Surface conditioning by ultrasonic wet peening

A. Kienzler, V. Schulze and D. Löhe

Institute of Materials Science and Engineering I, University of Karlsruhe (TH), Kaiserstraße 12, D-76131 Karlsruhe, Germany

ABSTRACT

A systematic investigation has been carried out on cavitation in abrasive suspensions and the impact on surfaces. A mixture of Al_2O_3 and distilled water is used. It is shown in this work that the generated surface topography depends strongly on the experimental conditions. Different surface topographies are obtained if only distilled water is used or if additionally particles are suspended in the fluid. The process is capable of removing burrs with heights of about 20 µm. Another positive result is the reduction of roughness in micro moulds for micro powder injection moulding during the process. Additional measurements show that by the impact of the particles high compressive residual stresses can be induced in the near surface layers. The capability of this process will be compared to other finishing processes in the micro regime.

KEY WORDS

Ultrasonic cavitation, Fine particle peening, Micro deburring, Smoothing, Micro Moulds

INTRODUCTION

For an economic large-scale production of micro parts, micro injection molding is a common process (Piotter, 2001). This process needs micro moulds which have good wear behaviour (Schneider, 2005) to ensure a long lifetime and a good surface quality with very low surface roughness to release the micro parts without damages. The best surface quality in micro moulds made of quenched and tempered tool steel is actually achieved by micro milling (Fleischer, 2007). But even this process generates striations and burrs coming up from the cutting process. The latter are caused by the necessity of milling hard material states in order to get good wear behaviour and to avoid distortions resulting from heat treatment processes after milling. Therefore, deburring and surface conditioning processes of cavities in the micro regime have to be developed and applied.

For example micro abrasive peening with non-abrasive blasting agents is an appropriate tool for removing burrs and surface textures (Horsch, 2005). Nevertheless abrasive peening often increases the surface roughness or leads to plastic deformations e.g. edge rounding.

Methods based on ultrasonic cavitation in fluids seem to have a high capability for the quality improvement of machined surfaces. Cavitation shotless peening (Soyama, 2003) or peening with abrasive particles accelerated by cavitation collapse treat the surface in a manner which is beneficial for the further application of the workpiece. These processes can be adopted to the micro regime because no form tools are needed.

In the collaborative research centre SFB 499 "*Development, production and quality assurance of moulded micro-components made out of metallic and ceramic materials*" (Löhe, 2005) an ultrasonic wet peening process (Horsch, 2006) was analysed for finishing of micro moulds, regarding the effect on surface and near-surface properties like roughness, material removal or residual stress state. It is shown that with appropriate peening parameters deburring and roughness reduction is possible within a few minutes. This can be achieved without generating strong edge rounding or other form errors. Another benefit is the creation of high compressive residual stresses in the near surface layers. To evaluate the suitability of this process it is compared to cavitation shotless peening and abrasive peening.

METHODS

All tests were carried out with specimens made from low-alloyed tool steel Toolox 44 (30CrMo6 SSAB Oxelösund, Sweden; 0.3% C, 1.35% Cr), which was quenched and tempered at 590 °C by the manufacturer to a hardness of 448 HV1. According to the manufacturer, this steel shows a high purity and homogeneity comparable to electro slag remelted steels.

A cutting tool made of hard metal with a width of 500 µm was used to mill a groove having a width of 500 µm at a depth of 100 µm along a track of 5 mm.

The finishing process was conducted by ultrasonic wet peening. For the experiment the horn of the ultrasonic processor type „Hielscher UIP-500” with a maximum acoustic power of 500 W and a frequency of 20 kHz was placed in a tank with the fluid. An adjustable table enables the setting up of the distance between the workpiece and the horn. As fluid distilled water or a mixture of distilled water and 5 wt.-% Al_2O_3 was used. A continuous exchange of the fluid between the horn and the workpiece (distance ~ 1 mm) was enabled by a magnetic stirrer and a pulse duration of 0.8 s followed by a break with no ultrasound of 0.2 s. The temperature of the fluid was kept constant at 25 °C by a water filled cooling coil.

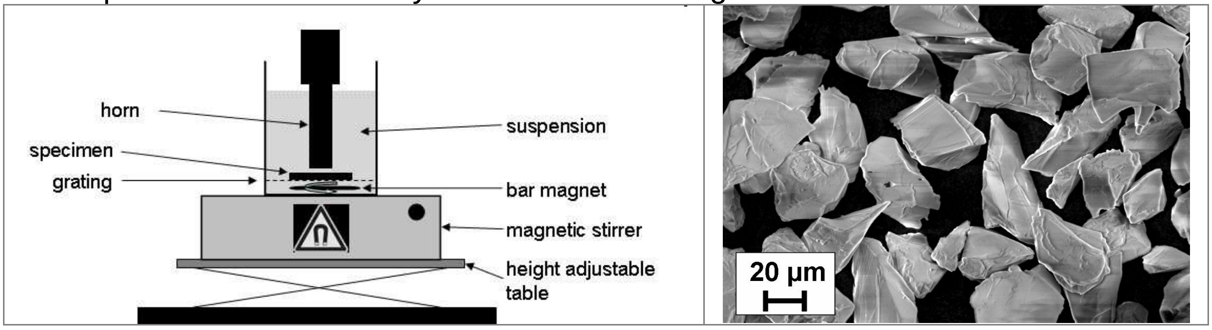

Figure 1: Schematic view of the experimental set-up (left), blasting agent Al_2O_3 (right)

The characterisation of the machined micro moulds was carried out with a confocal white light microscope of the type „Nanofocus µSurf“. For the determination of the roughness values (R-values), 102 profile lines were extracted out of the measured topography followed by the calculation of the Rz value for each profile line. To ensure that artefacts on the surface have no influence, the average was used as appropriate value. High-frequency and low-frequency components of the surface profile were sepa-rated by filtering with a cut-off wavelength of 250 µm.

X-ray diffraction measurements were conducted using conventional X-rays generated from a sealed tube. A D500 Siemens diffractometer was used to scan the α-Fe {211} Bragg peak at a characteristic spectrum of Cr-Kα radiation (λ = 0.22897 nm; E_{ph} = 5.41 keV). A range of $146° \leq 2\theta \leq 166°$ at $\Delta 2\theta = 0.2°$ at 5 sec/step was covered during the measurements. Thirteen inclination angles Ψ ranging from $-60° \leq \Psi \leq 60°$ varied at intervals of $\Delta\Psi = 10°$ were employed for the $\sin^2\Psi$-method (Macherauch, 1961).

RESULTS

Figure 2 shows scanning electron microscope (SEM) images of a polished surface after 20 min ultrasonic wet peening with different experimental conditions. Fig. 2 left) shows a finished surface obtained when no particles are suspended in distilled water.

One can see two deep round pits, each surrounded by a bright circle. The obtained surface after 20 min ultrasonic wet peening with 5 wt.-% Al_2O_3 but without continuous circulation (magnetic stirrer off) is shown in Fig. 2 middle).

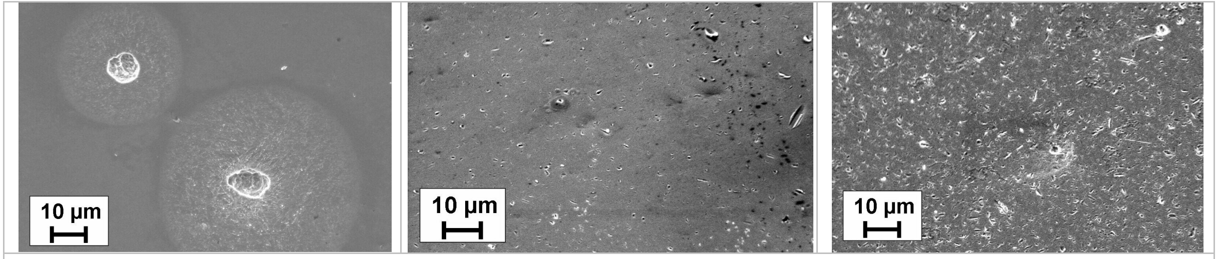

Figure 2: Polished surface after 20 min ultrasonic wet peening: Left) in distilled water; Middle) in distilled water with 5 wt.-% Al_2O_3 (magnetic stirrer off); Right) in distilled water with 5 wt.-% Al_2O_3 (magnetic stirrer on)

Scattered irregular shaped processing marks like scratches or wedge-shaped pits are observed. Large round pits as can be seen in Fig. 2 left) are no more observed. To increase the impact per time a magnetic stirrer was used to provide continuous circulation of the suspended particles, here again 5 wt.-% Al_2O_3 in distilled water. An increased number of irregular shaped processing marks can be seen on the new created surface (see Fig. 2, right) in comparison with the surface peened without continuous circulation.

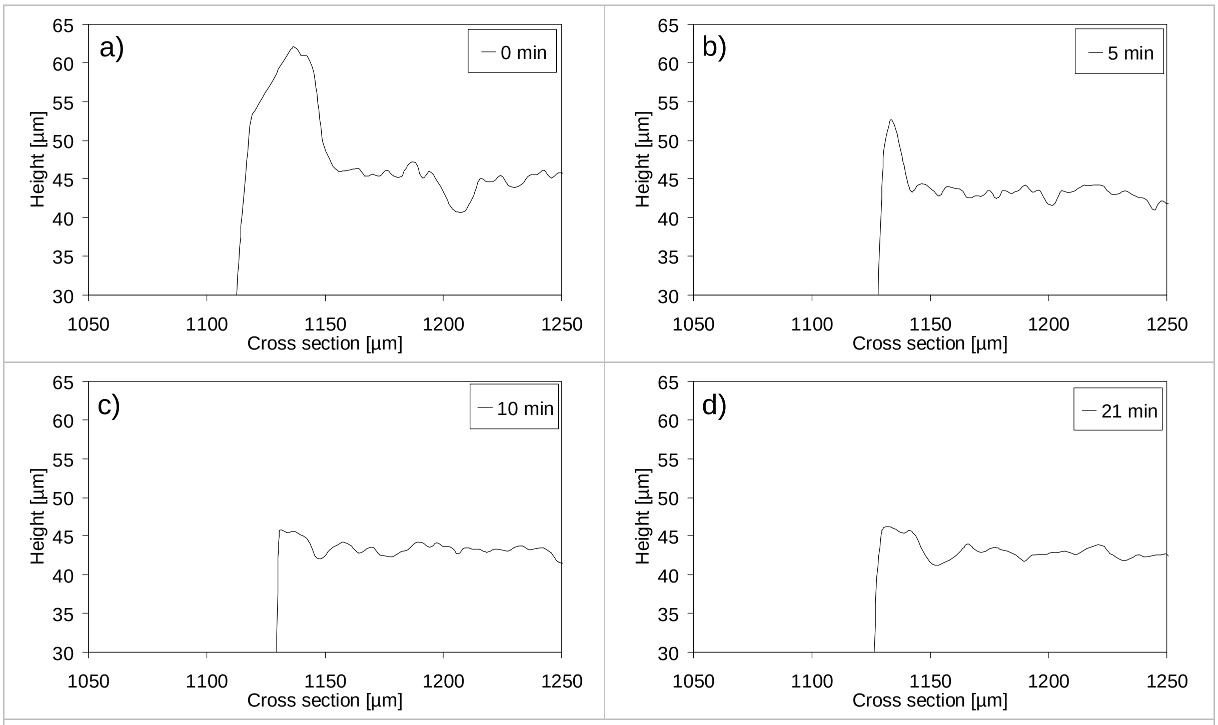

Figure 3: Cross-sections of the upper edge after a) 0 min, b) 5 min, c) 10 min and d) 21 min ultrasonic wet peening (magnetic stirrer on)

With these improved experimental conditions a micro milled groove was ultrasonic wet peened for 21 minutes. Fig. 3 shows cross-sections of an edge of the groove after different peening times. Before peening a large burr with a size of 20 µm is observed. After 5 min peening this burr was reduced to a height of about 10 µm. A peening time of 10 min yields to an almost complete elimination of the burr. Further peening for another 11 min only reduces roughness. A residual burr of about 2 – 3 µm is left on the edge of the groove.

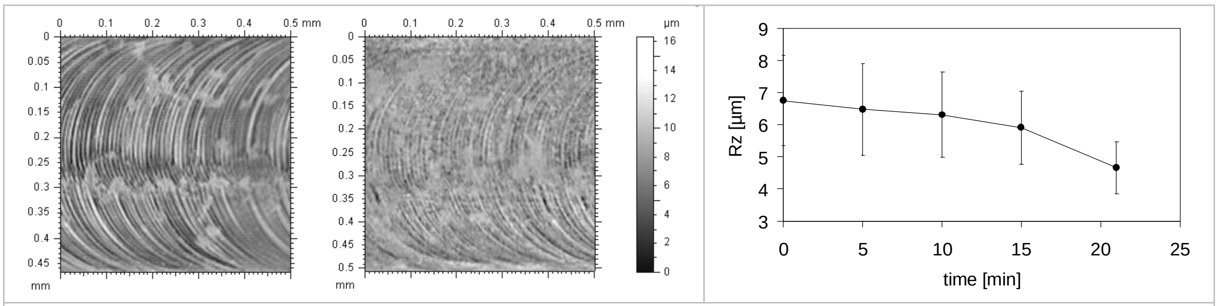

Figure 4: Surface topography before and after 21 min ultrasonic wet peening (left), roughness vs. time (right), magnetic stirrer on

The bottom of the milled groove was examined by a confocal white light microscope. The typical topography characteristics of a milled surface can be observed before ultrasonic wet peening. After 21 min surface conditioning a more uniform topography is observed, the striations weaken. The evolution of roughness vs. time indicates the smoothing effect of this process. After 21 min of ultrasonic wet peening the roughness is reduced from Rz = 6.75 µm to 4.66 µm.

In order to check the influence of ultrasonic wet peening on the residual stress state at the surface of the specimens, a stress free state was prepared. Measurements with conventional X-ray sources as described in (Kienzler, 2007) validate the stress free surface before ultrasonic wet peening (see Fig. 5). After 20 min ultrasonic wet peening with 5 wt.-% Al_2O_3 in distilled water equi-biaxial compressive residual stresses of about - 480 MPa are induced in the sample surface.

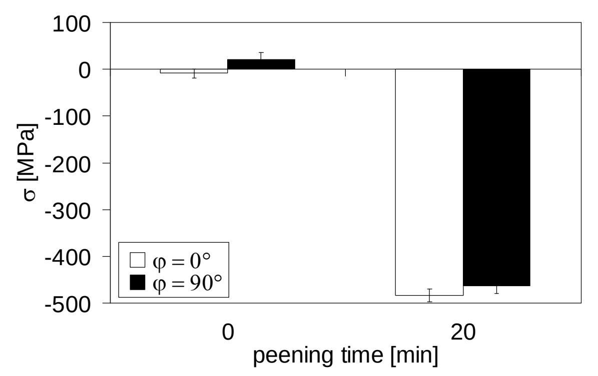

Figure 5: Residual stress values before and after 20 min ultrasonic wet peening of a stress free state

DISCUSSION

Concerning the results shown in Fig. 2 one has to separate the finishing processes occurring in the fluid (Ichida, 2005). The first process without abrasive particles in distilled water is based on the erosion due to cavitation collapse. Round processing pits with a diameter of about 5 µm and a depth of about 4 µm are generated. The outcome is a worse surface quality with an increased roughness. This process is the basic principle which is also used in cavitation shotless peening for surface treatment, where cavitation is induced by a submerged high-speed water jet, i.e. cavitation jet and not by an ultrasonic wave in a fluid. The second is the removal processing due to colliding or sliding of the particles accelerated by micro jets created by cavitation collapse. This process is similar to abrasive peening in air, where particles are accelerated towards the workpiece surface by air pressure. The most important difference is that in case of abrasive peening in air all particles impinge at almost the same angle whereas in ultrasonic abrasive peening the impact angle ranges from 0° to 90° to the workpiece surface. Irregular shaped processing marks of different size and orientations confirm this fact. To increase this removal mechanism i.e. to increase the coverage, a magnetic stirrer guarantees a continuous exchange of the fluid with abrasive particles between the horn and the workpiece and yields a number of increased impacts on the machined surface. It seems that during the process without continuous exchange the particles move away from the gap between the horn and the workpiece and the removal process is attenuating. Nevertheless it should be mentioned here that an increase of the density of the abrasive particles in the fluid will not result in an increase of the removal rate. If the density of the abrasive particles in the fluid is too high, they will interfere with each other and a decrease of processing marks is the consequence (Ichida, 2005). Another advantage of abrasive particles in the fluid is the suppression of the first process, the erosion due to cavitation collapse. With suspended particles in the fluid only very small round pits in the range of 1 µm can be observed on the machined surface.

Deburring and roughness reduction is another important aim of finishing processes. Despite the advantages of abrasive peening or cavitation shotless peening these processes yield to an increased roughness or to large edge rounding. In contrast ultrasonic wet peening may reduce roughness and almost avoid edge rounding. One reason for the small residual burr could be work hardening due to micro milling. The consequence is a decreased removal rate at the edges of the groove. Regarding Fig. 4, it seems that longer processing times yield to further roughness reduction and therefore more investigations on this issue have to be done.

Inducing high compressive residual stresses is an important intention when finishing a mechanical surface to enhance the fatigue properties and thus increase the service lifetime of the moulds. Cavitation shotless peening and abrasive peening are also capable to introduce high compressive residual stresses in the near surface layers of tool steel (Soyama, 2003; Kienzler, 2007).

High compressive residual stresses, which are induced by the ultrasonic wet peening process in the near-surface layers after 20 minutes, are quite comparable to residual stresses produced by the other finishing processes.

CONCLUSION AND IMPLICATIONS

In this paper a non-contact finishing process for moulds used in micro powder injection moulding was investigated. An increase of the removal rate due to the impact of accelerating abrasive particles was achieved by a continuous exchange of the fluid between the horn and the workpiece. This reduces the deburring time to a few minutes. The surface texture is changing and high compressive residual stresses are induced in the near surface layers which are beneficial for the wear behaviour of the micro moulds during injection moulding. This process has advantages regarding roughness reduction or avoiding edge rounding, the generation of residual stresses is quite similar compared to abrasive peening or cavitation shotless peening. Further investigations will focus on the smoothing effect and the induced compressive residual stresses.

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