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Roller Burnishing of Hard Turned Surfaces

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SUMMARY

In a hard roller burnishing operation, a hydrostatically borne ceramic ball rolls over the component surface under high pressures. The roughness peaks are flattened and the quality of the workpiece surface is improved. When combined with hard turning, this process provides a manufacturing alternative to grinding and honing operations.

The studies determined optimum working parameter ranges. Parameter settings were shown to be non-critical in this process, since constant surface qualities were attainable over wide setting ranges. A second phase of the studies examined the improvements obtained for various original roughnesses. Reductions of 30 to 50 % in mean peak-to-valley height R_z are, for example, achievable, depending on the original roughness.

Structure analyses and residual stress measurements were used to examine the effects of the process on the workpiece surface zone. Hard roller burnishing transforms tensile residual stresses present in the surface zone after hard turning into compressive residual stresses. Hard roller burnishing has no effect on the formation of white layers in the surface zone. © 1998 Elsevier Science Ltd

1. INTRODUCTION

The use of hard turning as a finishing process is often limited by surface quality requirements in the case of component surfaces designed to withstand rolling stresses. Low roughnesses can be achieved only at low feed rates. Moreover, tool wear leads to a deterioration in the surface after the tool has been in use for some time. A subsequent finishing operation can both increase the range of permissible feed rates towards higher values and prolong the tool life of the cutting edge. One finishing operation whose working principle suits it especially well for combination with hard turning is hard roller burnishing. The following paper explains the process, indicates suitable working parameters for improving the hard-turned component surface and discusses effects on the workpiece surface zone.

For the generation of high surface qualities an alternative to cutting processes is given by surface precision rolling. This technology can be used for increasing of the workpiece surface strength as well as decreasing its surface roughness. The increase of surface strength mainly serves in terms of an improved fatigue behaviour of workpieces under dynamic load. The biggest field of application are parts as axle journals and slide ways /1/.

Test results known from literature refer to roller burnishing of steels, aluminium alloys, titanium and other non ferrous materials with a surface hardness up to 50 HRC /2,3,4/.

Development of a tool specially adapted for the requirements of roller burnishing on highstrength materials means that even hardened steel materials with hardnesses up to 62 HRC can now be machined /5/.

The operation of the hard roller burnishing tool is based on the hydrostatic principle. A ceramic hard roller burnishing ball is pressed against the surface of the workpiece by a pressure medium (emulsion with 3-5 % oil component). The ball floats on a pressure cushion and can rotate in any direction, almost without friction.

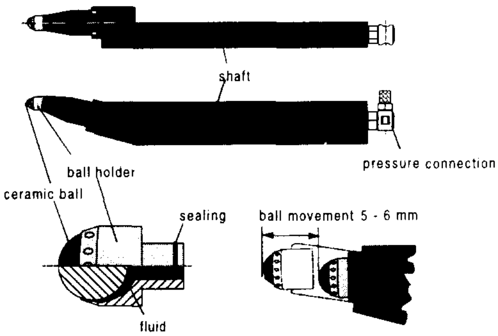

Fig. 1: *tool*

The hard material ball held in this way is pressed on to the working surface with a pressure of up to 500 bar, equivalent to a rolling force of 1400 N. Owing to the small diameter of the ceramic ball, high Hertzian stresses are exerted even with these comparatively small forces (Fig. 2), exceeding the yield point and flattening the roughness peaks.

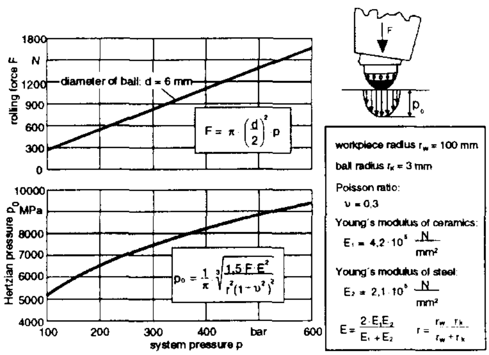

Fig. 2: *rolling force*

In the profilometer log, the roughness peaks appear extremely steep, leading at first sight to a suspicion that the smoothing effect may be due to a breaking away of the peaks. This phenomenon is, however, due solely to the different scales of magnification in the vertical and horizontal axes, which greatly distorts the height of the profile peaks in relation to their width.

The effect of smoothing on the roughness peaks is evident when SEM scans of a hard-turned surface before and after hard roller burnishing are compared. The lower photograph still shows the structures left by turning with a worn edge on the workpiece surface. The number and dimensions of the profile peaks are, however, visibly reduced. The optical impression of a smooth surface is confirmed by a comparison of the mean peak-to-valley heights.

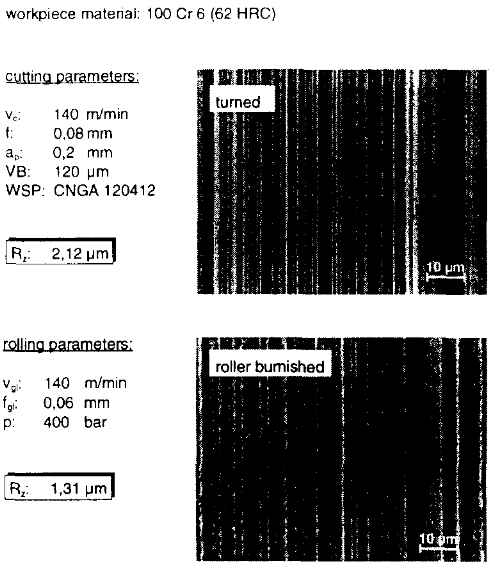

Fig. 3: *SEM photography of hard roller burnished surface*

No surface damage due to broken-off roughness peaks or cracks was observed in the studies.

3. Machining Results

The first phase of the studies examined the effects of the hard roller burnishing parameters on the surface quality of the workpieces. The process variables for hard roller burnishing are the rolling pressure p_{gl}, the rolling speed v_{gl} and the rolling feed f_{gl}. It is apparent from the results of systematic parameter variations shown in Fig. 4 that large ranges permitting maximum reduction of the original roughness are available for all three parameters.

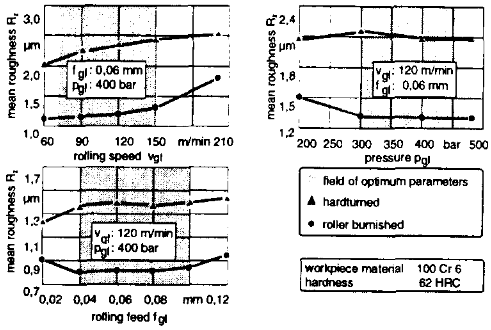

Fig. 4: *influence of machining parameters*

When setting the rolling feed rate, it is important to ensure that it is different from the turning feed rate used in the preceding operation. If the same feed rate is used for hard turning and hard roller burnishing, optimum improvement of surface finish will not be achieved, because the rolling motion will be parallel to the feed grooves in the turned surfaces and will not flatten the feed ridges.

A centre line average below $R_a = 0.17$ μm is required for ground surfaces on roller bearing components subjected to rolling stress. Such high surface qualities can be generated without additional finishing operations only if cutting edge wear is extremely slight and only at low feed values with correspondingly long process times. A finishing operation to achieve the very high required surface finish is therefore necessary on economic grounds.

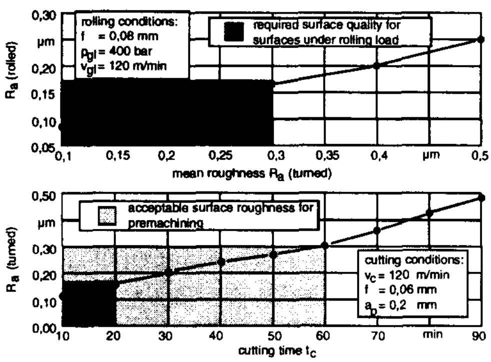

Fig. 5: *surface quality at roller burnishing*

Fig. 5 shows the surface quality which can be achieved after roller burnishing for various original roughnesses. It is evident that the permissible roughness after hard roller burnishing can be obtained up to an original roughness of $R_a = 0.3$ μm. The necessary original roughness is thus within a range which can be realised by the hard turning process at cost-effective cutting parameters and tool lives.

4. SURFACE ZONE PROPERTIES

Apart from its influence on surface structure, the effects of hard roller burnishing on the properties of the workpiece surface zone are of interest. The effects of hard roller burnishing were examined for various original states of the material, using specimen components which had been hard-turned using cutting edges with various degrees of wear. The rolling pressure was also varied in the studies. The remaining rolling parameters were kept constant.

Residual stresses and metallographic structure analyses were used to characterise the state of the surface zone.

Residual stresses

The mechanical stresses exerted on the component surface zone during hard roller burnishing lead to sustained modification of the residual stress state. The figure shows tangential and axial residual stresses before and after hard roller burnishing for the two extremes in the test series (VB = 0 μm and VB = 120 μm).

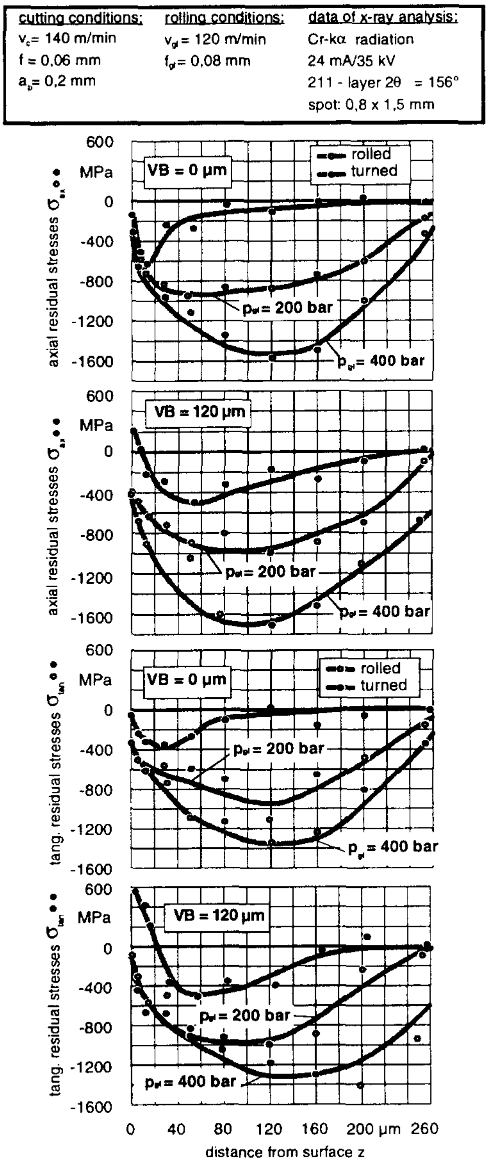

Fig. 6: *residual stresses*

The residual stresses after hard turning exhibit the familiar depth curves, dependent on the wear state of the cutting edge. After hard roller burnishing, compressive residual stresses occur throughout the zone; their curves are dependent on the rolling pressure and hence on the Hertzian stress during the roller burnishing operation. Residual stresses as high as -1600 MPa are measured at a depth of roughly 100 µm with a rolling pressure of 400 bar. Mechanical stress on the workpiece surface zone as a result of roller burnishing is so great that it is no longer possible to observe any influence of cutting-edge wear during the hard-turning process on the residual stress curves at deeper levels of the surface zone. Deviations are within the range of measuring uncertainty or the scatter between different workpieces.

On the workpiece surface, however, the influence of the preceding hard-turning operation is still apparent. When a cutting edge with a flank wear of VB = 120 µm is used, axial and tangential tensile residual stresses occur on the workpiece surface. Hard roller burnishing displaces the residual stresses into the compressive stress range.

The influence of rolling pressure on the residual stress curve is visible only from a depth of about 10 µm onwards, in accordance with the position of the comparative stress maximum due to Hertzian stress. Approximately the same residual stresses at the workpiece surface are found for both rolling pressures.

It is evident from a comparison of the tangential and axial residual stresses that hydrostatic support of the roller burnishing ball has led to virtually polyaxial plastic deformation in the workpiece surface zone. Whereas widely differing axial and tangential residual stresses are present after hard turning, due to the nature of the process, the curves differ only negligibly after hard roller burnishing. The original residual stress state prior to roller burnishing, i.e. after hard turning, has a much greater influence than the roller burnishing operation itself.

Surface zone structure

The metallographic sections of workpieces with various surface zone states, taken after hard turning with different flank wear, indicate no differences in the structures in the workpiece surface zone before and after hard roller burnishing.

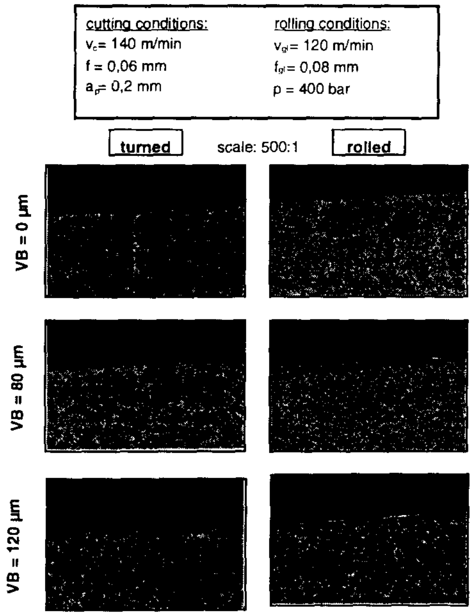

Fig. 7: *subsurface microstructure*

The white layer which exists after hard turning is still present as an even layer after hard roller burnishing. Cracks or spalling, which would be expected in a brittle layer, do not occur.

Considering a following destination of the parts in use under rolling load, the phenomena described must be judged opposite. Besides the improvement of surface quality by flattening the roughness peaks a positive effect can be expected by the shifting of the residual stresses at the workpiece surface from tensile to compressive status. The very high maxima of compressive stress in subsurfaces zones of roughly 100 µm can on the other hand mean, that the ductility of the material is already spent. Investigations on bearing balls have shown, that too high strain hardening has negative impact on the part's life time /6/. To answer this question life tests with hardturned and roller burnished bearing rings are essential. These tests are currently conducted at the WZL.

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