Grinding burn inspection – tools for supervising and objectifying of the testing process

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Abstract

Any form of mechanical processing of steel parts results in a change of near-surface areas. The term grinding burn is used, when the heat impact during grinding is high enough to generate local tempering or even re-hardened zones. Different test methods are applied to detect grinding burn. Surface temper etching (STE) is the most common method. Further used are electromagnetic methods such as Barkhausen noise analysis (BHN), the 3MA method and recently eddy current testing (ET). Reference blocks with defined defects and different characteristics are required for the evaluation of non-destructive test methods as well as for STE.

This lecture shares experience and results of manufacturing and assessment of reference blocks with artificial defects generated by laser treatment for grinding burn detection. The reference blocks can be used for electromagnetic testing methods as well as for STE. These blocks are used for calibration of the test equipment, especially to verify the sensitivity before testing real parts. In addition, reference blocks are applied in certain intervals within the process in order to guarantee testing reliability.

1. Grinding Burn and Testing Methods

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

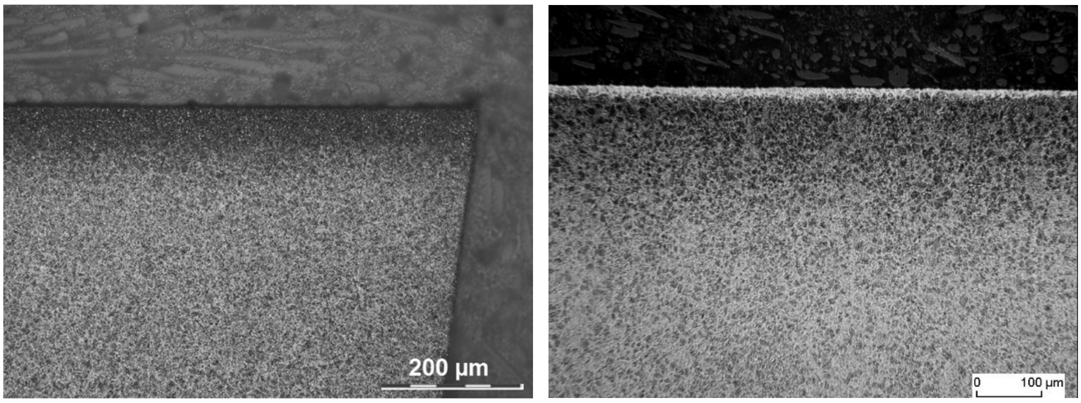


Figure 1: Cross sections of a tempered zone (left) and of a re-hardened zone (right)

The tempered zones are characterized by tempered martensite, a lower hardness than the unaffected material and by tensile residual stress. Re-hardened zones, characterized as “white layers” consist of quenched martensite and retained austenite. These layers show higher hardness and residual tensile or compressive stress. 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 (ISO 14 104:2014 [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. The Barkhausen noise analysis (BHN) [3], the 3MA-method [4] and in recent times, eddy current testing (ET) [5], are already successfully applied. Independent of the applied testing method the reliability must be ensured. Even grinding burn of very small dimension needs to be unfailingly detected. At the same time false indications must be avoided. In order to evaluate the applied testing method reference blocks are necessary [6].

2. Manufacturing of Reference Blocks

Reference blocks with defined defects and different characteristics are required for the evaluation of non-destructive test methods as well as for STE. They allow the calibration and monitoring of the testing process, the selection of appropriate testing methods and the definition of preliminary threshold values. Unfortunately, the generation of reproducible grinding burn on components causes problems regarding size and depth of the influenced area. 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 reproducibly manufactured in size, location and characteristic on the tested components. Furthermore, 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. The type of defect and its position on the work piece can be chosen according to the particular needs of the customer. Furthermore it is possible to generate defined defect shapes, sizes and different depth profiles. This can be done on flat surfaces as well as on convex or concave surfaces. A big challenge was to generate the defects with a high degree of reproducibility. Our present state of art allows reproducing e.g. a tempered zone of 100 µm depth with an accuracy of ± 20 µm.

Another question was whether the LASER defects are suited to simulate real grinding burn. A lot of metallographic investigations, micro hardness measurements and measurements of residual stresses had been done [7] [8]. As an example, the depth profiles of residual stresses of LASER generated artificial defects and of grinding burn caused by abusive grinding are plotted in Figure 2. It was shown that the structure and physical properties of these artificial defects are at least very similar to the real defects.

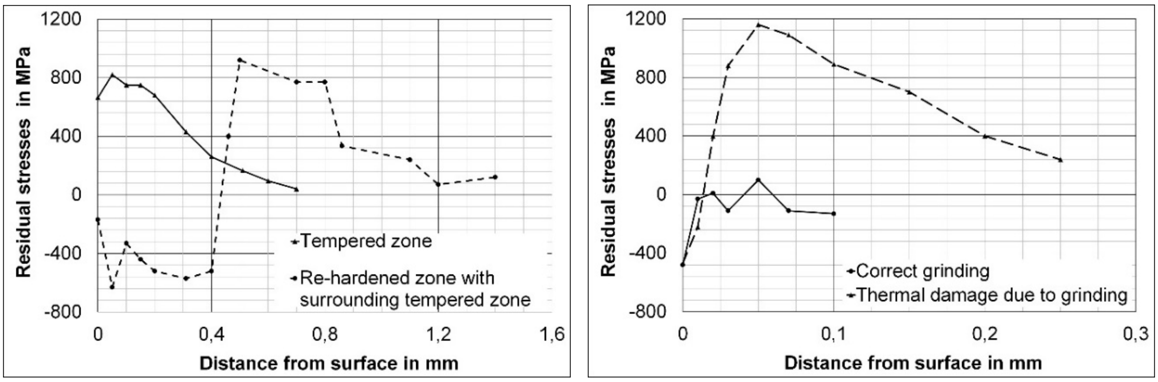


Figure 2: Residual stress profiles; left: LASER generated defects [7], right: Grinding burn caused by abusive grinding [8]

3. 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. Therefore electromagnetic 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]. In this paragraph, four examples of the application of these reference blocks shall be discussed.

The first example concerns the eddy current testing of roller bearings (Figure 3). The reference parts, which are necessary to supervise the testing process, are defined in company specifications. These specifications describe the shape, dimension and location of the defects on the reference part. As an example Figure 3a) shows a roller with a LASER generated dot shaped tempered zone on the bearing face. Other company specifications demand line shaped tempered zones or re-hardened zones. According to the needs of the customer, imq designs and generates the artificial defects on the parts, which are provided by the customer. The properties of the reference part are documented by an imq - conformation sheet describing the artificial defect (shape, dimension, depth profile, location on the part). Such reference parts are applied in many eddy current testing facilities. Figure 3b) shows an eddy current probe scanning an inner ring [7]. A big challenge consist in the reproducibility of the defects: Firstly, defects on different shaped parts should exhibit nearly the same eddy current signal. Secondly, if it is necessary to reproduce a damaged or lost reference part, the new part should exhibit the same signal as the primary one. Deviations of indication signals guaranteed by imq are: amplitude differences are smaller than 2 dB and phase shift is smaller than 10 ° (Figure 3c).

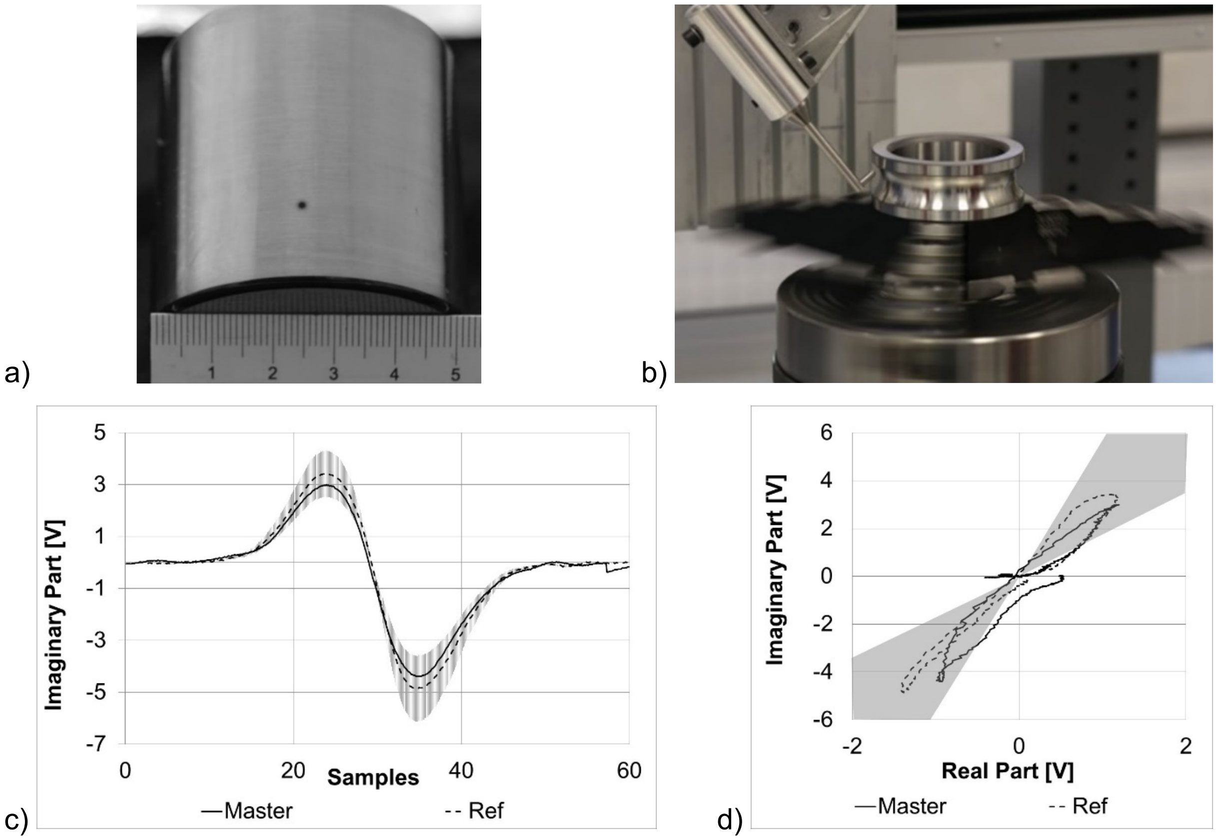


Figure 3: Eddy current testing of roller bearings a) roller with dot shaped tempered zone b) eddy current probe scanning an inner ring [7] c) comparison of eddy current signals: master vs. reference repeatability of ET signals: $\Delta y \leq \pm$ 2 dB; $\Delta\phi \leq 10°$

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 (Figure 4). 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.

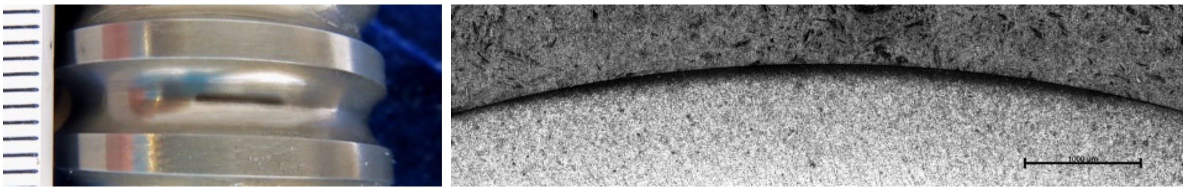


Figure 4: Reference parts for detection of grinding burn on ball screws; left: rack with circumferential tempered zone, right: microsection of tempered zone (length 5700 µm; width 1000 µm; depth 145 µm)

The next example concerns the application of an array probe, described in [11]. For the usage of an array probe a detailed knowledge about the probe characteristics is necessary. Therefore reference parts with known properties are needed. The reference block here is a roller with different shaped tempered zones in various positions (Figure 5– small pictures in upper line). The image of eddy current signals is plotted in Figure 5.

Photographs of artificial defects, etched with nital

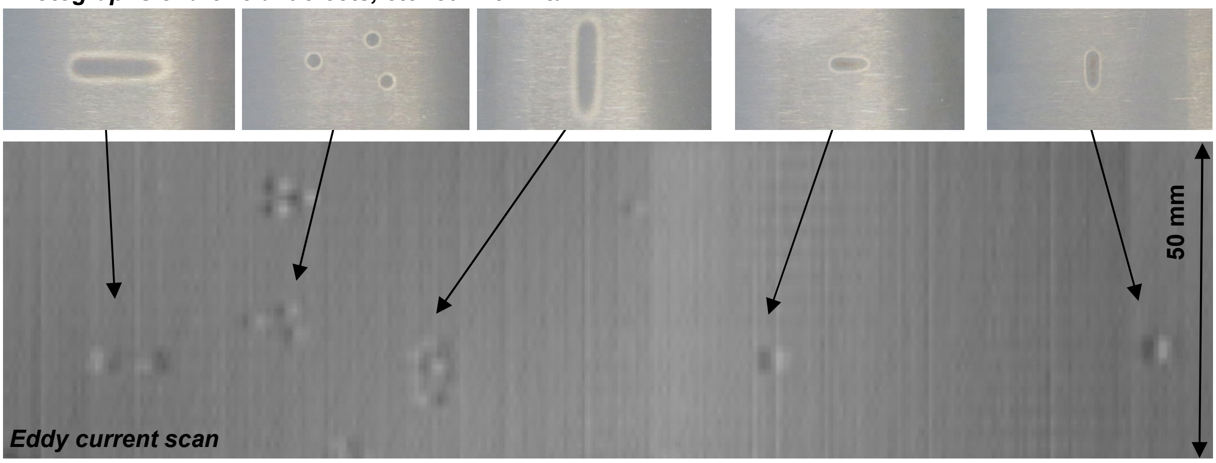


Figure 5: Eddy current testing with an array probe described in [11]; upper line: artificial defects on the reference part, picture below: plot of eddy current signal

It needs only one rotation to evaluate the reference probe. The different defects are clearly detectable. A special CNC unit or robot system is not necessary to scan the complete surface.

The last 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 (Figure 6a) were evaluated with a BHN-Rollscan [3]. The laser generated grinding burn causes a significant peak in the Barkhausen signal corresponding to the created level of burn.

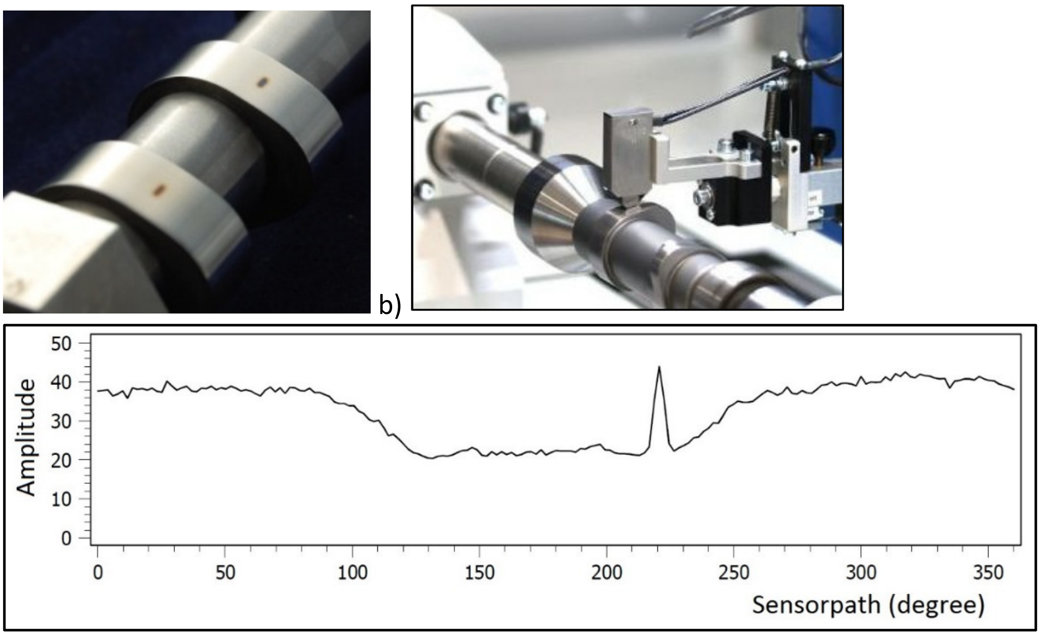
a) b) c)


Figure 6: Reference Blocks for Barkhausen Noise Testing [12] a) tempered zones on a cam shaft b) BHN probe of a Rollscan (Source: www.Stresstech.de) c) Plott of BHN-Signal

4. Reference Blocks for 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, the results of a round robin test (described in [10]) may demonstrate the problems of the STE method. In total 15 laboratories tested and evaluated 29 reference blocks with different LASER generated defects. Figure 7 shows the test results.

It is obviously that the results of the laboratories differ significantly. Whilst the probability of detection (PoD) of grinder burn class E and D (heavy tempering) is 100% the PoD of class B (light tempering) is only 75%. The classification between “reject” or “ok” shows significant differences, too. The light tempering was classified as “reject” by 45% of the laboratories. The other ones stated the tempering as “ok”. In the case of heavy tempering the rate is 75 % to 25 %. This example demonstrates the different capabilities of the participating laboratories to perform the STE.

Circumstances during the optical inspection of the etched parts and the skills and experiences of the operators may cause some of these deviations. However, the main reason is the state of the etching bath. In order to monitor the etching process ISO 14104 demands the usage of reference blocks. Up to now, components with grinding burn are often used as reference blocks. However, the application of these parts has some disadvantages since they have unknown depth profiles, are not reproducible and will be worn-out in an un-definite degree by multiple use.

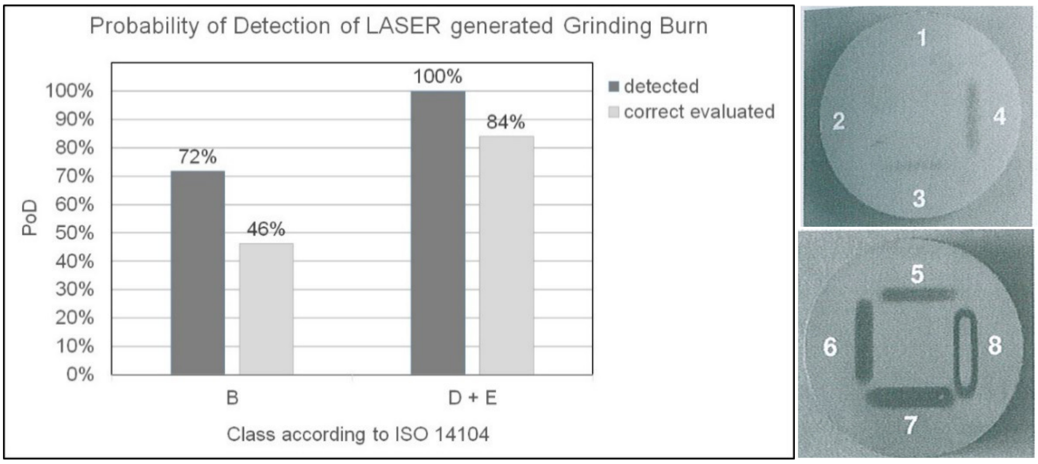


Figure 7: Round Robin Test of STE method: LASER generated defects on a case hardened part steel grade 16MnCr5, evaluation results of 15 laboratories [10]

In order to avoid these disadvantages imq developed special reference blocks named NE Test Set (Figure 8).

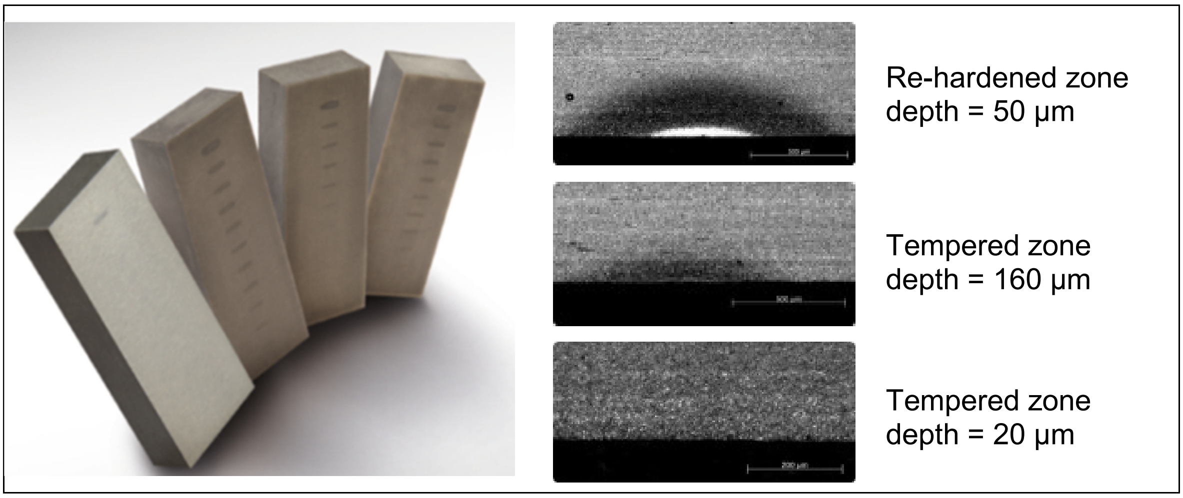
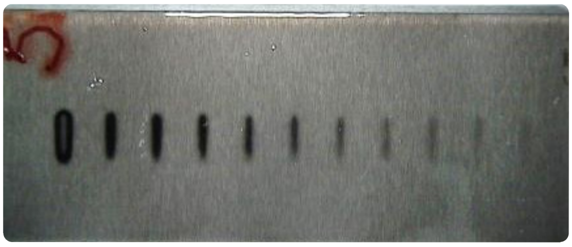


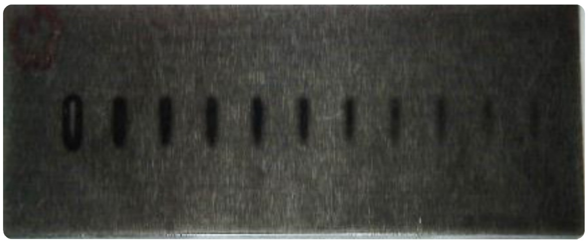
Figure 8: Grinding burn reference blocks NE Test Set (left) and cross sections of LASER marks (right)

These reference blocks are made of case hardened 21MoCr5 steel blocks with one re-hardened zone and 10 tempered zones. The latter have depth profile between 25 µm to 230 µm. Figure 9 demonstrates the monitoring of the etching bath with NE Test Set.

The first block was etched in a fresh etching bath. It meets the above mentioned demands of ISO 14104. After that, 113 parts were etched in this bath. Afterwards the next block was etched. The block became very dark and non-uniform. Therefore, it did not meet the demands of the standard. The bath had to be exchanged. The measured values of the dissolved Fe content corresponded with the consumption of the bath. However, the pH-values in the fresh bath as well as in the consumed bath were lower than 1. It proves that the STE Set blocks have a higher sensitivity for the changing of the etching bath than a pH measurement can offer.



Fresh etching bath (15.07.2015)



Consumed etching bath (12.08.2015)

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

Figure 9: Supervising of etching bathes: NE Test blocks etched in fresh and in used bathes (above), pH-values and content of dissolved iron (below)

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 avoid this disadvantage imq developed the special device NE Test (

Figure 10).

The NE Test allows an automatic evaluation of NE Test blocks according to the demands of ISO 14104. The Figure 11 a through c demonstrate the three steps to perform the test by using the NE Test.

Figure 10: NE Test for automatically validation of NE Test reference blocks

Step 1 (Figure 11a) 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 an uniformly grey level according to the demands of ISO 14104. These testing results are saved. In the step 2 (Figure 11b) 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 (Figure 11c). These guarantees the traceability of the quality of the etching process. These evaluations are very well reproducible and performed within seconds.

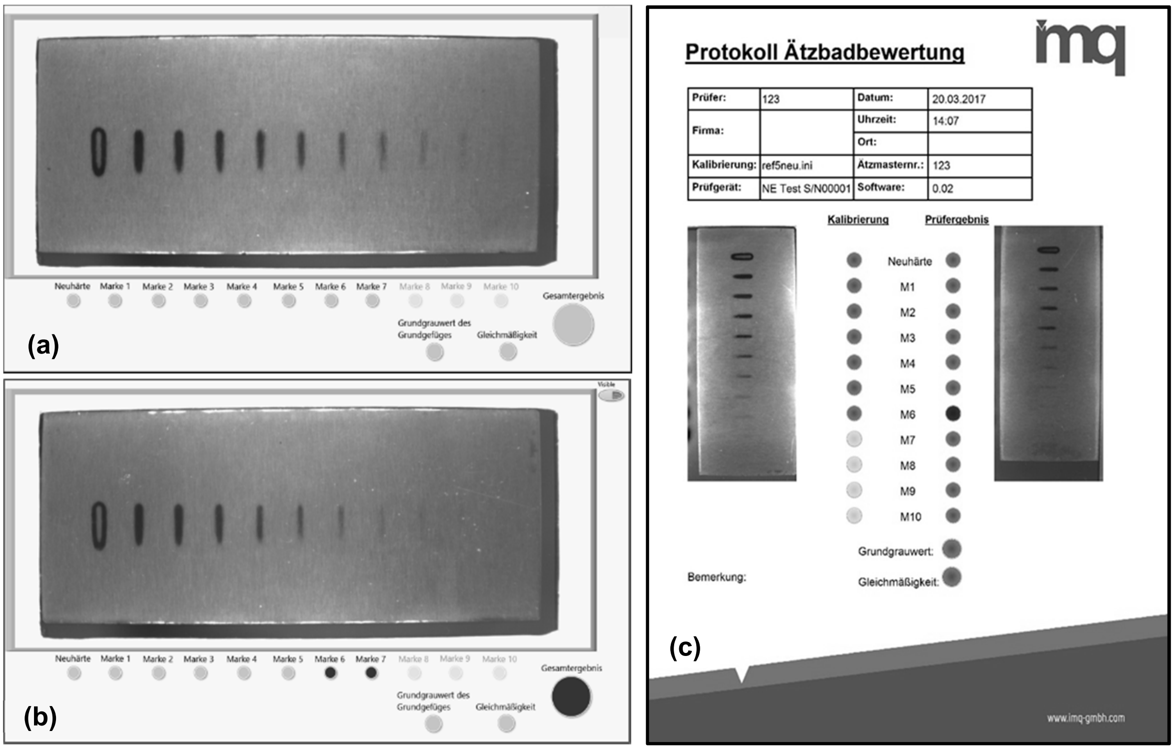


Figure 11: Screenshots from the NE Test display of the application of NE Test to evaluate NE Test blocks, a) Generation of evaluation master in a fresh etching bath b) Evaluation of a NE Test block in a used bath c) Report of testing results

5. 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 by imq. 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.

According to the company specifications imq designs and generates artificial defects for non-destructive testing on the parts, which are provided by the customer. The top priority of generating these artificial defects consist in the high degree of repeatability. Our present state of art allows reproducing e.g. an annealing zone of 100 µm depth with an accuracy of ± 20 µm.

Furthermore, imq developed special reference blocks for surface temper etching. 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.

6. References

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