Reference blocks generated by laser treatment for grinding burn inspection

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Abstract

Grinding burn is defined as a result of unintentional heat impact during processing of hardened steel surfaces such as claimed surfaces of gear parts. Depending on heat intensity local tempered zones or in case of more intense impact so-called re-hardened zones are generated. The occurrence of grinding burn within the production process is a risk for the safety of the components. Extensive investigations have been and are still carried out regarding the subject of grinding burn; its formation during the grinding process, its effect on the component features and the possibilities of the detection by means of non-destructive testing methods without interpreting this phenomenon conclusively and compressively. But this is not to be expected, as the factors during the grinding process, the working materials with various shapes of the component are so varied and the grinding burn shows different appearances.
Different test methods are applied to verify grinding burn. Surface temper etching (STE) is the most commonly used method for detecting grinding burn up to now. Furthermore, it is the only standardized testing method (ISO 14 104:2014). However, industrial automation of this method is limited and the evaluation of the etched parts is performed visually by an operator. For this reason, non-destructive methods are of high interest as they allow reproducible detection of grinding burn without influence of human factors. The 3MA-methode, the Barkhausen noise analysis and in recent times, eddy current testing are already applied.
Components with defined defects of different characteristics are required for the evaluating of non-destructive test methods as well as for STE according to ISO 14104. Generation of reproducible grinding burn on components cause problems regarding to size and depth of the influenced area. An alternative is the generation of artificial defects. Artificial defects have to be fabricated reproducibly in size, location and intensity. Furthermore, they have to show similar physical behavior like real defects.
Experiences and results of manufacturing and assessment of reference blocks with artificial defects generated by laser treatment for grinding burn detection are presented. The artificial defects meet the requirements mentioned above and may be used for non-destructive testing methods as well as for STE. The reference blocks are used for calibration of the test equipment, especially the required test sensitivity. In addition, reference blocks are applied in certain intervals within the process in order to guarantee testing reliability.

1. Introduction

Local overheating during mechanical processing of hardened steel parts leads to local changes in microstructure (Figure 1).

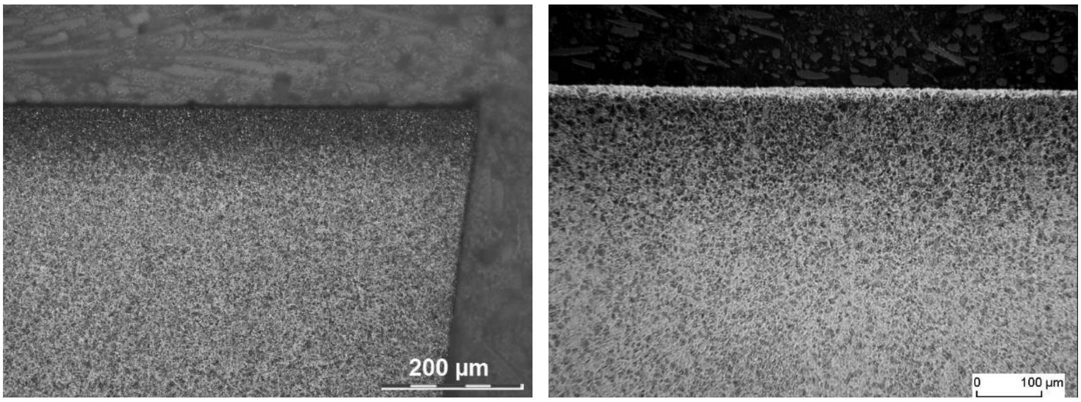


Fig. 1: Cross sections of a tempered zone (left) and of a re-hardened zone (right)

The tempered zones are characterized by tempered martensite, a lower hardness than the unaffected material and by tensile residual stresses. Re-hardened zones, known as “white layers” consist of quenched martensite and retained austenite. These layers show higher hardness and may have residual tensile or compressive stresses. In most cases they are surrounded by tempered zones.
Surface Temper Etching (STE) is the most common method for detecting grinding burn. Up to now it is the only standardized testing method, described by ISO 14 104:2017 (1), AMS 2649:2011 (2). However, industrial automation is limited because 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 the detection of grinding burn without the influence of human factors and with better reproducibility. Successfully applied methods are Barkhausen noise analysis (BHN) (3), Micromagnetic Multiparameter Microstructure and stress Analysis (3MA), that combines the signal processing of Barkhausen noise, tangential field strength, multi-frequency eddy current signal and incremental permeability (4), and in recent times, eddy current testing (ET) (5).
Independent of the applied testing method the reliability must be ensured. Even grinding burn of very small dimensions needs to be detected unfailingly. At the same time false indications must be avoided. In order to evaluate the applied testing method reference blocks with defined defects and different characteristics are required for the evaluation of non-destructive test methods as well as for STE (6). They allow the calibration and monitoring of the testing process, the selection of appropriate testing methods and the definition of preliminary threshold values.

2. Manufacturing of Reference Blocks

Unfortunately, the practical experience shows that it is nearly impossible to generate grinding burn with defined size, location and characteristic (e.g. type and level of grinding burn) on components. Furthermore, it is also impossible to do that in a repeatable way. An alternative is the generation of artificial defects. Artificial defects have to be manufactured with reproducible properties as specified above and they have to show similar physical properties like real defects.
A special LASER method in order to generate tempered and re-hardened zones on components was developed by imq. This technology allows to generate defined defect

shapes, sizes and depth profiles. This can be done on flat surfaces as well as on convex or concave surfaces. An important prerequisite for a successful application of reference blocks consists in the reproducibility of the defects. The present state of art allows reproducing e.g. a tempered zone of 100 µm depth with an accuracy of ± 20 µm measured in a metallographic cross section.
Another question was whether the LASER defects are suited to simulate real grinding burn because laser defects are generated only by a thermal load. A widely accepted fact is that the transformation into friction energy takes the largest amount in the power balance of grinding processes. Therefore it may be assumed that the thermal influence predominates the generation of grinding burn. Nevertheless, a lot of metallographic investigations, micro hardness measurements and measurements of residual stresses had been done (7, 8). It was shown that the structure and physical properties of these artificial defects conform to the relevant properties of real defects. As an example, the depth profiles of hardness of LASER generated artificial defects and of grinding burn caused by abusive grinding are plotted in Figure 2.

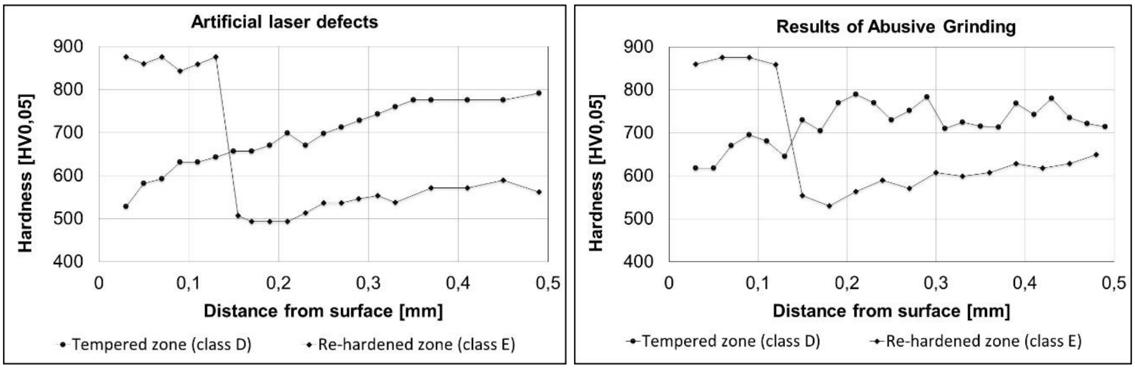


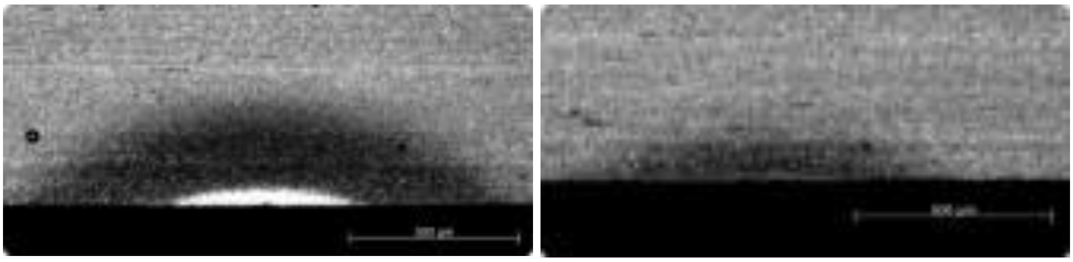
Fig. 2: Hardness profiles; left: LASER generated artificial defect, right: Grinding burn caused by abusive grinding

3. Application of Reference Blocks

3.1. Surface Temper Etching

The STE is based on the fact that the etching process highly depends on the microstructure. After etching re-hardened zones appear to be bright compared to the grey-brown tempered zones. The technical standards ISO 14 104 (1) and AMS 2649 (9) specify the process of STE. This testing method is applicable nearly independently of the shape of the parts. From the first point of view, it seems rather simple to perform the testing procedure. However, practical experience as well as round robin tests demonstrate the problems of the STE method (10). Circumstances during the optical inspection of the etched parts and the skills and experiences of the operators may cause some of these deviations. The state of the etching bath proves to be the main reason. In order to monitor the etching process the standard ISO 14104:2017 demands the usage of reference blocks. Up to now, production components showing grinding burn are often used as reference blocks. The application of these parts has some disadvantages since they have unknown depth profiles and are not reproducible. Furthermore they will be worn-out in an un-definite degree by multiple use because the etching discoloration has to be removed by an abrasive process before they can be used again. Thus the grinding burn will be dissipated step by step with the material.

In order to avoid these disadvantages imq developed special reference blocks for supervising STE (11). These reference blocks are made of case hardened 21MoCr5 steel blocks. Using LASER technology graded level of grinding burn are generated: one re-hardened zone, 9 tempered zones with increasing depth between 25 µm up to 230 µm and one zone having only changes in the stresses. Figure 3 shows two examples.



Re-hardened zone, depth = 50 µm, surrounded by a tempered zone **Tempered zone, depth = 160 µm**

Fig. 3: Cross sections of LASER marks on reference blocks NE Test Set

Comparing the etching colours of reference blocks etched in a fresh bath and etched after usage it is possible to detect even small deviations of bath concentrations and contaminations. The performance of the STE procedure can be checked and the result is documented by the etching colours. The surface has to be in a uniform grey colour and a certain number of laser marks has to be visible clearly.

Experience shows that the NE Test Set blocks have a higher sensitivity for changings of the etching bath than a pH measurement can offer. Table 1 gives the measured parameters over the lifetime of an etching bath. After etching of 113 work pieces the values of the dissolved Fe content was increased but the pH-values in the fresh bath as well as in the consumed bath were both lower than 1. The reference block etched in this bath became very dark and non-uniform compared to the reference block etched in the fresh bath. Therefore, it did not meet the demands of the standard. The bath had to be exchanged.

Table 1: Measurement of pH-values and content of dissolved iron

Date	Etching: Nitric acid in ethanol		Bleaching: Hydrochloric acid in ethanol		Remarks
	pH value	Iron content [g/l]	pH value	Iron content [g/l]	
15.07.2015	< 1	< 0.02	< 1	< 0.02	Re-conditioned etching bath
12.08.2015	< 1	1.7	< 1	0.27	Used for 113 work pieces

The reference blocks for STE can be evaluated manually using a grey scale. However, evaluations performed by operators may exhibit considerable disadvantages (i.e. subjective evaluation). In order to avoid this disadvantage, imq developed the special device NE Test (11). The NE Test allows an automatic evaluation of NE Test blocks according to the demands of ISO 14104. The Figure 4 a through 4 c demonstrate the three steps to perform the test by using the NE Test.

Step 1 (Figure 4 a) consists in etching a block in a fresh etching bath. This step creates the etching normal, in this case with seven completely visible marks and a uniformly grey level according to the demands of ISO 14104. These testing results are saved. In the step 2 (Figure 4 b) a new NE Test block is etched in a used etching bath. The NE test compares the test results with the etching normal. In this example, the block has a basic grey level and uniformity according to ISO 14104. However, only five marks are completely visible. In conclusion the validation is “not ok”. In the last step, the results are saved in a report (Fig. 4c). These guarantees the traceability of the quality of the etching process. These evaluations are very well reproducible and performed within seconds.

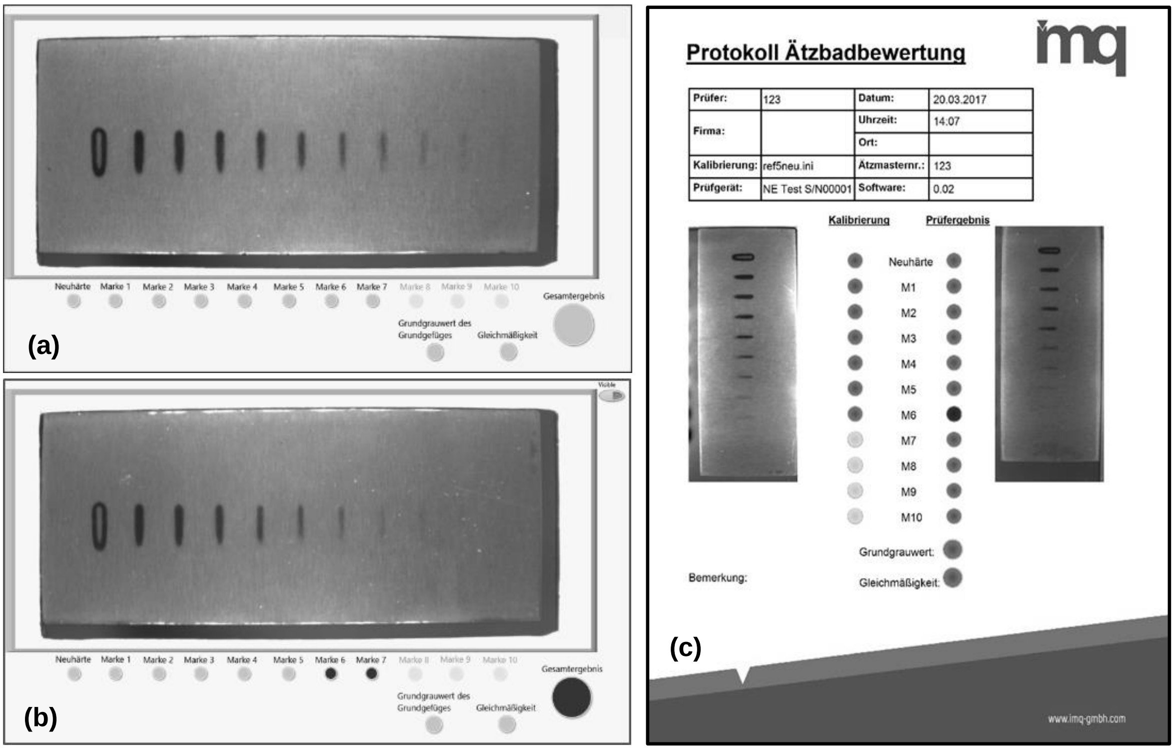
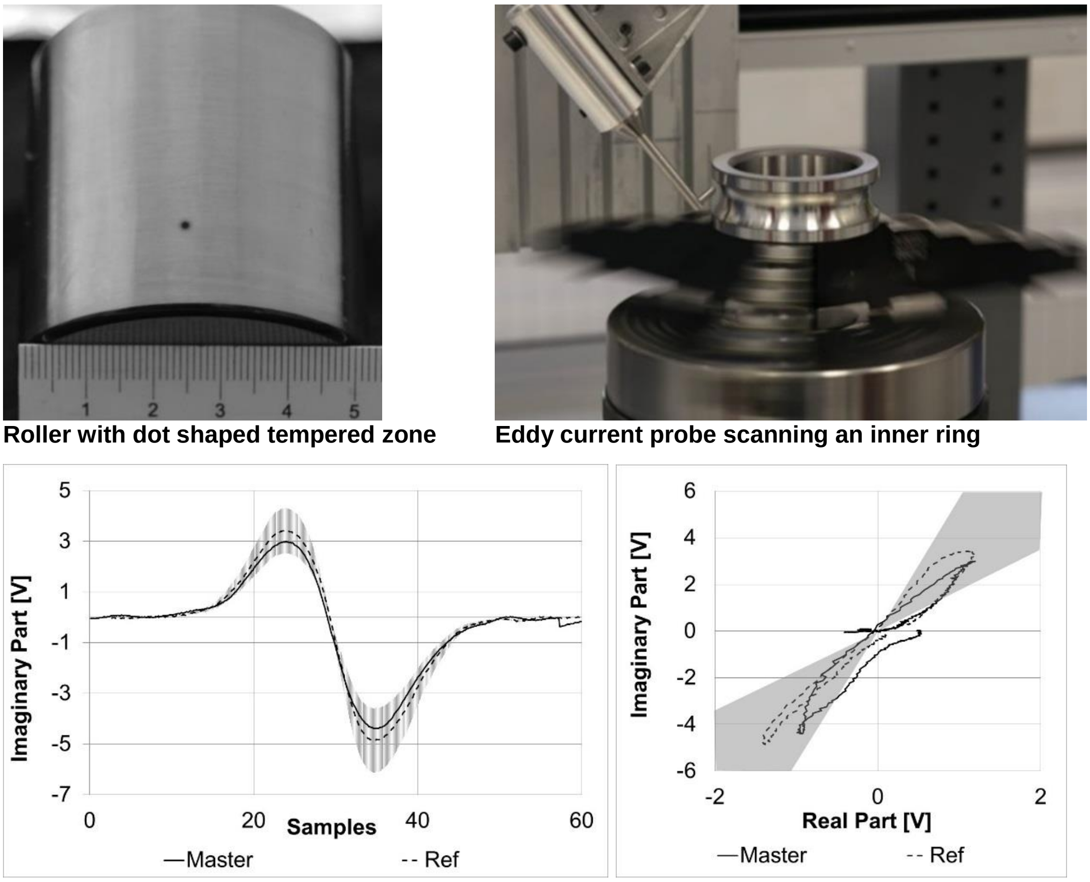


Fig. 4: Screenshots from the NE Test display of the application of NE Test to evaluate NE Test blocks, a) Generation of evaluation master in a fresh etching bath b) Evaluation of a NE Test block in a used bath c) Report of testing results

3.2. Reference Blocks for Electromagnetic Testing Methods

The electromagnetic testing methods are based on the correlation between structure and electromagnetic properties. Tempering and hardening have a high influence on magnetic permeability and electric resistance as well as on the mechanical properties and the level of residual stresses. Electromagnetic NDT methods need to be calibrated with parts with known properties. As mentioned above these reference parts cannot be generated by the grinding process. In 11/2016, the Deutsche Institut für Normung DIN issued a technical specification that describes the guidelines of the manufacture and the application of LASER generated reference blocks for electromagnetic grinding burn testing (9).
The reference parts are defined in company specifications according to the requirements for the testing procedure. These specifications describe the shape, dimension and location of the defects on the component. As an example Figure 5 (top left) shows a roller with a LASER generated dot shaped tempered zone on the bearing face. Other specifications demand line shaped tempered zones or re-hardened zones. Such reference parts are applied in many eddy current testing facilities. Figure 5 (top right) shows an eddy current probe scanning an inner ring (7).

For comparable results and, if it is necessary to reproduce a damaged or lost reference part, the new part should exhibit the same signal as the primary one. The deviations for the indication signals should be specified. For imq reference parts tolerances are set as followed: amplitude differences smaller than 2 dB and phase shift smaller than 10° (Figure 5, charts).



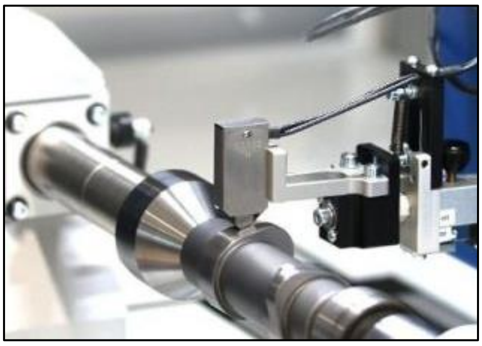
Comparison of eddy current signals: master vs. reference repeatability of ET signals: tolerable deviations for amplitude Δy ≤ ± 2 dB (left) and phase Δϕ ≤ 10° (right)

Fig. 5: Reference Blocks for Eddy current testing of roller bearings

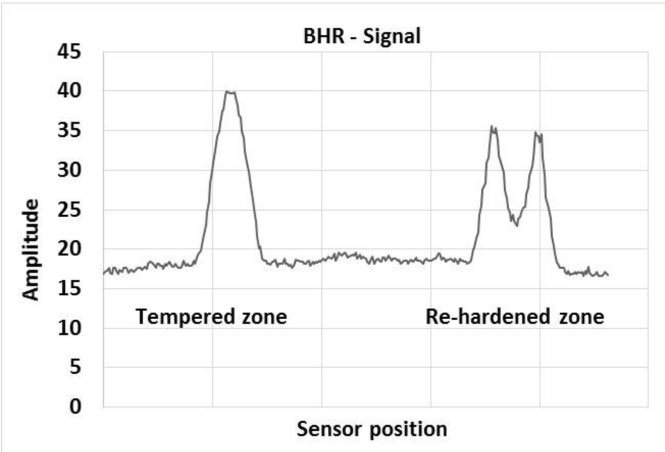
Laser generated defects can be produced on different part geometries. Circumferential tempered zones in the path of ball screws and racks demonstrate that even on extremely shaped surfaces defined artificial grinding burn can be generated reproducibly. Such variations of geometry and position can be used in order to determine capabilities and limitations of the testing method as well as the probability of detection.

Second example concerns reference parts for the Barkhausen noise analysis (Figure 6). Barkhausen Noise Signal corresponds to changes of hardness and residual stresses. Tempered and re-hardened zones on cam shafts were evaluated with a BHN-Rollscan (3). The Barkhausen signal follows characteristic curves corresponding to the created level of grinding burn.

Tempered zones on a cam shaft



BHN probe of a Rollscan
(Source: www.Stresstech.de)



Plot of BHN-Signal, measured across laser generated defects

Fig. 6: Reference Blocks for Barkhausen Noise Testing

4. Summary

Abusive grinding results in local changes of structure and properties in near surface areas of hardened steel parts. The occurrence of grinding burn within the production process is a risk for the durability of the component. In order to minimize these risks reliable testing methods are needed. Reference blocks are an important tool to optimize and monitor the testing process. Unfortunately, it is impossible to generate such reference block with defined grinding burn by grinding.
A special LASER method in order to generate tempered and re-hardened zones on components was developed. These reference blocks with defined defects of different characteristics are usable for non-destructive electromagnetic testing methods as well as for surface temper etching according to ISO 14104 or AMS 2649. Reference blocks with artificial defects can be designed and generated according to the requirements of the testing procedures. The top priority of generating these artificial defects consist in the high degree of repeatability. For example an accuracy of ± 20 µm can be reached for an annealing zone of 100 µm depth.
Furthermore, special reference blocks for surface temper etching were developed. These blocks, named NE Test Set are tools, which allow the monitoring of etching bathes. The blocks can be evaluated automatically with the device NE Test in order to avoid the influence of human factors.

Acknowledgements

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