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# Micro structure rolling process with laser structured roller tools

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**Abstract**

In recent years, there has been an enormous increase in the need to specifically functionalize surfaces through microstructures and coatings. This is an attempt to meet increased performance requirements and the use of new materials in mechanical and automotive engineering. In most scientific publications on this subject, microstructures are created by laser ablation. However, this process is often not economical in the context of large-scale production. The structure rolling process for microstructuring of rotationally symmetric workpieces can close this gap. Short process times, comparatively simple handling and resource-efficient structuring characterize the structure rolling process.

In the publication the workflow for structuring typical components is described. In addition, different processing strategies for the production of structured rolls using laser material processing are presented and compared. Based on the optimal manufacturing strategy derived from this, several structured rollers with different microstructure variants were manufactured. The successful application of the workflow and the tooling concept used for the structure rolling process is validated by experimental replication tests with different microstructures. The main focus is on the evaluation of the methodology for predicting and setting the necessary embossing force on the structure rolling tool to achieve the required structure depth.

Machining, Rolling, Tribology, Surface modification, Laser

## 1. Motivation

The systematic influencing of technical surfaces to improve the performance of the components and in particular materials used is increasingly becoming the focus in the development and optimization of mechanical systems. In addition to full-surface and partial coating solutions, microstructures are also being used to enhance functions. In this context, microstructures on functional surfaces can be used, for example, for improved coating adhesion as well as for influencing tribological properties in the hydrodynamic range [1]. The manufacturing process micro structure rolling is a combination of the processes surface roller burnishing and micro embossing, which has been designed for the structuring of rotationally symmetrical components. The advantages of the process include the rapid transfer of the microstructures to the functional areas of the components, low process and tooling costs, the machining of small diameters with a high aspect ratio, and easy integration into existing process chains.

As part of a research and development project, a tool concept was developed for structuring internal diameters up to Di > 25 mm on a 3-axis machining center. The concept has already been presented at EUSPEN's virtual conference 2020 [2]. In the current paper, the tool concept is qualified for use in lathes and a workflow for structuring components is described. This was tested under real machining conditions and the achieved machining results are evaluated.

## 2. Structure rolling - Workflow

The following section describes the individual work steps for structuring rotationally symmetrical components, such as plain bearings or cylinder liners, for machining on CNC-controlled lathes. In addition to the explanations, the structure rolling tool used is shown in Figure 1.

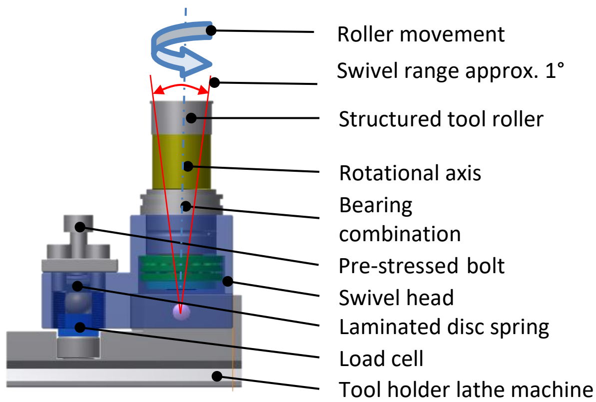


Figure 1. Embossing roller tool concept with load cell

### *2.1. Technical design process*

Before the manufacturing process can be started, the necessary technological parameters for producing the microstructured tool roll and for setting the tool and the lathe must be determined. The design of the tool roll, in particular the distances between the individual structures on the roll, is carried out depending on the structure specification values for the final workpiece. Based on the design, a CAD model with the positive structure can be created as a input for the laser ablation process. In addition, the calculated process parameters are required for both the setting of the tool and the lathe. The individual components of the theoretical preliminary considerations are shown in Figure 2.

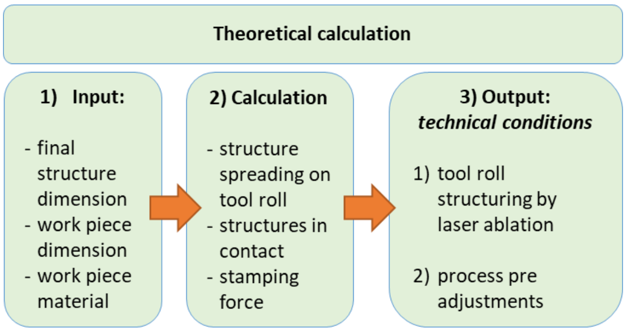


Figure 2. Procedure for determining the technological parameters

### *2.2. Workflow - technical implementation*

For a better description of the workflow, an overview of the individual process steps is shown in Figure 3. The workflow is divided into three parts. Part 1 «pre adjustment» describes the preliminary work required for the process. This includes the theoretical calculations described in 2.1, the steps for adjusting the rolling tool, and the specification of the final structure depth. Part 2 «Process steps» shows the three main processing steps. Part 3 lists the secondary process steps «process control», which are used to validate the process.

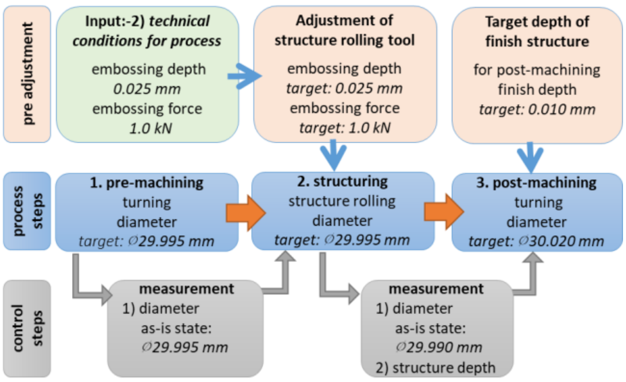


Figure 3. Technical workflow of micro structure rolling process

Sequence in part 1: Based on the determined, necessary process parameters, the microstructured tool roll can be manufactured and implemented in the overall rolling tool. This is followed by the presetting of the tool on the tool setting device and the parameter input into the lathe. During the presetting of the tool, the setting of the calculated embossing force is made by adjusting the preload of the spring pack installed on the swivel head of the tool. The application of the force can be checked by the built-in load cell. After that, the tool head can be tilted from its position parallel to the workpiece surface by 0.2 mm in its direction, which in the structuring process corresponds to the radial infeed of the lathe.

Sequence in part 2 and part 3: In the first main process step, the inner diameter of the workpiece is pre-machined up to the structural allowance. The main process step is always followed by a secondary process step from Part 3, in which the real manufactured diameter value is determined and then used during the rest of the process. The second process step starts with the positioning of the structure rolling tool at the edge of the inner bore. The subsequent radial infeed aligns the tool head parallel to the workpiece surface again, the set spring force is applied and the tool roll can be guided through the bore on a helix path. During the subsequent measurement of the bore, a smaller diameter is usually determined, which is due to the process-related throw-ups. With the third main process step, the final calculated infeed is set and the bore is chip finished. The calculation of the final infeed takes into account the diameter measurement values after micro structure rolling, the structure depth actually produced and the structure depth after final machining. After the third main process step, the workflow is complete.

## 3. Manufacturing of the embossing rolls by laser ablation

The structured rolling tools used in the experiments were fabricated by laser ablation. An 8 W Nd:$YVO_4$ picosecond laser was used for this purpose in order to avoid melt throw-up [3, 4]. The circumferential structuring of the rotationally symmetric structural rolling tool was implemented by using an NC-controlled dividing head. In the course of this, two different ablation strategies for roller fabrication were investigated, which are contrasted in Figure 4 below.

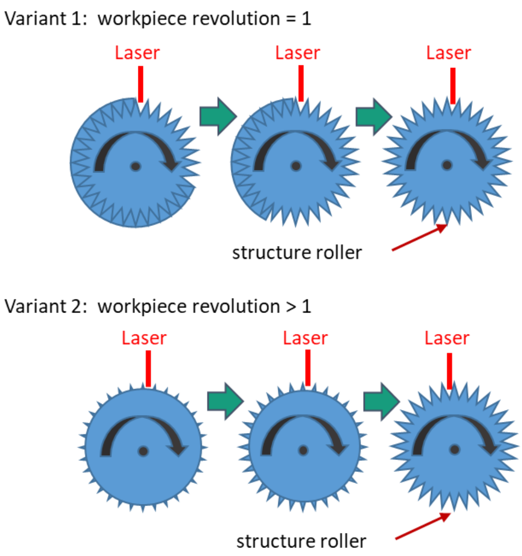


Figure 4. Removal strategy for structure roller finishing: single segment processing (above), sequential processing (below)

In variant 1, each structural element is machined individually to its full depth and the dividing head is then rotated to the next structural element until the entire tool circumference has been machined. As a result, only one tool revolution is performed and the angular error is accordingly minimal. The cut between the structural elements in the base is negligible due to the raised structure to be molded.

This cut can be avoided by partial machining of the structure geometry in several depth increments until the structure default depth is reached (variant 2) and a variable intersetion edge per tool revolution. However, it has been observed that the angular error of the dividing head has a significant influence due to the high number of tool revolutions. Therefore, for the production of the final micro structured roller tool geometries, the first removal strategy (variant 1) was applied. Figure 5 shows an example of a laser scanning image of a section of the micro structured roller tool with a structure diameter of D = 100 µm that was manufactured using removal strategy 1. To avoid burrs at the edges of the individual structural elements, an overlap area of 10 µm was set. In this overlap area, a trench is created which has no influence on the embossing process and the quality of the structured surfaces.

In the following investigations, the structure roll was used with the individual structures shown and a maximum structure depth of 25 µm that can be embossed.

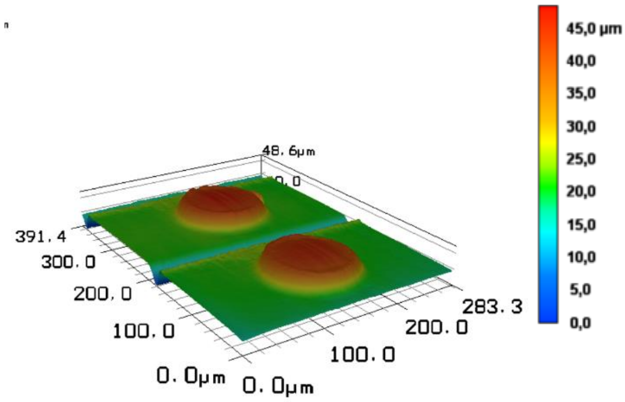


Figure 5. Laser scanning microscope image of a section of the micro structured roller

## 4. Experiment setup

Semi-finished plain bearings with an outer diameter of 42 mm and an inner diameter of 29.5 mm were used as test specimens for the structuring tests. The tolerance range of the finished inner bore diameter can vary between 30.000 mm and 30.050 mm. The structuring tests were carried out on a Gildemeister GMX 250 linear lathe. A clamping device was manufactured for holding the semi-finished plain bearing parts in the lathe, which fixes the semi-finished parts in the axial direction. The reason for this is to reduce form errors during internal bore machining. An overview of the arrangement of the tools and the workpiece in the lathe is shown in Figure 6. The turning tool shown was used for both pre-machining and post-machining and was equipped with a CCGW06T304 type indexable insert and a CVD diamant coating.

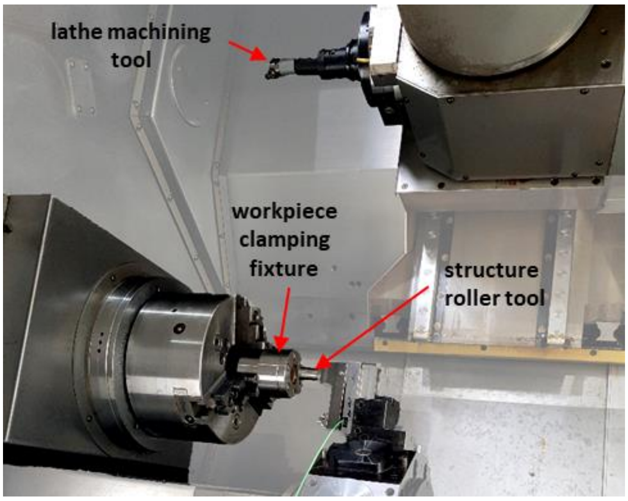


Figure 6. Arrangement of cutting and structure roller tool as well as the workpiece in to the machine

Figure 7 shows in detail the direction of rotation of the workpiece holder with semi-finished product as well as the structure rolling tool with the resulting rolling movement. Furthermore, a partial area of the micro structured roller with the applied positive structure is shown.

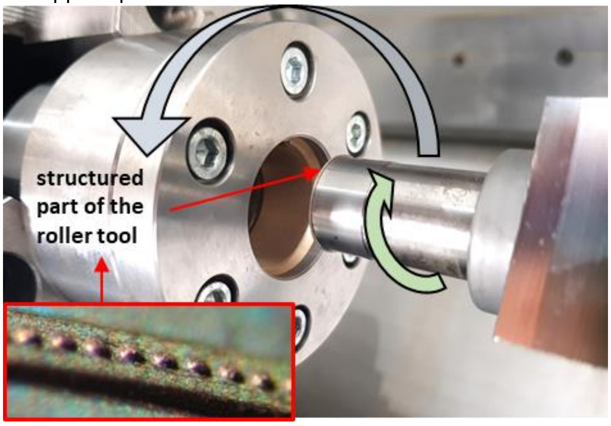


Figure 7. Workpiece and tool movement as well as position of positive structure on carbide roller tool

For the structure rolling tests, the positive structures shown in Figure 8 were selected and transferred to a carbide tool roll by laser ablation. The maximum individual structure height that can be replicated to the part is 25 µm in each case.

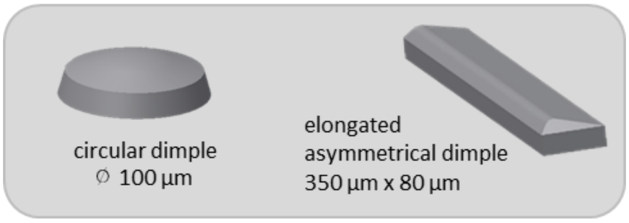


Figure 8. Structural geometry for experiments

To check the settings, the manufactured microstructures as well as the workpiece diameters, the measuring equipment described below was used to carry out the experiments.

The setting of the embossing force on the micro structure rolling tool was carried out using a Kistler Type 9011C piezo force washer, the associated amplifier and a voltmeter. This made it possible to visualize the embossing forces during the process and to compare them between the experiments. The basic determination of the tool lengths and the setting of the position of the structure rolling tool were carried out on a tool setting system from the company Zollern. A digital three-point inside micrometer was used to check the manufactured diameters.

Due to the inner bore size of 30 mm, no commercial measuring equipment was available for in-process measurement to determine the depth of the embossed structures. Alternatively, a manufactured workpiece was destroyed in order to optically measure the structure and manufacture further components with the same settings. Against this background, a tactile measurement method was developed to be able to measure the structure depth in the machine. For this purpose, a measuring tip was attached to the sensing ball of a lever gauge, which can dip into the inserted cavities as it passes over the structured surface, thus providing a height value. The smallest diameter at the measuring tip is approx. 35 µm and the measuring resolution of the lever gauge is 2 µm. In order to be able to make a reliable estimate of the structure depth with this measuring device, multiple measurements are necessary.

## 5. Experimental results

When implementing the workflow and manufacturing the structured components, three good parts were produced for each structure variant. The target value for the structuring depth was a range of 8 µm to 10 µm. Optical inspection of the manufactured structure variants was performed non-destructively in a scanning electron microscope with the detector swiveled in. Figures 9 and 10 show examples of the embossing results for the two structural geometries.

It is apparent that a roughness has been replicated in the base of the structures. This results from the manufacturing process of the roling tool. The embossed roughness is a grinding trace from the upstream manufacturing process of the tool roll. These grinding marks were not removed by the laser ablation process, but were removed equidistantly to the structural model. To avoid this, the tool rolls should be polished before structuring. Furthermore, burr formation can be observed in the cutting direction at the edges of the microstructures due to the machining process. This usually occurs at low cutting depths or large cutting edge radii. In the case shown, the low cutting depth of the finishing process of about 10 µm is probably responsible for this.

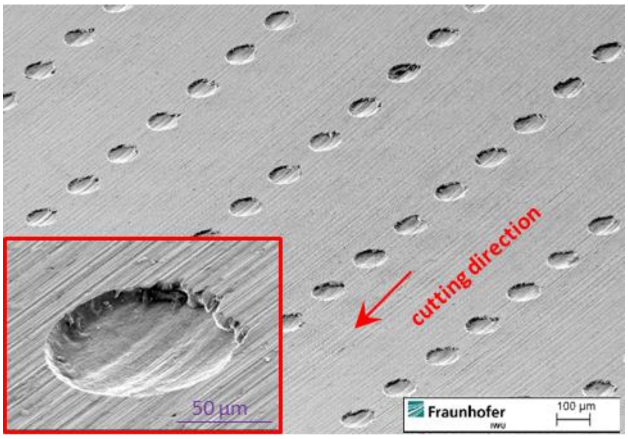


Figure 9. Structured surface with circular dimple Ø 100 µm

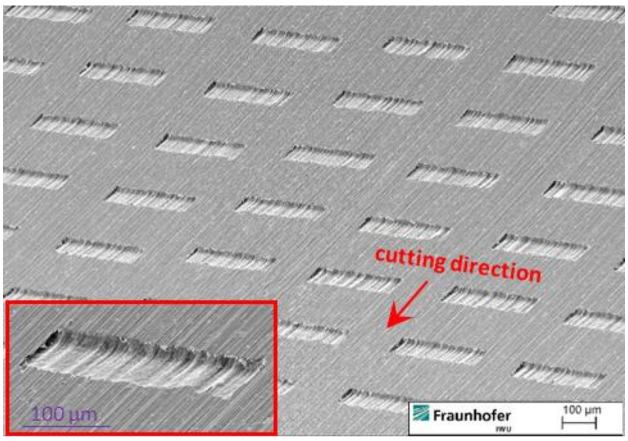


Figure 10. Structured surface with elongated asymmetrical dimple

The measurement of the structure depth was determined indirectly via an optically measured silicone replica, since another non-destructive measurement method was not available during the evaluation period.

The evaluation for the circular cavities with a structure diameter of 100 µm showed that the average structure depths produced for component KN1 at three different measuring points vary between approx. 11 µm and 15 µm. For another component KN2, the values vary only between 10.5 µm and 11.5 µm. Thus, the average structure depth is about 11 µm to 12 µm, which is slightly higher than the target range.

The evaluation of the elongated asymmetric dimple structures with dimensions of 350 µm x 80 µm showed that the average structure depths generated are homogeneous within the measured bearing, but there are differences between the bearings. For example, the average structure depth for the components LN1 is approx. 8 µm, LN2 approx. 12 µm and LN3 approx. 13 µm.

In the first case of the fluctuating depth values, it can be assumed that the casting for the indirect structure measurement was influenced and that this caused the deviations. The measuring accuracy of the lever gauge, which must be used to reach the deepest point of the rolled structures, is probably responsible for the deviations between the bearings. Especially with the asymmetrical structures, this is difficult to reach because it is not in the center of the structures and thus a more shallow structure is measured.

For future investigations, the method for measuring the embossed structures should be modified or optimized in order to calculate the correct infeed for the post-processing step. Furthermore, a direct measurement method for the final structure measurement should be selected for the evaluation of the structured components.

## 6. Conclusion

A workflow with test results for structural roller embossing of microstructures for small inner diameters and an two ablation strategie for roller manufacturing was presented in this paper. The functionality of the workflow and the fabrication of the structure rollers as well as the test results were discussed. Finally, a further research needs for the future were identified.

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