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DEVELOPMENT IN MACHINING TECHNOLOGY

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Edited by
Wojciech Zębala
Ildikó Maňková

Cracow University of Technology

This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

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PREFACE

Machining is one of the most popular technique to change shape and dimensions of the objects. Machining operations can be applied to work metallic and non-metallic materials such as ceramics, composites, polymers, wood.

Cutting tools have been used since ancient times to remove excess material from forgings and castings. Nowadays, metal cutting became one of the primary manufacturing processes for finishing operations. In the last few years we have observed a rapid development in automation of manufacturing processes, especially in automatic control systems. Progress in cutting stimulates a significant increase in the metal removal rate and achieving high accuracy in terms of dimensions and shape of machine parts. New materials, which play the key role here, are used to produce cutting tools.

To meet today's high demands concerning accuracy and efficiency of the manufacturing process of machine parts, it is necessary to use computer methods for designing of technological processes.

This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

Wojciech Zębala

PART 1

Machining of Difficult-To-Cut Materials

Chapter 1.6

SELECTED PROPERTIES OF THE TOP LAYERS OF CORROSION-RESISTANT STEEL SURFACES SUBJECTED TO SMOOTHING WITH NEW-GENERATION FLEXIBLE GRINDING DISCS

Niżankowski Cz., Otko T.
Cracow University of Technology, Cracow, Poland

***Abstract**: The paper presents and discusses the results of experimental comparative tests, concerning the selected properties of the top layers of cylinder surfaces made of corrosion-resistant steel, subjected to mechanical smoothing with new-generation flexible grinding discs. The tests involved TKp grinding discs, manufactured in Poland, of fixed conformability, and TKpS grinding discs, of locally varied conformability of the cutting surface.*

***Keywords:** Grinding, new-generation flexible grinding discs, corrosion-resistant steel*

1. Introduction

Speaking of abrasive smoothing, we mean such a method of surface working and finishing, which is aimed at giving the workpiece a low roughness, a favourable state of stresses in its top layer, as well as a required value of the directional light reflection factor. The abrasive smoothing constitutes the oldest method of surface finishing treatment. It can be accomplished as a normal, or a mirror polishing. In the industrial practice, the most commonly used are the mechanical and abrasive smoothing, and wet-blast smoothing. Until recently, the processes of mechanical and abrasive smoothing employed various kinds of flexible rotating discs, with abrasives bonded to them. Wooden discs, covered with leather, discs made of wool felt, synthetic felt, flannel, tarpaulin, or cloth, which were either homogenous or sewn together, were used. Also utilized were leaf grinding discs, made of scraps of linen that were sewn together or of bonded leaves of abrasive paper. Abrasives were applied either in the form of abrasive compounds or pastes, or with the use of leather- and bone glues, which were cold- or hot-applied. Sometimes, mixtures of abrasives with kaolin and liquid glass, or mixtures of abrasives with formaldehyde resins were used to cover the abrasive smoothing discs. Currently, processes of mechanical and abrasive smoothing employ, most often, the conformable abrasive tools. They constitute a separate group of abrasive tools of specific properties. Those properties result either from the dispersion of abrasive grains in the highly flexible and highly porous polyurethane bonds (flexible grinding discs), or from the dispersion of abrasive grains on polyamide web fibres (polishing grinding discs of nonwoven abrasive fabric and polishing brushes) [5].

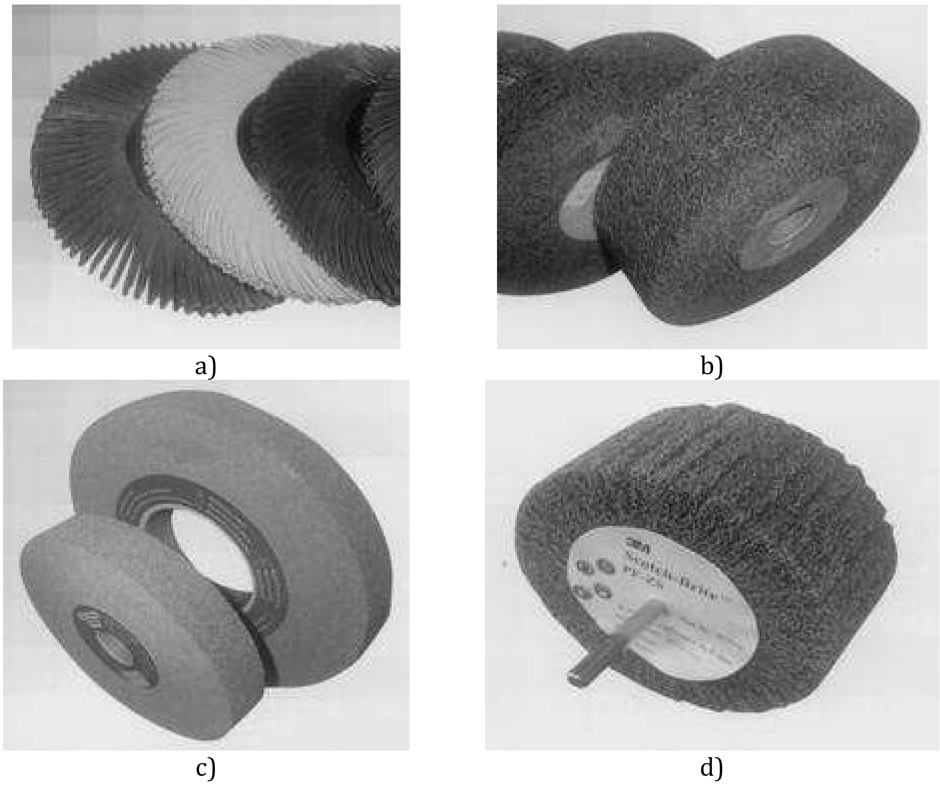
a) b) c) d)

Fig. 1. Contemporary flexible abrasive smoothing tools: a) abrasive brushes of straight unwoven fabric; b) brushes of tangled non-woven fabric of the ScotchBrite type; c) flexible polyurethane-bond grinding discs; d) brushes of pleated non-woven fabric of the Cut & Polish type [3]

Those specific construction features of modern, conformable abrasive tools cause that active abrasive grains on the cutting surface of a tool may move within the working area under the influence of friction resistance, elastic and plastic strains, or under the influence of machining resistance. By changing the conformability of bond or fibres, it is possible to adjust the stiffness of grain fixing in the tool, and, consequently, influence the effects within the working zone. The conformable abrasive tools are marked by high stability of their operating properties and conformability to mechanization and automation of abrasive smoothing processes. Those tools can be used to smooth shaped surfaces, often those of complicated profiles (e.g. moulds, dies, etc.). The tools make it possible to get a lower roughness of the workpiece surface than after regular finish grinding, thus yielding high factor values of directional light reflection from the smoothed surface [4].

2. Abrasive smoothing

Actually, abrasive smoothing is a complex process, which cannot be interpreted exclusively in terms of quantitative and qualitative changes in the surface roughness level. Such an understanding of the issue dates back to the times of Hooke and Newton. Presently, knowing the results of research on surfaces subjected to abrasive smoothing and polishing as presented by Rayleigh, Rabinowicz, Beilby, Bowden, Hughes, and Samuels we realize that the process of abrasive smoothing is determined in parallel by complex chemical effects, as well as friction and heat effects that occur in the smoothing area. The mechanism of abrasive smoothing has so far not been explicitly determined. This is due probably to the fact that under differentiated conditions of abrasive smoothing, particular physical and chemical effects occur with diverse intensity. It is assumed that the process of abrasive smoothing takes place in three phases. During the first phase the previous working marks become reduced. In the second phase the previous working marks are completely removed and a homogenous, mostly non-directional geometrical structure of the top layer is obtained, while in the third phase the required polish, if any, is obtained and the workpiece roughness becomes further reduced. During abrasive smoothing of corrosion-resistant steel and other high-plasticity materials, it is particularly important to consider the crossing and concentrating of the working marks [6].

The surface of the workpiece to be smoothed should be properly prepared. Most often, this is achieved by means of the finish rolling or milling processes. No matter what technique of the surface preparation is used, the roughness of the surface prior to abrasive smoothing should never be lower than that defined by the R_a parameter amounting to 1.25 μm. The biggest impact on the course and results of mechanical and abrasive smoothing is exerted by such factors, as the abrasive grain size, smoothing speed and unit pressure on the surface subjected to smoothing, as well as the structure and type of bond, which has been applied in the abrasive tool. When performing mechanical and abrasive smoothing of the corrosion-resistant steel, the speed of abrasive smoothing should not exceed 40 m/s, while the feed motion speed should fluctuate around ca. 4 m/min. The recommended values of unit pressure on the surface subjected to abrasive smoothing should range from 2.5 to 5 dN/cm^2. At the so-adopted parameters of abrasive smoothing, one obtains low roughness values of surfaces subjected to working (R_a=0.16μm), with high efficiency of smoothing. Such a level of roughness, together with the associated light reflection is sufficient in the operations of "spotting" or "texturing" of the worked surfaces. Those operations are often performed in relation to objects made of corrosion-resistant steel in order to provide the surfaces subjected to working with decorative textures [4, 5, 6].

3. TKp and TKpS flexible grinding discs

The flexible grinding discs of porous polyurethane bonds, manufactured by Stalmax at Końskie, Poland, are made either as tools of fixed conformability of the grinding disc cutting surface, and then labelled TKp, or as grinding discs of locally diversified conformability of the cutting surface, and then labelled TKpS. They are designed for the abrasive smoothing of metal surfaces. They do not require honing, can be used until completely worn out, and do not cause any dusting in the work place. Owing to the flexibility of their polyurethane bonds, they adjust to the shape of the worked surface, thus ensuring even smoothing.

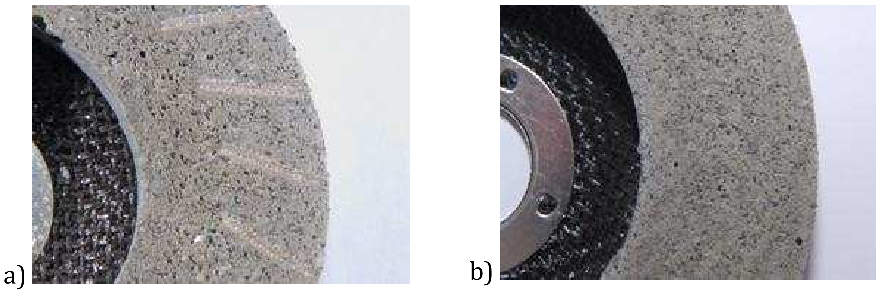

Fig. 2. View of the active surface of the grinding disc: a) of the TKpS type; b) of the TKp type

The TKp grinding discs, designed for steel grinding, contain only abrasives made of alundum 99A, of the 24 or 40 grain size. On the other hand, the TKpS grinding discs, also designed for steel grinding, contain additionally abrasives of fused zircon alundum, in the form of regularly distributed radial and oblique inserts of the same grain size as that in the remaining part of the grinding disc. The introduction of such local diversifications in conformability of the grinding disc cutting surface aims at the improvement of the quality of the surface subjected to smoothing, extension of the grinding disc durability and increase of its cutting capability through the changes of friction and vibration damping factors and changes in the distribution of pressures in the grinding area. According to the manufacturer, flexible grinding discs of that type are most useful for the abrasive smoothing of tanks, pipeworks and fittings that are made of corrosion-resistant steel and used in the chemical, pharmaceutical and milk industries. When working with grinding discs of that type, the use of water as a coolant and a lubricant can be allowed [1].

4. Experimental tests

4.1. Outline of tests, description of factors

The outline of face abrasive smoothing of acid-resistant steel by means of flexible grinding discs of polyurethane bonds upon testing the selected properties of the top layer of the worked surface is shown in Fig. 3.

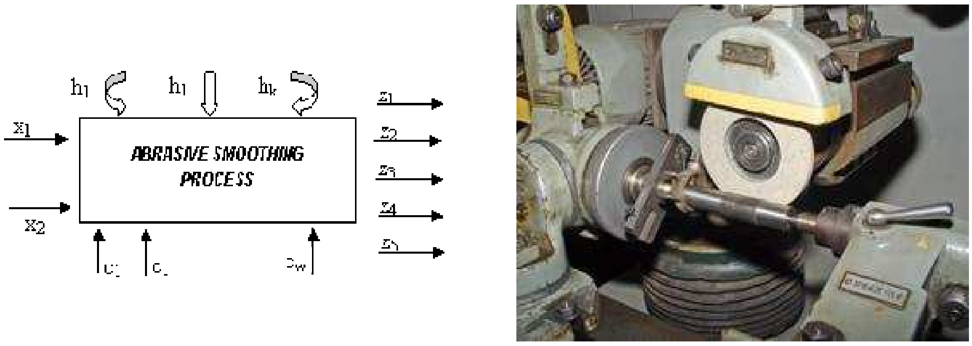

Fig. 3. Diagram of tests and fragment of test stand for the face abrasive smoothing of acid-resistant steel by means of flexible grinding discs of polyurethane bonds

X: - input quantities:

- x_1 – type of the cutting surface of the grinding disc (cf. Fig. 2 – cutting surface of the grinding disc with fixed or variable conformability),
- x_2 – abrasive grain size in the grinding disc abrasive (P24 and P40).

Z: - output quantities:

- z_1 – mean arithmetic deviation of the worked surface roughness profile from the R_a average line in µm, in accordance with the ISO PN – PN-EN ISO 4287:1999 and the PN-89/M-04256/2 Polish Standards,
- z_2 – maximum height of the R_m worked surface roughness profile in µm, in accordance with the ISO PN – PN-EN ISO 4287:1999 and the PN-89/M-04256/2 Polish Standards,
- z_3 – microhardness of the top layer in the worked surface as per the Vickers scale, in accordance with the PN-EN ISO 6507-1:1999 Polish Standard, PB 23/LIM, 2nd ed. of 24 January 2000
- z_4 – axial direction stresses in the top layer of the workpiece,
- z_5 – circumferential direction stresses in the top layer of the workpiece,

C: - constant quantities:

- c_1 –ZM 642 type grinding machine of Russian manufacture
- c_2 – grinding discs for abrasive smoothing:
  42 125x10x22 99A P24 TKp 42 125x10x22 99A P24 TKPs
  42 125x10x22 99A P40 TKp 42 125x10x22 99A P40 TKPs
  manufactured by "Stalmax - narzędzia ścierne", Poland
- c_3 – abrasive smoothing conditions: v_c = 20 m/s, circumferential feed of the workpiece: v_o = 0.235 m/s, transverse push = 0.01 mm,
- c_4 – grinding method: precise, face, plunge-cut, up-cut abrasive smoothing of a cylinder surface,
- c_5 – machining liquid: dry machining,
- c_6 – workpiece material: corrosion-resistant steel of the 1H18N9T grade, of Polish manufacture, with the microhardness as per the 275 $HV_{0.5}$ standard, a semi-finished product in the form of a cylinder, of the dimensions [ΦxL] of 25x42 mm,
- c_7 – abrasive smoothing cycle: type II as per Lur'e, a three-phase cycle, without the stabilization phase, finish polishing.
- c_8 – roughness of the output surface (after grinding) R_a= 0.63 µm,
- c_9 – methods of input quantities measurement: as described in Section 4.3,
- c_{10} – method of grinding disc honing: no honing.

H: - disturbing quantities as non-controllable variable factors that affect the examined process in a non-controllable way.

4.2. Methodology of test planning

The exploratory tests were performed on the basis of static randomized block plan, a complete PS/RB-C, with single- or multiple experiment repetition, depending on the type of the output variable. The decision on the choice of that type of plan was influenced by such premises, as purpose and type of tests, random nature of the test object, necessity of simultaneous evaluation of the significance of the impact of two input quantities on the output quantity, and the possibility of an efficient performance of measurements. Following the principles of the experiment theory, the randomization procedure was conducted before actual tests [2]. The verification of the significance of impact of the x_1 and x_2 input quantities on particular output quantities was performed with the use of the F-Snedecor test, with the consideration of the so-called double classification. Computations were performed with the use of the Statistica software.

4.3. Measurement technique

The exploratory tests were performed by measuring the roughness of worked surfaces with the use of a computerized profile measurement gauge, type Hommeltester T 1000E (measurements on 5 samples for each configuration of the test plan).

Microhardness was tested with the use of the Vickers FutureTech FM 700e microhardness tester (measurements on 2 samples for each configuration of the test plan) and the top layer stresses with the use of the Japanese, x-ray measuring device, type Strainflex PSF 2M (measurements on 1 sample for each configuration of the test plan). Measurements were conducted under normal temperature conditions.

Fig. 4. Hommeltester T1000E profile measurement gauge: a general view

Fig. 5. FutureTech FM700e microhardness tester:a general view

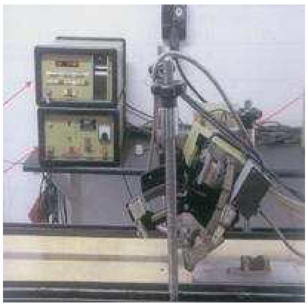

Fig. 6. Strainflex PSF 2M device for stress measurement: a general view

4.4. Test results and analysis

The results of tests for each of the input quantities considered were set out in Tables 1, 2, 3 and 4.

Table 1. Parameter measurement results: roughness (R_a) of surfaces subjected to abrasive smoothing

P grain size (the x_2 factor)	Type of grinding disc cutting surface (the x_1 factor)			
	(Grinding discs with variable cutting surface conformability)		(Grinding discs with fixed cutting surface conformability)	
	Sample	R_a	Sample	R_a
P 24	C	R_a = 0.18	B	R_a = 0.22
	G	0.19	F	0.16
	N	0.21	H	0.20
	R	0.20	M	0.22
	T	0.17	U	0.22
P40	A	R_a = 0.14	D	R_a = 0.14
	E	0.12	J	0.14
	I	0.16	K	0.15
	L	0.14	O	0.13
	S	0.18	P	0.14

At the significance level of $\alpha = 0.1$ and the degrees of freedom of $f_1 = 16$ and $f_2 = 1$, the critical value for the F-Snedecor test is $F_{0.1:16:1} = 2{,}83$. Since when determining the influence of the grain size on the roughness of the worked surface $F = 2{,}86$, and so $F_{0.1:16:1} < F$, it should be assumed that the grain size does significantly influence (at the so-determined test conditions) the results of roughness measurements of the workpiece subjected to abrasive smoothing.

At the significance level of $\alpha = 0.1$ and the degrees of freedom of $f_1 = 16$ and $f_2 = 1$, the critical value for the F-Snedecor test is $F_{0.1:16:1} = 2{,}83$. Since when determining the influence of the type of the grinding disc cutting surface conformability on the roughness of the worked surface $F = 0{,}34$, and so $F_{0.1:16:1} > F$, it should be assumed that the conformability type of the grinding disc cutting surface does not significantly influence the results of roughness measurements of the workpiece subjected to abrasive smoothing.

Table 2. Parameter measurement results: microhardness (HV0.5) of surfaces after abrasive smoothing

P grain size (the x_2 factor)	Type of grinding disc cutting surface (the x_1 factor)			
	(Grinding discs with variable cutting surface conformability)		(Grinding discs with fixed cutting surface conformability)	
	Sample	$HV_{0,5}$	Sample	$HV_{0,5}$
P 24	F I	325.5 290.2	B H	341.9 330.4
P40	C L	305.4 323.1	D S	339.1 380.5

At the significance materiality level of $\alpha = 0.05$ and the degrees of freedom of $f_1 = 4$ and $f_2 = 1$, the critical value for the F-Snedecor test is $F_{0.05:4:1} = 7.71$. Since when determining the influence of the grain size on the microhardness of the worked surface F = 8.1, and so $F_{0.05:4:1} < F$, it should be assumed that the grain size significantly influences (at the so-determined test conditions) the results of microhardness measurements of the workpiece subjected to abrasive smoothing.

Since when determining the influence of the type of the grinding disc cutting surface conformability on the microhardness of the worked surface F = 49, and so $F_{0.05:4:1} < F$, it should be assumed that the type of the grinding disc cutting surface conformability significantly influences (at the so-determined test conditions) the results of microhardness measurements of the workpiece subjected to abrasive smoothing.

Table 3. Parameter measurement results: axial direction stresses in surfaces subjected to abrasive smoothing

P grain size (the x_2 factor)	Type of grinding disc cutting surface (the x_1 factor)			
	(Grinding discs with variable cutting surface conformability)		(Grinding discs with fixed cutting surface conformability)	
	Sample	Stress in axial dir. [MPa]	Sample	Stress in axial dir. [MPa]
P 24	F	10	B	16.1
P40	C	13	D	20

At $F_{0.05:1:1}$ the critical value for the F-Snedecor test is 161. Since when determining the influence of the grain size on axial stresses in the top layer F = 172.5, and so $F_{0.05:1:1} < F$, it should be assumed that the grain size significantly influences the results of axial stress measurements in the workpiece subjected to abrasive smoothing.

Since when determining the influence of the type of the grinding disc cutting surface conformability on axial direction stresses in the top layer of the worked surface F = 365.3, and so $F_{0.05:1:1} < F$, it should be assumed that the type of the grinding disc cutting surface conformability significantly influences (at the so-determined test conditions) the measurement results of axial direction stresses in the top layer of the workpiece subjected to abrasive smoothing.

Table 4. Parameter measurement results: circumferential direction stresses in surfaces subjected to abrasive smoothing

P grain size (the x_2 factor)	Type of grinding disc cutting surface (the x_1 factor)			
	(Grinding discs with variable cutting surface conformability)		(Grinding discs with fixed cutting surface conformability)	
	Sample	Circumferential direction stress [MPa]	Sample	Circumferential direction stress [MPa]
P 24	F	1.4	B	3.4
P40	C	2.3	D	5

At $F_{0.05:1:1}$ the critical value for the F-Snedecor test is 161. Since when determining the influence of the grain size on circumferential stresses in the top layer of the worked surface F=12.7, and so $F_{0.05:1:1} > F$, it should be assumed that the grain size does not significantly influence (at the so-determined test conditions) the results of circumferential stress measurements in the workpiece subjected to abrasive smoothing.

Since when determining the influence of the type of the grinding disc cutting surface conformability on stresses in circumferential direction in the top layer of the worked surface F=46.04, and so $F_{0.05:1:1} > F$, it should be assumed that the type of the grinding disc cutting surface conformability does not significantly influence (at the so-determined test conditions) the measurement results of in circumferential direction stresses in the top layer of the workpiece subjected to abrasive smoothing.

5. Conclusion

Based on the conducted experimental tests of an exploratory nature, one can assume with the 90% probability that the roughness of surfaces subjected to abrasive smoothing (as defined by the R_a parameter) with grinding discs of fixed and variable cutting surface conformability CPS do not show significant differences. Also, with the 95% probability, the state of circumferential stresses in the top layer of workpieces subjected to abrasive smoothing with grinding discs of fixed and variable cutting surface conformability CPS, diversified in the grain size range applied, do not show any significant differences.

On the other hand, the microhardness and the state of axial stresses in the top layers of surfaces subjected to abrasive smoothing by means of grinding discs that differ in respect of conformability of their cutting surfaces and abrasive grain size show significant differences.

It should be emphasized that stresses in top layers of surfaces subjected to working with grinding discs of variable conformability show lower values in both directions of measurement than stresses in top layers of surfaces subjected to working with grinding discs of fixed conformability.

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