Manufacturing and characterisation of artificial defects for non-destructive grinding burn detection

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Brief description: Grinding burn during production is a risk for the safety of the component. Reference standards are required for evaluation, setting and verification of suitable test methods for grinding burn detection. They may be created by means of laser treatment. Those artificial defects show analogue features like the real damage symptoms. They can widely be reproduced at defined locations according to the testing requirement (kind and depth of microstructure change, spacially dimension).

1. Introduction

Extensive investigations have been and are still carried out regarding the subject grinding burn, its development during the grinding process, its effect on the component features and the possibilities of detection by means of non-destructive test methods, without interpreting this phenomenon conclusively and comprehensively. It cannot be expected as well, as the factors during the grinding process, the materials to be worked, the various shapes of the component are so varied and the grinding burn shows different appearances. In our metallographic laboratories, when examining deep groove ball bearing rings, we found grinding burn appear as lines across the grain on the races. At integral flanges of roller bearing rings, grinding burn occasionally appears in circumferential direction and covers larger areas. However, it cannot be excluded that such grinding burn also appears on the race.

As per ISO 14104, grinding burn is a locally overheated area near surface. As a matter of course, each mechanical process alters the areas near surface. Grinding burn is called when the heat impact is strong enough to generate local annealing or, if heat impact is much more intense, to generate so-called re-hardening zones.

Different test methods are applied to verify grinding burn: A quasi-non-destructive method is nital etching as per ISO 14104 [1]. However, automation of this method is limited and the evaluation of the etched parts is performed visually by an operator. For this reason, a non-destructive method is of high interest as it allows detection of grinding burn without subjective bias, is reproducible and automatable. Already applied are especially the so-called 3MA-method and Barkhausen noise [2] and in recent times, eddy current testing [3,6].

Components with defined defects of different characteristics are required in order to be capable of evaluating the applicability of non-destructive test methods for detection of defects on components. Grinding burn poses problems because it is practically impossible to generate specific and reproducible grinding burn and in addition defined, with regard to size and depth of the influenced area. An alternative is the so-called artificial defect. So, for instance, notches or a deepening of defined depth are eroded to set the sensitivity of the eddy current test instrument as per DIN EN 10246-3.

This lecture presents experiences and findings of manufacturing and assessment of artificial defects for grinding burn detection.

2. Artificial defects

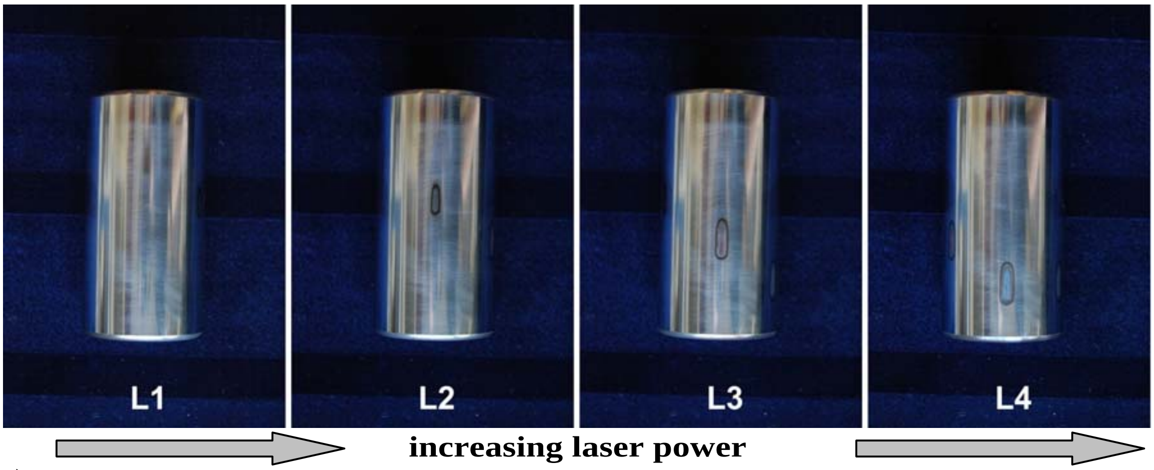
Artificial defects must able to be reproducibly fabricated defined per size, location and intensity. Furthermore, they shall have a similar physical behaviour like real defects. It is, however, not possible, and it would certainly be in vain to try, to produce artificial defects which are identical to real defects; and it is not necessary. The thresholds for sorting into "good" and "bad" parts have to be determined by comparison with real defects (validation of method). For this, parts with natural defects and certain signals of the test equipment must be taken and examined by a reference method.

Artificial defects are used for calibration of the test equipment, especially the required test sensitivity, before testing real parts. In addition, artificial defects reference standards are run in certain intervals through the process in order to guarantee that testing is effected under constant, reproducible conditions. The latter requires that no time-depending changes run in the Standard which could change the produced artificial defect.

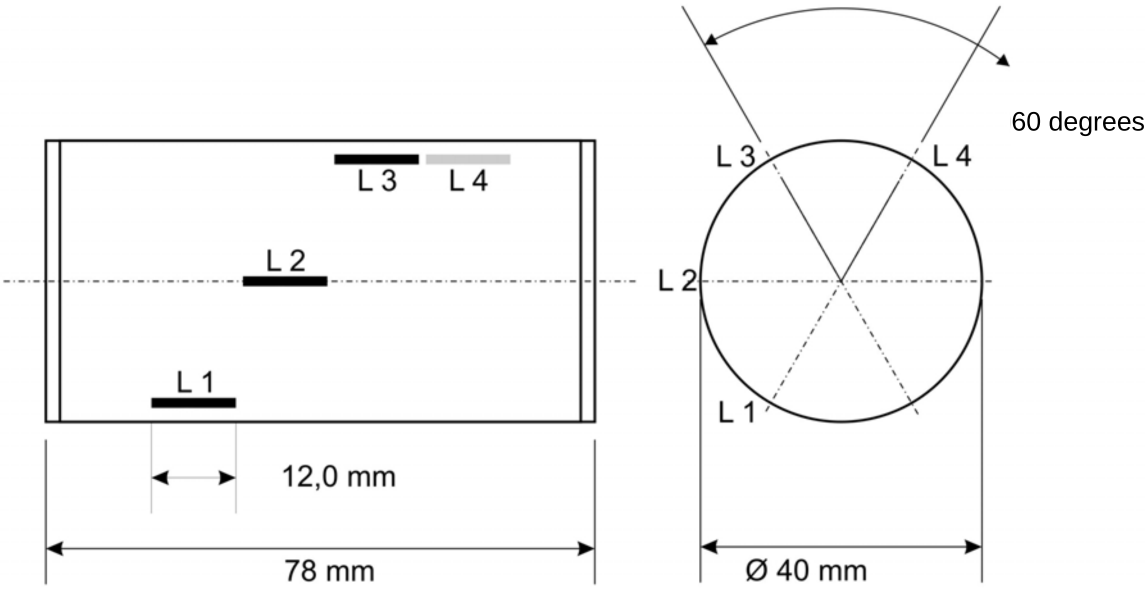
One option for manufacturing of reference samples for grinding burn detection is heat impact, defined and locally very limited, onto the surface by means of a laser. [4] presents results of an interlaboratory test on laser-damaged case-hardened parts; [5] are results comparing investigations regarding "white layers" (re-hardening zones) on case-hardened 16 MnCr6 occurring during grinding, hard-turning and lasing. The white layers which were generated during the three aforementioned processes show both concordant and divergent characteristics. It must be taken into consideration that residual stress which occurs by a local heat impact during grinding or hard-turning is the result of an overlapping of thermal interaction and mechanical stress. The laser process has no mechanical impact. The effects on the residual stress profile are not specifically explained in [5]. However, the cracks caused by residual stress below a re-hardening zone are mainly created by concentrated heat impact and not by mechanical working [4]. Laser treatment is thus at least very close to the real damage.

Different artificial defects were produced in roller bearing rings and in cylindrical rollers using a diode-pumped disk laser. The laser optic had a fibre diameter of 0.3 mm. The advantage of such a disk laser is especially the fact that narrowly limited areas could be treated with defined linear energy.

The following shall explain the manufacturing of such laser marks, their features and their application at eddy current testing on cylindrical rollers whose surface was prepared with a local heat impact. Figure 1 shows laser marks and their location on rollers prepared with different laser powers.



a)

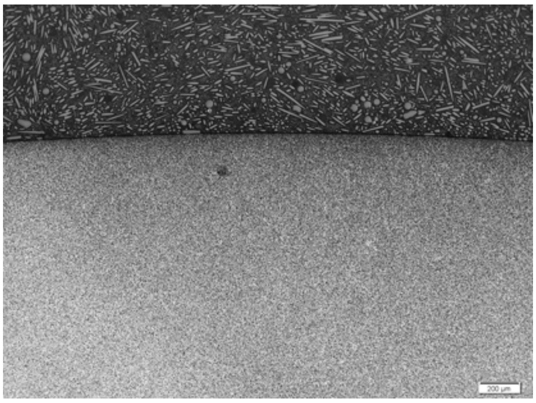


b)

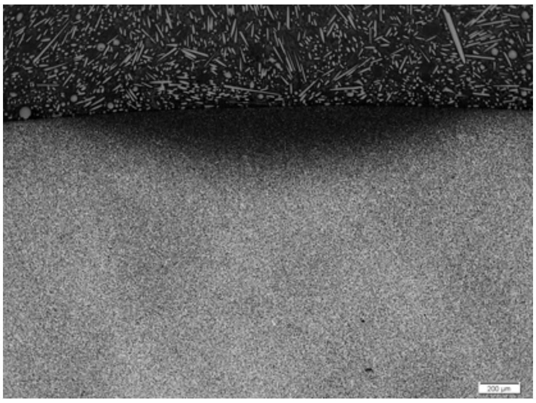
Fig. 1 a) Laser marks, created with increasing laser power on rollers out of 100Cr6
b) Location of the marks on the roller

Two parts were treated with the same laser parameters. One part was used for a destructive examination and the second part as reference standard for non-destructive testing. Figure 1.a) shows the laser-treated areas in axial direction, with different laser powers. The width is approx. 2 mm and the length approx. 12 mm.

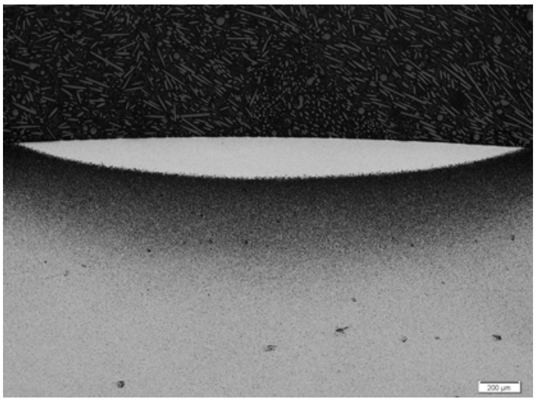
Cross cuts were taken of the lasered areas of the rollers in the homogenous zone of the laser trace. Figure 2 shows micro pictures of those area. At lowest laser power L1, no visible mutations could be recognised. The higher energies (L2) cause annealing effects. Still higher powers from L3 cause re-hardening zones.



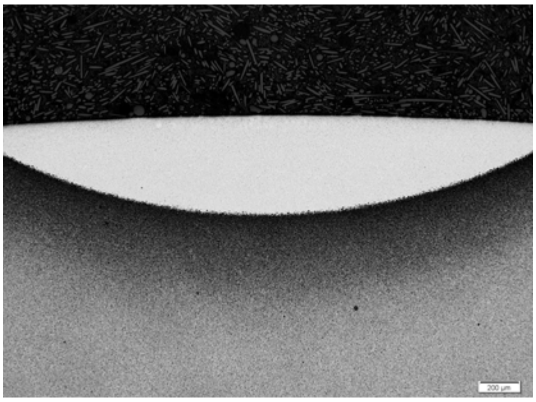
a) L1: no visible microstructure changes



b) L2: only annealing zone (depth 359 µm)



c) L3: annealing zone (depth 230 µm)
re-hardening zone (depth 620 µm)



d) L4: annealing zone (depth 540 µm)
re-hardening zone (depth 900 µm)

Fig. 2: Metallographical cuts through the laser marks show the microstructure changes at increasing laser power from L1 to L4

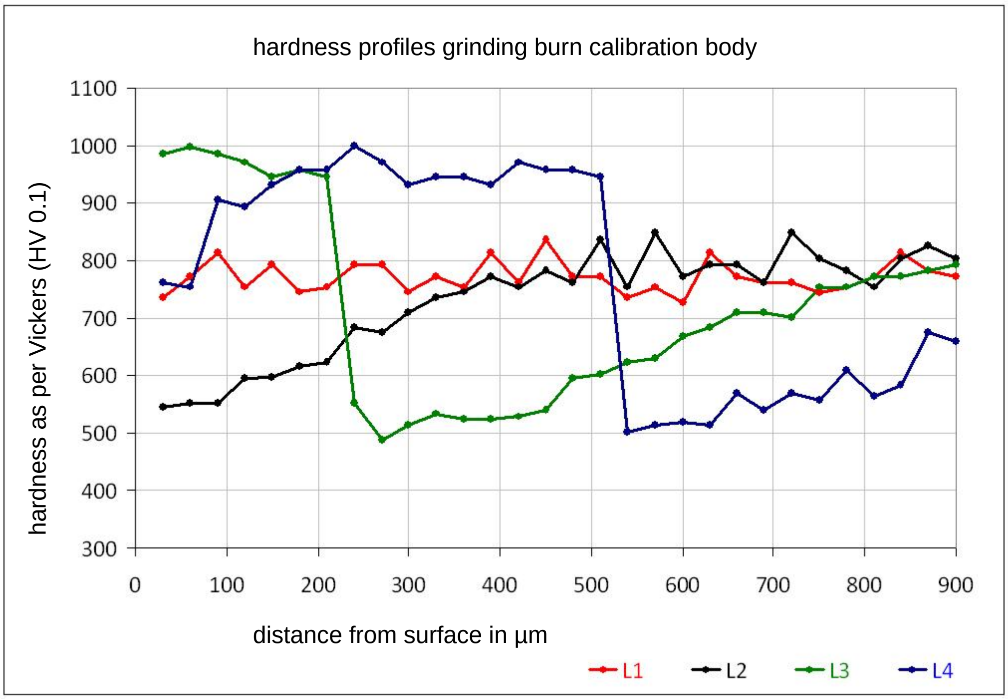
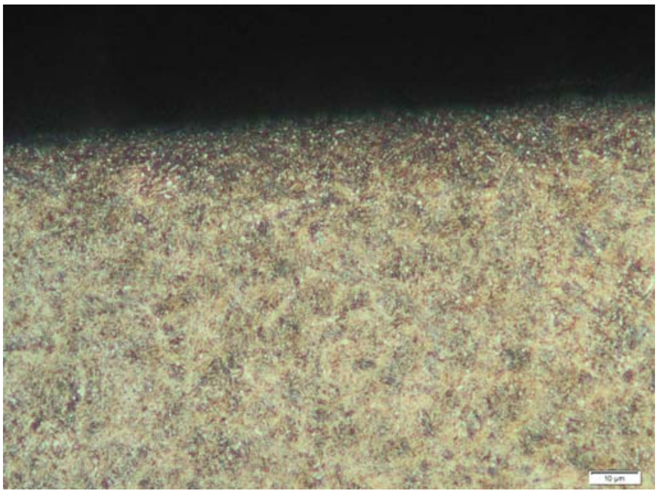
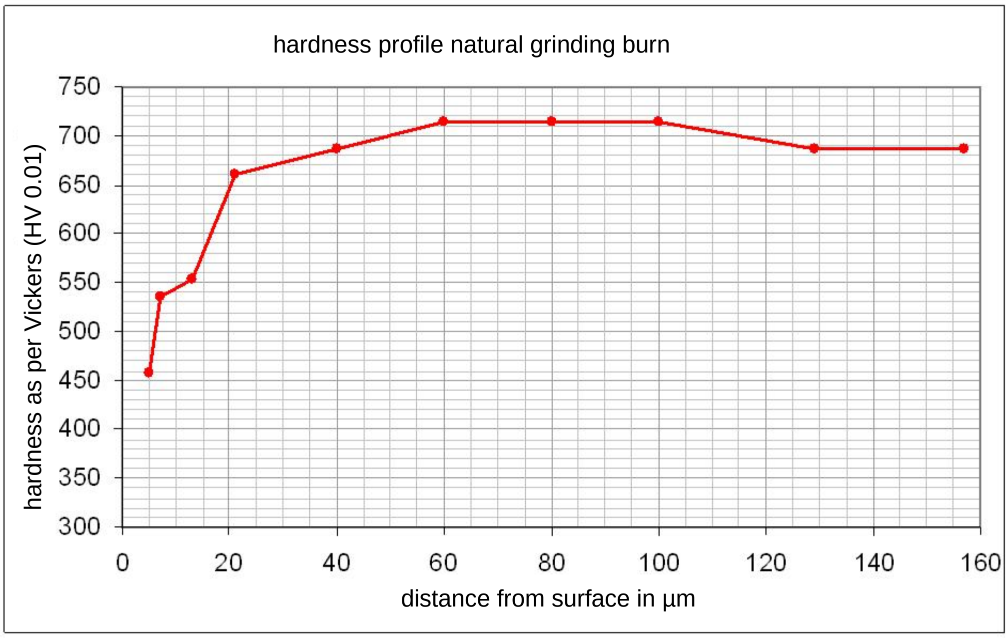


Fig. 3: Micro hardness measurement from edge to core (hardness profile for different laser powers)

The results of the micro hardness measurement at the four laser marks are displayed under figure 3. The hardness profile is similar to annealing zones and re-hardening zones in real components. In comparison, figure 4 shows as an example the results of the grinding burn mark of a bearing roller: characteristic discolouration of the surface after nital etching; annealing zone in metallographical cut and decrease of hardness values in the area near to the surface which corresponds to the annealing zone.

a) 

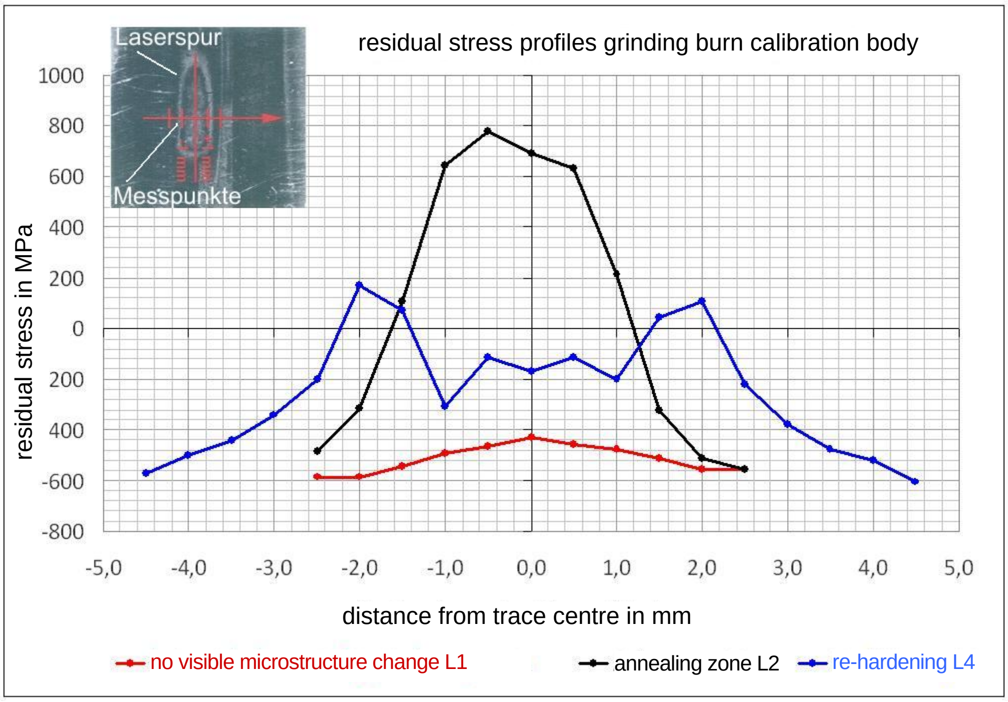
b) 



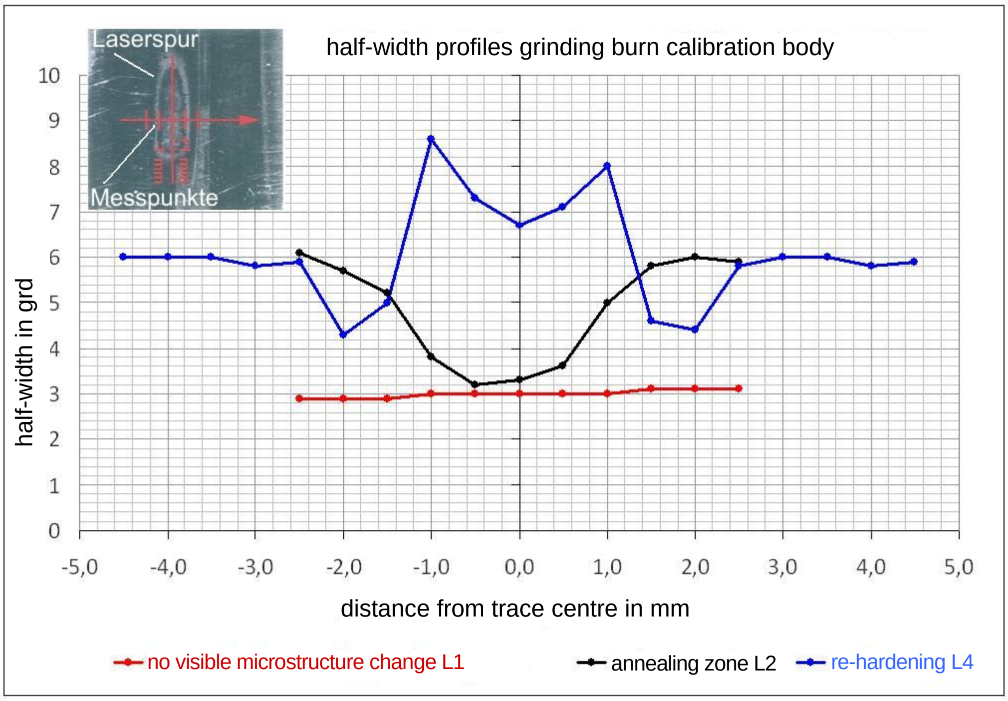
c)

Fig. 4: Results of the examinations on a bearing roller with natural grinding burn
a) survey of nital etching
b) metallographic cut: annealing zone (depth 16 µm)
c) hardness profile at cut (small load hardness as per Vickers HV 0.01)

Perpendicular to the laser marks on the surface of the rollers the residual stress has been determined radiographically as well as the half-width of the interference profiles (figure 5). The determined residual stress as well as the half-width correspond to those which were recorded at annealing zones and re-hardening zones in real components with grinding burn.



a)



b)

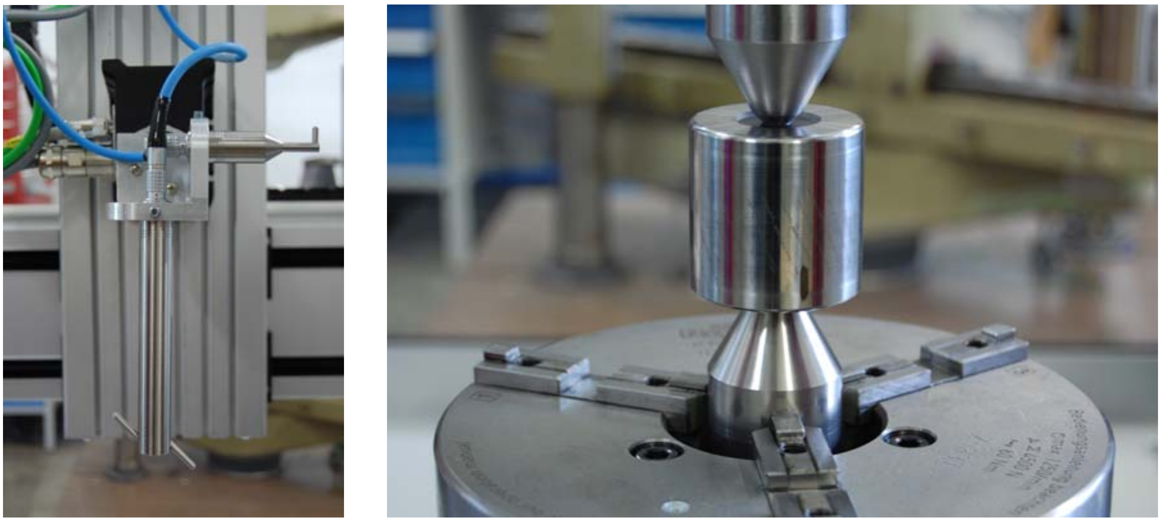
Fig. 5: a) Radiographically determined residual stress and
b) Half-width of the interference profile crosswise to the laser marks

3. Eddy current testing

The Preventive Multi-Filter Technology with a differential probe was used for detection of laser marks. The test instrument **eddyvisor®** of the german manufacturer IBG was integrated in the specifically-developed test machine QuaSor E. It consists of a CNC-controlled test device which enables an automatic test process.

Depending on part type to be tested (inner ring, outer ring, roller) the operator selects the relating test program. The test part is fed manually. Automation was intentionally omitted due to very different part types and dimensions as well as partly small batches. When the part is positioned, the test runs automatically. The part-specific test parameters are called and set. Then the crack detection probe moves along the test areas. Test is possible on the races, integral flanges, end faces of inner and outer rings as well as on rollers. The test signals are gathered automatically and assessed on base of the also deposed assessment criteria. The operator immediately gets the test result "good" or "bad".

Figure 6.a shows the arrangement of the eddy current crack detection probe when testing a roller bearing inner ring. The angled shape of the probe and the combination of three probes enable access to all relevant surfaces. Fig. 6.b shows a clamped roller. Race and end face are tested at the same time.



a) Probe arrangement b) Testing a roller

Fig. 6. Grinding burn test by means of QuaSor E

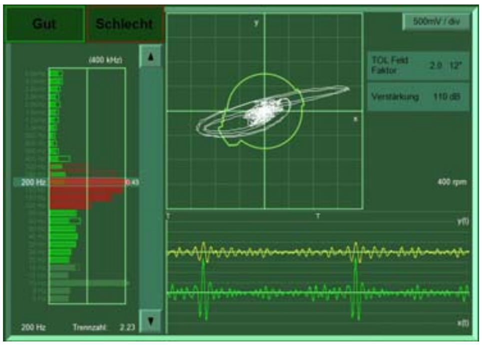
Fig. 7: Test device QuaSor E in production environment at Spindel- und Lagerungstechnik Fraureuth GmbH

The test device QuaSor E is utilised in production for detection of grinding burn and structure defects near the surface (figure 7).

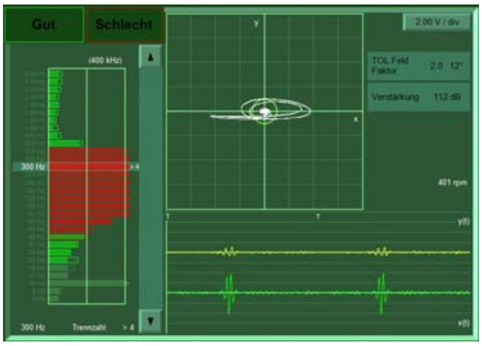
Figure 8 shows the results of the eddy current test of the roller with four laser marks. As basis for the evaluation, reference data of the eddy current signals of parts without any defect are gathered. The signals of the tested parts are then assessed relative to the reference data. A separation figure is determined as measure for the deviation of the eddy current signals of the tested part from the signals of the reference parts. The signals of the reference parts are widened by a tolerance zone so that faultless parts have a separation figure of about 0.5. The sensitivity of the test method depends on the defined threshold for the separation figure that triggers NOK sorting of the part.

The separation figures for the artificial defects increase with increasing laser power. The laser marks L2 to L4 which clearly show visible microstructure changes as well as significant hardness and residual stress variations have very high separation figures and can therefore be reliably detected.

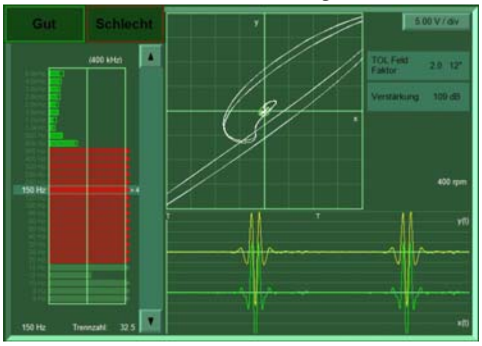
The test signals of laser mark L1 shows no microstructure changes and only a small difference of residual stress resp. half-width of X-ray profile compared with the basic material, result in a separation figure of 2.23 and also stand out clearly from the reference quantity.



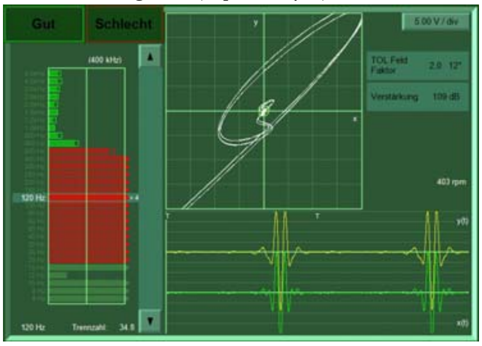
a) L1: max. separation figure 2.23
no visible microstructure change



b) L2: max separation figure >4
annealing zone (depth 350 µm)



c) L3: max. separation figure 32.5
re-hardening zone (depth 230 µm)
and annealing zone (depth 625 µm)



d) L4: max. separation figure 34.8
re-hardening zone (depth 540 µm)
and annealing zone (depth 900 µm)

Fig. 8: Results of eddy current test by means of QuaSor E & eddyvisor on a roller with laser marks L1 to L4 (screenshots IBG´s eddyvisor)

4. Summary

It is feasible to produce defined artificial defects on roller bearing components by means of disk laser treatment. The artificial defects show similar features to actual grinding burn. Artificial defects can be reproducibly manufactured at defined locations corresponding to requirements (kind and depth of microstructure change, spacially dimension).

The parts with artificial defects may be used as reference standard for non-destructive grinding burn detection as well as nital etching. Furthermore it is possible to use them for interlaboratory tests as reference sample for examinations to compare suitability of different methods for grinding burn detection.

It is recommended to state uniform criteria for manufacturing of artificial defects for grinding burn detection by means of laser treatment.

The Preventive Multi-Filter Technology with a differential crack detection probe is capable of reliably detecting artificial defects as well as real grinding burn, independently if it is an annealing or re-hardening zone.

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