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Complementary Machining – Machining Strategy for Surface Modification

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Abstract

In metal production mechanical surface treatments are used to optimize workpiece characteristics like fatigue strength. Complementary Machining is a new machining strategy which is characterized by the combination of cutting and mechanical surface treatment. After cutting the insert is used reversely acting as a tool for mechanical surface treatment. This paper shows the effect of high plastic deformation rates in the surface layer reducing surface roughness and increasing strain hardening. Furthermore, it is supposed that the process induces grain refinement in the surface layer. The process strategy Complementary Machining is investigated during machining Armco-Iron and AISI 4140.

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Keywords: Surface Modification; Hybrid Machining; Machining Strategy

Nomenclature

α	clearance angle
β	wedge angle
γ	rake angle
r_β	cutting edge radius
v_c	cutting speed
v_{st}	surface treatment speed
h	cutting depth
a_p	penetration depth
F_c	cutting force
F_{st}	surface treatment force
F_p	passive force
k_p	specific passive force

1. Introduction

In industrial metal production a high efficiency and quality of machining processes is of great importance. In this context the aim for high quality parts is to produce surfaces with high geometric accuracy and surface integrity to enhance the workpiece characteristics like fatigue strength, wear, tribology or corrosion [1]. The component state in the surface layer (e.g. residual stresses, roughness, micro hardness or grain size) has a significant influence on these workpiece behaviors [2-5]. The investigations showed that workpieces with a grain size of a few nanometers in a surface layer with a thickness of 30 to 200 µm have increasing fatigue strength, micro hardness, resistance to friction wear and fatigue endurance limit [6-7]. Due to severe plastic deformation (SPD) nanocrystalline (nc) structures can be generated [8-9]. However, nanostructured surface layers can be produced with surface severe plastic deformation (S^2PD) [10-11]. Actually, these processes are realized with an additional surface treatment process.

The Complementary Machining is a new machining strategy which is characterized by the combination of cutting and mechanical surface treatment [12]. After the cutting process the cutting tool is used in opposite direction resulting in a plastic deformation of the surface layer. On the one hand the process is reciprocal because the tools are used in the opposite direction. On the other hand the process is integral, because standard machining is supplemented by mechanical surface treatment. For that reason the machining strategy is called Complementary Machining. One of the objectives of the current investigation is to generate knowledge about how specified nanocrystalline surface layers can be produced in machining operations. Further, the objective of Complementary Machining is the reduction of surface roughness and an increasing strain hardening.

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This study presents the effect of high plastic deformation rates in the surface layer on the surface roughness and on the strain hardening.

2. Experiments

2.1. Material

For the investigations Armco-Iron and AISI 4140 (German steel 42CrMo4 V450) were used. In Tab. 1 their chemical compositions are presented. The initial micro hardness HV for Armco-Iron and AISI 4140 are 87 HV 0.01 and 335 HV 0.01, respectively.

Table 1. Chemical compositions of Armco-Iron and AISI 4140 (in wt%).

Material	Fe	C	Si	Mn	Cu	Cr	Ni	Al	Mo
Armco	Basic	0.003	0.016	0.079	0.011	0.019	0.013	0.007	0.001
AISI 4140	Basic	0.398	0.259	0.802	0.072	1.15	0.03	0.031	0.21

2.2. Experimental setup

Fig. 1 shows the contact condition for realization of the process strategy Complementary Machining. The experiments were carried out using a vertical broaching machine from Karl Klink with a maximum cutting speed of $v_{c,max} = 160\ m/min$. The workpiece was clamped vertically on the linear machine slide which moves upwards with the relative velocity v_{rel}. The length of the workpiece is $l = 80\ mm$, the width $w = 7\ mm$ and thickness $t = 4\ mm$. An uncoated cutting tool from Walter Tools (WKM P8TN-6028833) was used.

For the Complementary Machining different machining strategies are possible. After cutting, the subsequent surface treatment can be repeated multiple times. In this paper, Complementary Machining was investigated using AISI 4140. The parameters for the investigation are shown in Tab. 2. Although the ratio of $r_\beta/a_p = 2$ during the surface treatment no chip formation in combination with the strongly negative rake angle occurs. To establish a deeper process understanding, the surface treatment step was examined separately using a ductile material (Armco-Iron). In this case, the surface treatment was repeated several times. To guarantee equal machining conditions for the surface treatment of Armco-Iron, the same cutting tool and process parameters as for the machining for AISI 4140 were used.

The process forces were measured by a Kistler three component dynamometer Type Z 3393. For analyzing the micro hardness HV a Qness micro hardness tester type Q10A with 10x and 40x lens was used. The roughness measurements were conducted utilizing a perthometer by Mahr. The surface roughness was analyzed orthogonal to the cutting and machining direction at three measurement points.

At the machining strategy Complementary Machining the tool is additionally loaded due to the surface treatment and an increasingly tool wear would be expected. However, in the context of these investigations no significant tool wear was observed.

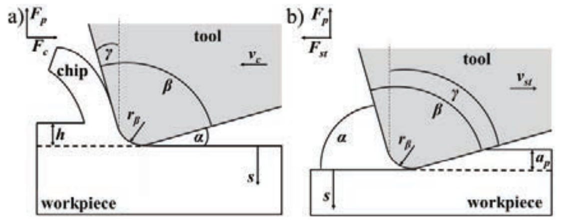

Fig. 1. Contact conditions for realization of Complementary Machining: a) cutting b) surface treatment

Table 2. Parameters for the Complementary Machining.

Parameter	Cutting	Surface treatment
Clearance angle α [°]	7	83
Wedge angle β [°]	90	90
Rake angle γ [°]	-7	-83
Cutting edge radius r_β [µm]	40	40
Cutting depth h [µm]	60	-
Cutting speed v_c [m/min]	100	-
Penetration depth a_p [µm]	-	20
Surface treatment speed v_{st} [m/min]	-	100

3. Results and discussion

3.1. Roughness

The measurements of the surface roughness *Ra* and *Rz* show the conditioning potential of the machining strategy Complementary Machining influencing the surface roughness. Fig 2. shows the progress of the surface roughness *Ra* and *Rz* for AISI 4140. Due to the cutting process the surface roughness *Ra* and *Rz* increase significantly compared to the initial values. With the subsequent surface treatment, this rise of surface roughness can be reduced again. After the complete Complementary Machining the surface roughness can be adjusted into the range of $Ra = 0.14\ \mu m$ and $Rz = 0.75\ \mu m$.

For analyzing the sub-processes, the surface treatment was carried out separately using Armco-Iron. In these experiments, the surface treatment was repeated up to 10 times. Fig. 3 shows the progress of the surface roughness *Ra* and *Rz* for this investigation. Due to the first surface treatment the surface roughness decreases down to $Ra = 0.86$ and $Rz = 5.8\ \mu m$. In succession of additional repetitions of the surface treatment the surface roughness can be reduced down to $Ra = 0.18$ and $Rz = 1.11\ \mu m$.

The analysis of the surface after the surface treatment and the Complementary Machining shows the reduction of the surface roughness due to the plastic deformation in the surface layer. As a result, irregularities in the surface can be reduced or eliminated. Another effect of repeated surface treatments is the formation of burrs whereby the workpiece height can be influenced. This effect is already shown in [12].