Surface finishing of hardened steel with abrasive brushes

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Abstract. Standard finishing processes normally require special machine tools whereby the process can be time-consuming and cost-intensive due to a high non-productive time. An integration of the finishing process into the existing machine tools should reduce or avoid the mentioned disadvantages. A high potential to integrate the finishing process into the existing machine tools offers abrasive brushes. Until now, due to limited fundamentals of the cutting process of abrasive brushes the high potential is unused. This paper presents new findings concerning the brushing process of hardened steel as a typically used material for functional surfaces. Therefore, characteristic values of the specific abrasive brushes were detected and the influence of the process parameters on the machining results was determined. The results show that the process parameters and the use of cooling lubricant have a significant influence on the brushing process. Furthermore, a suitable use of different process parameter combinations allows an efficient manufacturing of a surface roughness Ra < 0.1 µm.

Introduction

A high quality on the workpiece surface can be manufactured by an additional finishing process at the end of the manufacturing process chain. Typically, the finishing process will be executed on special machines by what high costs and a high process time can occur. A reduction of the costs and the process time as well as an enhancement of the flexibility can be enabled by integrating the surface finishing process into the existing machine tools of the previous manufacturing processes. A manufacturing process which offers this potential is brushing with abrasives. The corresponding tools, called abrasive brushes, consist of a brush body and high-flexible filaments of plastic with embedded abrasive grains, Fig. 1. The possibility of using different types and sizes of abrasive grains allows the manufacturing of high surface qualities on different materials. Until now, only a small number of publications on brushing with abrasives are available which restrict the configuration of an appropriate surface finishing process. The actual findings are described below.

FITZPATRICK AND PAUL [1] determined in their investigations an enhancement of the material removal rate with the contact pressure. The contact pressure depends thereby on different process parameters. Furthermore, a rise of the material removal rate was detected for higher rotational speeds of the brush v_b, shorter abrasive filaments and bigger grains [2, 3]. A comparison of the often-used grain materials silicon carbide (SiC) and aluminium oxide (Al_2O_3) shows additionally a higher material removal rate by using SiC grains [3]. Next to the process parameters the condition of the abrasive brush has an important influence on the material removal rate. New and dressed abrasive brushes have a higher material removal rate than long time used brushes [2]. During the brushing process the tip of new and dressed filaments first adapt to the form of the workpiece surface and reduce after that point their length [2,4]. Next to the material removal rate the manufactured surface roughness is an important result of the brushing process. LANDENBERGER [2, 3] and UHLMANN ET. AL. [5] determined that small values of the surface roughness can be manufactured by using small rotational speeds of the brush v_b and small grain sizes.

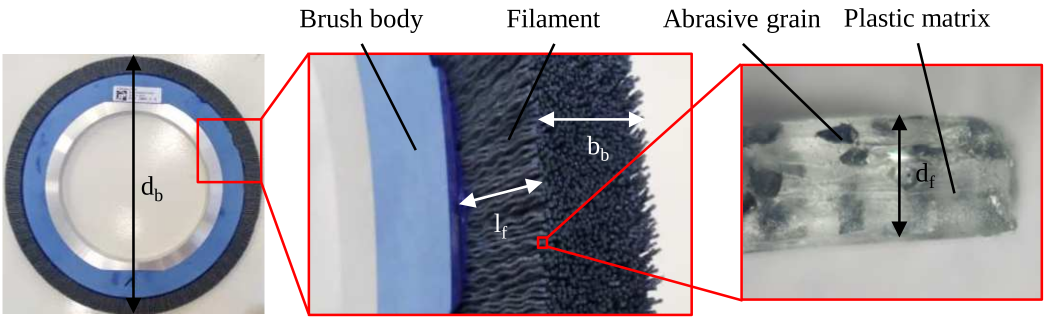


Figure 1: Dimensions of an abrasive brush

The objective of this study is to manufacture a surface roughness of Ra < 0.1 µm on grinded workpieces of the hardened steel 16MnCr5 with abrasive brushes in an efficient way. Therefore, the mentioned findings should be enhanced by characterizing different brush specifications and further investigations on the influence of process parameters on the material removal rate and the resulting surface roughness. The results are used to develop a surface finishing process for abrasive brushes to achieve the mentioned results.

Characterization of abrasive brushes

For this study two different abrasive brushes with varying values for the grain size are chosen, Table 1. A variation of the grain size can change the structures of the filament by what the cutting behaviour during the brushing process can be influenced. To analyse the influence of the grain size on the filament structure three-dimensional models of the different filament specifications were pictured with the computer tomography scanner Metrotom 800 from CARL ZEISS AG, Oberkochen, Germany. Therefore, a piece of a single abrasive filament was positioned on a table in the workspace of the computer tomography scanner. A rotation of the table enables thereby different X-ray pictures around the filament contour. During the measurement the X-rays permeate the filament and will be differently absorbed by the polyamide 6.12 as the plastic material and the SiC as the grain material. This results in a spectrum of different grey values after the detection. An analysis of the grey scale spectrum with the software VGStudio from CARL ZEISS AG, Oberkochen, Germany, enables a separation of the polyamide 6.12 and the SiC grains as Voxel-graphics. The Voxel-graphic of the SiC grains was used to determine the dimensions, the volume and the position of the grains. Thereby, the Voxel-graphic shows that the grains have a complex geometry, Fig. 2a. To reduce the complexity, the grains were approximated by spheres for the further investigation, Fig. 2b. Therefore, a single sphere has the volume of the corresponding grain and the midpoint of the sphere is positioned at the centre of gravity of the grain.

Table 1: Chosen abrasive brushes

Brush	d_b [mm]	w_b [mm]	d_f [mm]	l_f [mm]	Plastic matrix	Abrasive grain	Grain size [mesh]
1	340	20	0.6	30	Polyamid 6.12	SiC	320
2	340	20	0.6	30	Polyamid 6.12	SiC	120

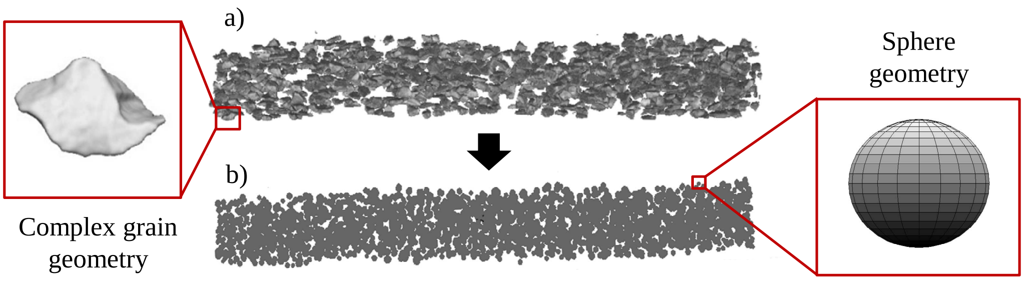


Figure 2: Filament structure analysis: a) voxel-graphic of the abrasive grains and b) approximation of the abrasive grains by spheres

The replacement of the grains by spheres was used to analyse the grain distribution in the filament. Therefore, the Euclidean distances between the midpoints of the spheres were determined. A mean grain distance $\bar{d}_g$ was calculated for each sphere by the five smallest Euclidean distances to the neighbouring spheres. The results show that the mean grain distance $\bar{d}_g$ and the spread of the mean grain distance $\bar{d}_g$ rise with the grain size, Fig. 3. Based on the result, the number of grains in contact with the workpiece decreases with the grain size. Furthermore, a high spread of the mean distance $\bar{d}_g$ refers to grain accumulations and grain voids and therefore to an inhomogeneous filament structure which can lead to varying material removal rates during the brushing process.

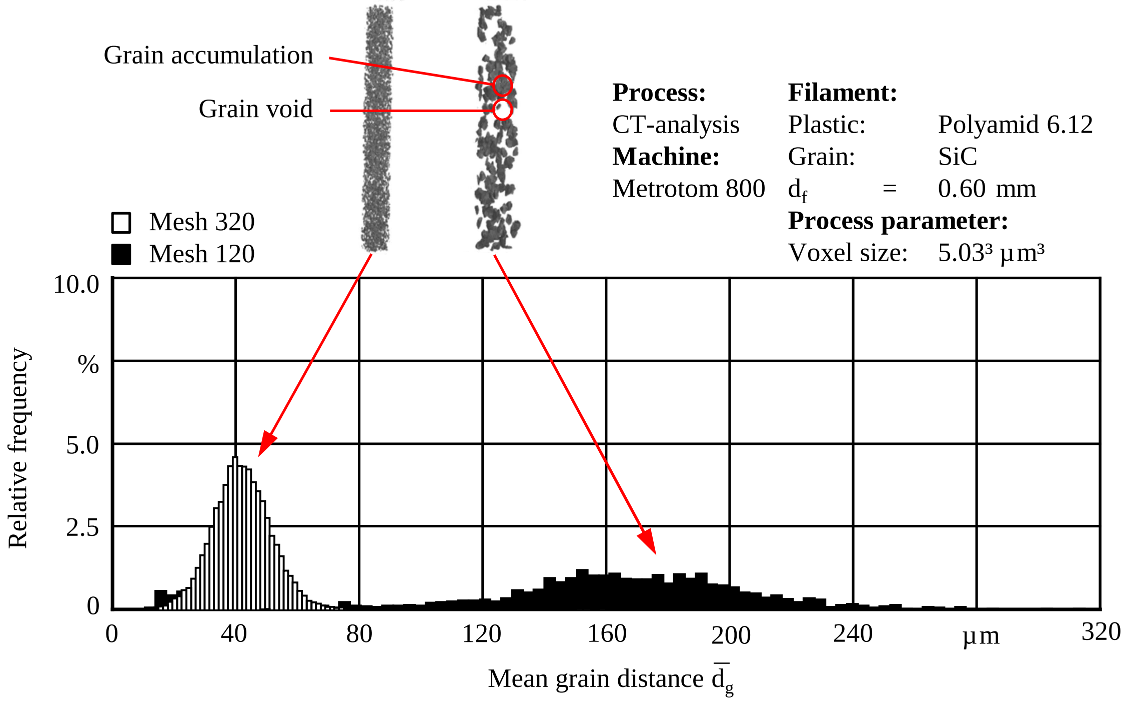


Figure 3: Mean grain distance $\bar{d}_g$ in abrasive filaments

An analysis of the contact zone during a dry brushing process with the infrared camera Jade II MWIR from INFRATEC GMBH, Dresden, Germany, shows that the temperature can rise to more than 50 °C by using the chosen abrasive brushes and generally for industrial brushing processes used machine parameters, Fig 4a. The increased contact zone temperature or the use of cooling lubricant can reduce the stiffness of the filaments and thereby influence the cutting behaviour of the brushing process as well. To investigate the influence of the temperature and the cooling lubricant on the filament stiffness the Young's modulus, as the corresponding characteristic material value, was determined with a tensile test by using DIN EN ISO 527 [6]. The tensile test was carried out on the tensile testing machine T1-FR150SN from ZWICK GMBH

& CO. KG, Ulm, Germany, with a clamping length of $l_c = 50$ mm and a test velocity of $v_t = 5$ mm/min. Thereby, filaments of the used specifications were heated up to 50 °C, as the determined contact zone temperature for a dry process, during the tensile test or placed in different typical used cooling lubricants before the tensile test. The variation of the filament temperature during the tensile test shows that an enhancement of the filament temperature reduces significantly the Young's modulus, Fig 4b. As cooling lubricant the use of oil and emulsion were compared. The filaments were laid in the cooling lubricants for eight hours. The results of the tensile test show that the Young's modulus of the filaments doesn't change significantly after lying in oil for eight hours. In contrast, the Young's modulus reduces strongly after lying in emulsion. The used emulsion has a ratio of 95 % water and the used plastic matrix of the filaments can absorb some of this water which leads to a more flexible filament. To reduce the influence of the contact zone temperature and the water absorption of the filament on the cutting behaviour, oil was used as cooling lubricant for the brushing investigations.

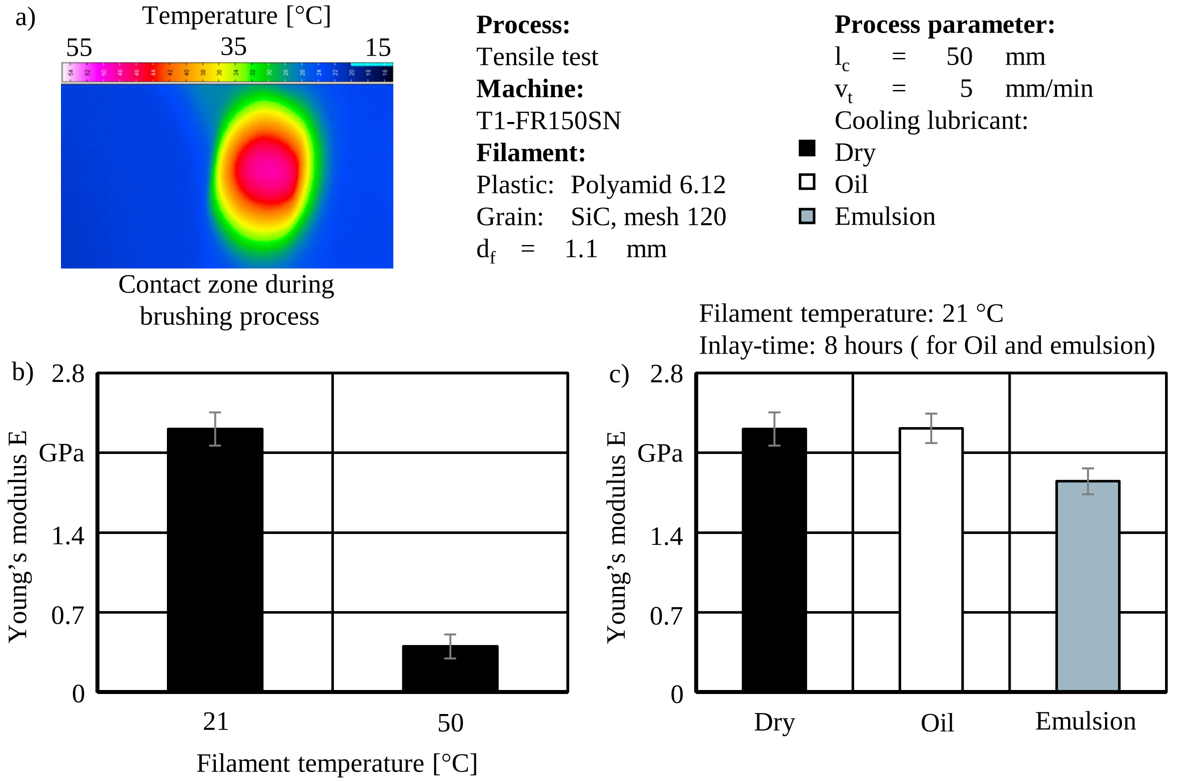


Figure 4: Influence of the contact zone temperature and the cooling lubricant on the Young's modulus

Experimental set-up

The brushing investigations were carried out on the plane grinding machine Profimat MT 408 HTS from BLOHM JUNG GMBH, Hamburg, Germany, with a rotational speeds of $v_b = 20$ m/s, a feed rate of $v_f = 100$ mm/min and a depth of cut of $a_e = 1$ mm as generally for industrial brushing processes used machine parameters. For a process one of the chosen abrasive brushes were fixed on the spindle of the grinding machine and the used plane workpieces of the steel 16MnCr5 with a hardness of HRC 56 were clamped on a dynamometer which is fixed on the machine table. Further, the fixed brush was rotated by the spindle with the rotational speeds v_b and placed by the axes of the machine tool in front of the workpiece with the depth of cut a_e. A subsequent linear movement of the machine table with the feed rate v_f

leads to a contact between the workpiece and the abrasive brush. The linear movement ends after the workpiece passes completely the brush. During the brushing process the dynamometer records the acting normal force F_n and the acting tangential force F_t. Furthermore, the roughness on the workpiece surface was measured before and after the brushing process by the surface roughness tester SJ-210 from MITUTOYO CORPORATION, Kawasaki, Japan.

Finishing process

The objective of this study was to develop a brushing process which processes a roughness of Ra < 0.1 µm on hardened surfaces of the steel 16MnCr5 in an efficient way. Therefore, a brushing investigation was executed to determine the limiting roughness of the chosen brushes during the process time, Fig. 5. The results show that the roughness doesn’t change anymore for brush 1 with a grain size of mesh 320 at a value of Ra < 0.09 µm and for brush 2 with a grain size of mesh 120 at a value of Ra < 0.16 µm. Hence, a surface roughness of Ra < 0.1 µm can be manufactured by brush 1. Furthermore, the results of the investigation show that a surface roughness of Ra < 0.16 µm can be manufactured faster with the bigger grains. This confirms the findings of [4] and can be explained by the number of grains in contact with the workpiece. Table 2 shows that during the brushing process the acting forces are closely the same for both brushes. Therefore, the normal force F_n and the tangential force F_t distributes to a smaller number of grains by using the bigger grain size, Fig. 3. The higher load on the single grains leads further to a higher penetration of the workpiece surface which causes deeper scratches and a higher limiting roughness. Next to the grain size, the influence of using cooling lubricant on the process time t_p was investigated. The investigation shows no significant influence on the reduction of the surface roughness by using cooling lubricant compared to a dry brushing process, Fig. 5b. It is expected that an additional lubricant effect which leads to a reduced friction counteracts the high filament stiffness due to the low contact zone temperature by using oil as cooling lubricant.

Process:	Brushing tools:		Process parameter:
Brushing with abrasives	d_f = 0.6 mm	Plastic: Polyamid 6.12	v_b = 20.0 m/s
Machine:	d_b = 340.0 mm	Grain: SiC	v_f = 100.0 mm/min
Profimat MT 408 HTS	b_b = 20.0 mm	Brush 1: mesh 320	a_e = 1.0 mm
Workpiece:	l_f = 30.0 m	Brush 2: mesh 120	
Steel block			
16MnCr5, 56 HRC			

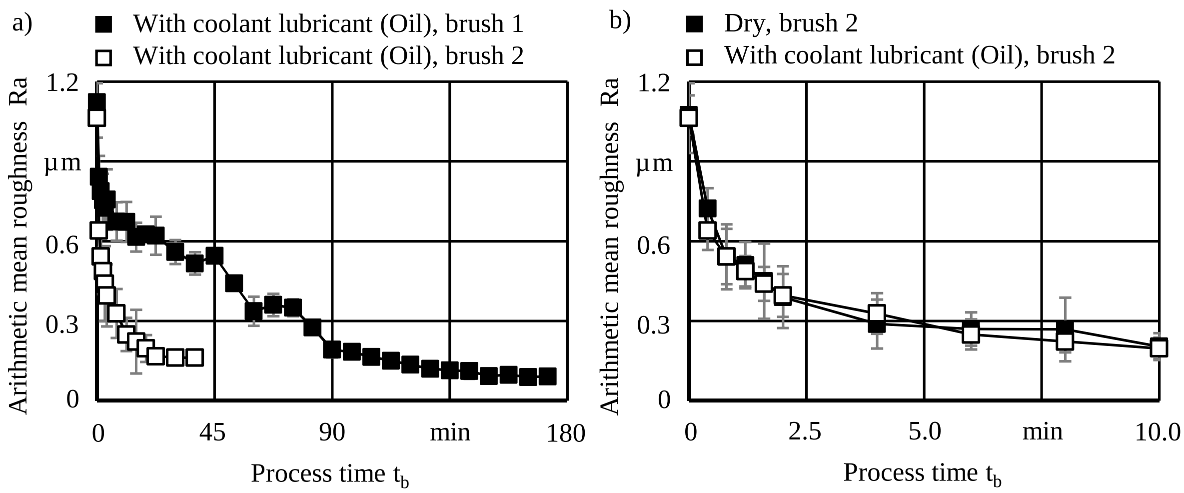
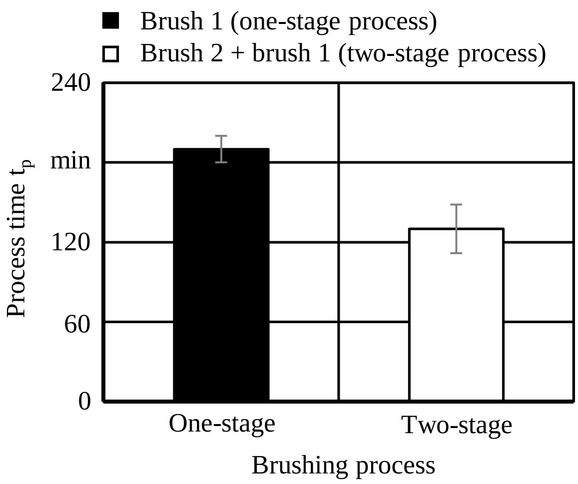


Figure 5: Brushing investigations: a) limiting roughness for the chosen brushes and b) roughness reduction for a dry and an cooled brushing process

Table 2: Acting forces during the brushing process

Brush	Normal force F_n [N]	Tangential force F_t [N]
1	73.6	5.3
2	74.6	5.0

Based on the presented results a two-stage manufacturing process was derived to manufacture a surface roughness of Ra < 0.1 µm in a short time. Thereby, the first brushing operation manufactured a surface roughness of Ra < 0.16 µm in a short time with brush 2. A following second brushing operation with brush 1 reduced the surface roughness to a value of Ra < 0.1 µm. Compared to a one-stage brushing process by using brush 1 the developed two-stage process reduces the process time t_p about 32 %, Fig. 6.



Process:
Brushing with abrasives
Machine:
Profimat MT 408 HTS
Brushing tool:
d_f = 0.6 mm
d_b = 340.0 mm
b_b = 20.0 mm
l_f = 30.0 mm
Plastic: Polyamid 6.12
Grain: SiC
Brush 1: mesh 320
Brush 2: mesh 120
Workpiece:
Steel block
16MnCr5, 56 HRC
Process parameter:
v_b = 20.0 m/s
v_f = 100.0 mm/min
a_e = 1.0 mm

Figure 6: Process time t_p to manufacture a surface roughness of Ra < 0.1 µm for different brushing processes

Summary and outlook

A developed finishing process with abrasive brushes was presented in the paper to manufacture a surface roughness of Ra < 0.1 µm on the existing machine tools in an efficient way. Therefore, the influences of different grain sizes, the contact zone temperature and the cooling lubricant on the brushing process were analysed. Based on the findings a two-stage brushing process by using brushes with different grain sizes was developed to achieve the objective. Compared to an often used one-stage brushing process the developed two-stage brushing process significantly reduces the process time t_p.

In continuative investigations it is planned to analyse the influence of different machine parameters and further brush parameters on the brushing process. The additional findings should be used for a further reduction of the surface roughness and the process time t_p.

References

[1] F. R. Fitzpatrick, F. W. Paul, Robotic Finishing Using Brushes Material Removal Mechanics, Deburring and Surface Conditioning, Phoenix, Arizona, 17. - 19.02.1987.

[2] D. Landenberger, Feinbearbeitung von metallischen Konstruktionswerkstoffen durch Bürstspanen, Jahrbuch Schleifen, Honen, Läppen und Polieren 63 (2007) 436 - 450.

[3] D. Landenberger, Flexible Feinbearbeitung für die Refabrikation von Automobilkomponenten, Dissertation, Shaker, Aachen, 2007.

[4] R. W. Overholser, R. J. Stango, R. A. Fournelle, Morphology of metal surface generated by nylon/abrasive filament brush, Journal of Machine Tools & Manufacture 43 (2002) 193 - 202.

[5] E. Uhlmann, C. Sommerfeld, M. Renner, M. Baumann, Bürstspanen von Profilen, Werkstattstechnik (wt) online 107 (2017) 472 - 478.

[6] DIN EN ISO 527-1, Teil 1, Kunststoffe-Bestimmung der Zugeigenschaften-Teil 1: Allgemeine Grundsätze, Beuth, Berlin (1996).