0.43 µm,
Test II: (blue brush): n=3650 rpm, v_f=1000 mm/min, one pass, Ra=0.39 µm,
Test III: (blue brush): n=3650 rpm, v_f=250 mm/min, one pass, Ra=0.29 µm. The value of shortening (wear out) of brush after 3 tests was 0.015 mm,
Test IV: (white brush): n=3650 rpm, v_f=1000 mm/min, one pass, Ra=0.43 µm,
Test V: (white brush): n=3650 rpm, v_f=250 mm/min, one pass, Ra=0.49 µm.

4.2. Non-alloy steel machining

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

Pass I: n=3650 rpm, v_f=1000 mm/min, g=0.6 mm, roughness obtained Ra=4.48 µm,
Pass II: n=4250 rpm, v_f=500 mm/min, g=0.6 mm, roughness obtained Ra=4.05 µm,
Pass III: n=4250 rpm, v_f=500 mm/min, g=1.5 mm, roughness obtained Ra=3.38 µm.

4.3. Aluminium machining

Tools marked with white or red are dedicated for aluminium machining (**Figure 5**). 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, Ra=1 µm. The obtained roughness values are presented in **Table 3**. 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 **Figure 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 a_p = 0.5 mm, feedrate 4000 mm/min, revolution speed n=4000 rpm.

Table 3 Values of surface roughness Ra obtained depending on brush type and feedrate [µm]

Brush type/v_f	4000 mm/min	2000 mm/min	1000 mm/min	500 mm/min	250 mm/min
red	0.53	0.45	0.40	0.50	0.65
white	0.75	0.82	0.96	0.95	0.95

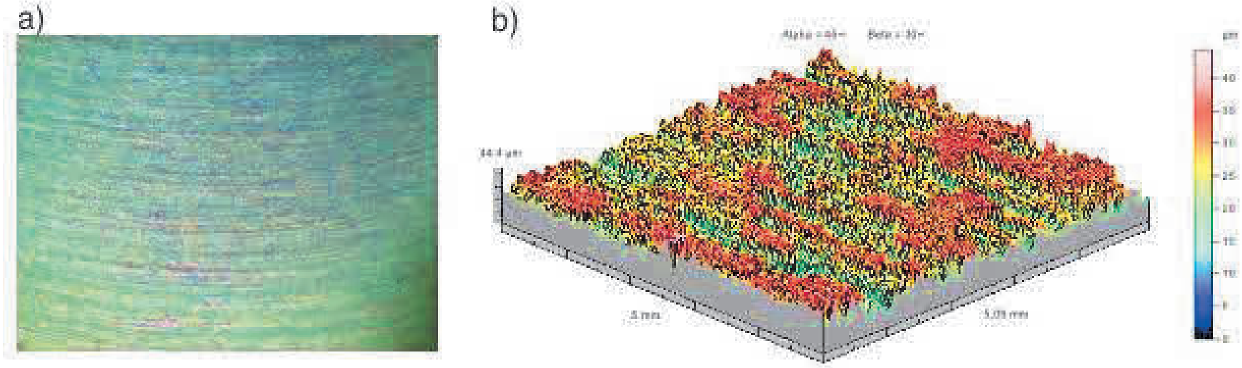

Figure 8 a) view of a surface machined with a brush ceramic tool (magnification 15x); b) surface geometrical structure (source: own case study)

5. CONCLUSIONS

The conducted own 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. The brush construction of tools may also be used for laying thin metallic layers (for instance of titanium) on ceramic surfaces to ease further welding of ceramic materials with metals [6]. Research on this subject is currently conducted at the Institute of Manufacturing Technologies of Warsaw University of Technology.

REFERENCES

[1] BURAKOWSKI T., WIERZCHOŃ T., Inżynieria powierzchni metali. WNT, Warsaw, 1995.

[2] LOESER company materials

[3] IWASZKO J., KUDŁA K., SZAFARSKA M., Remelting treatment of the non-conductive oxide coatings by means of the modified GTAW method, Surface and Coatings Technology, vol. 206, (11-12), 2845-2850, 2012, DOI: 10.1016/j.surfcoat.2011.12.009

[4] SAŁACIŃSKI T., WINIARSKI M., Obróbka wykończeniowa powierzchni z wykorzystaniem szczotkowych narzędzi z włókien ceramicznych, Przegląd Spawalnictwa, vol. 89 (30), p. 19-23, 2017

[5] GOLANSKI D, GRZES J., The numerical analysis of residual stresses in surface layers deposited by brush-plating method, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 220 (3), 429-437, 2006

[6] CHMIELEWSKI T., GOLAŃSKI D., WŁOSIŃSKI W., ZIMMERMAN J., Utilizing the energy of kinetic friction for the metallization of ceramics, Bulletin of the Polish Academy of Sciences - Technical Sciences 63 (1), 201-207, 2015.

[7] CHMIELEWSKI T., GOLAŃSKI D., WŁOSIŃSKI W., Metallization of ceramic materials based on the kinetic energy of detonation waves Bulletin of the Polish Academy of Sciences - Technical Sciences 63 (2), 449-456, 2015

[8] SZAFARSKA M., IWASZKO J., KUDŁA K., ŁĘGOWIK I., Utilisation of high-energy heat source in magnesium alloy surface layer treatment, Archives of Metallurgy and Materials, vol. 58 (2), 619-624, 3013. DOI: 10.2478/amm-2013-0047

[9] CZUPRYŃSKI A., GÓRKA J., ADAMIAK M., TOMICZEK B., Testing of flame sprayed Al2O3 matrix coatings containing TiO2, Arch. of Metallurgy and Materials, vol. 61 (3), 1363-1370, 2016, DOI: 10.1515/amm-2016-0224

[10] [SPADŁO S., KOZAK J., MŁYNARCZYK P., Mathematical modelling of the electrical discharge mechanical alloying process, Procedia CIRP, vol. 6, 422-426, 2013

[11] [NOWICKI B., PIERZYNOWSKI R., SPADŁO S. "Investigation of electro-discharge mechanical dressing (EDMD) of diamond abrasive wheels with conductive bonds using brush electrodes", Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture vol. 220 (3), 421-428, 2006. DOI :10.1243/095440505X32922

[12] SPADŁO S., MŁYNARCZYK P., DEPCZYŃSKI W. "Investigation of the Selected Properties of the Superficial Layer Alloying with the Tungsten Electrodes" Proceedings of 24th International Conference on Metallurgy and Materials, METAL 2015, pp. 863-867

[13] CHMIELEWSKI M., DUTKIEWICZ J., KALIŃSKI D., LITYNSKA-DOBRZYNSKA L., PIETRZAK K., STROJNY-NEDZA A., “Microstructure and properties of hot-pressed molybdenum-alumina composites”, Archives of Metallurgy and Materials 57 (3), 687-693, 2012.

[14] BAŃKOWSKI D., SPADŁO S. “Influence of the Smoothing Conditions in Vibro-Abrasive for Technically Dry Friction the Parts Made of Steel X160CRMOV121”. Proceedings of 25th International Conference on Metallurgy and Materials, METAL 2016, pp. 1019-1024.