Fabrication and application of reference blocks for grinding burn detection and crack testing

Martin Wolfgang SEIDEL[1], Antje ZÖSCH[1], Christopher SEIDEL[1],
Konstantin HÄRTEL[1], Frederic GRAFE[2]

[1] imq-Ingenieurbetrieb für Materialprüfung, Qualitätssicherung und Schweißtechnik GmbH, Crimmitschau

+49 3762 95370, info@imq-gmbh.com, www.imq-gmbh.com

[2] Westsächsische Hochschule Zwickau Fakultät Automobil- und Maschinenbau, Zwickau

Abstract. In non-destructive testing various reference bodies are applied for test medium monitoring respectively process monitoring. On the one hand, the indication capability of the test medium, e.g. a magnetic powder suspension, can be monitored. Furthermore, they are applied for functionality control of the testing apparatus and for procedure comparisons. Such reference bodies are required to contain inhomogeneities whose properties (e.g. type, shape, dimensions) are defined and can be fabricated reproducibly. In a natural manner such imperfections are often not producible in a definable way. Therefore, so-called artificial inhomogeneities (in the following referred to as standard defect) are inserted into the reference body instead of natural ones.

For non-destructive grinding burn detection by means of electromagnetic testing methods a process for the fabrication of grinding burn standard defects was developed by the authors. New developments in reproducible fabrication of such standard defects e.g. extensive and circumferential standard defects on rotationally symmetric parts as well as standard defects on curved surfaces shall be introduced. Furthermore, it shall be reported about the option of test medium monitoring of reference bodies for grinding burn detection as well as about the current status of standardization.

For surface crack testing by means of ultrasonic resp. eddy current testing standard defects have been inserted into reference bodies in the form of saw cuts or eroded notches up to now. On examples it shall be demonstrated that the test signals which these kinds of standard defects emit, differ significantly from those of real cracks. A newly developed reference body with definably inserted cracks shall be presented as well as its application in non-destructive testing. By means of the developed procedure, cracks of 0.1 to 0.7 mm depth have been fabricated reproducibly so far. They could be detected by eddy current testing, ultrasonic testing, magnetic powder testing and penetration procedure in a reliable way. Thus a uniform reference body for various NDT methods is available.

1. Reference bodies in NDT

In DIN EN 1330-4:2010 “Non-destructive testing - Terminology - Part 4: Terms used in ultrasonic testing” reference bodies are defined as follows: “A reference object containing well defined reflectors, used to adjust the gain of the ultrasonic amplifier in order to compare detected indications with those arising from a known reflector“.

Generalized to other NDT methods, reference bodies are objects containing defined properties such as dimension, chemical composition and, in particular, defined inhomogeneities. In a natural manner, however, inhomogeneities such as grinding burn and cracks cannot be inserted into the reference bodies. Instead of natural inhomogeneities so-called artificial inhomogeneities (also known as artificial defects or discontinuities) are applied. According to DIN EN 1330-2:2010 “Non-destructive testing - Terminology - Part 2: Terms common to the non-destructive testing methods” these are inhomogeneities “such as drillings, scratches or notches which are inserted into a work piece by processing”. In general language the terms standard defect or reference defect are frequently used.

Reference bodies are required in order to select appropriate testing methods and to monitor these during their application. This includes as well the execution of test comparisons and the organisation of comparative studies between testing laboratories and round robin tests. Moreover they serve for determination of preliminary threshold values. The emphasis hereby lays expressively on preliminary since the final threshold values are usually only to be defined within the scope of a validation. Reference bodies are supposed to be employed regularly during the testing process in an undisclosed way in order to ensure strict adherence to the testing conditions.

2. Reference bodies in grinding burn detection

Grinding burn is caused by unintentional thermic overstressing during the grinding process on work piece surfaces. This may lead to local structural change and change in the material properties (see figure 1). Tempering zones and, in case of increased energy input, so-called new hardening zones may arise. Not all of these structural changes are detectable by light microscopy. However, they are always connected with the occurrence of residual stress.

Figure 1: Formation and appearance of grinding burn

Due to a wide range of influencing variables during the grinding process the occurrence of grinding burn depends to a large extension on a more or less random interaction of various factors. Therefore grinding burn may not be completely avoided with complete certainty. Furthermore it has to be taken into consideration that even within a good charge single parts may be affected by grinding burn. Conversely, this means as well that it is not possible to introduce clearly defined grinding burn inhomogeneities into reference bodies by means of grinding.

Particularly well suited is in this case the application of laser radiation /1-3/. At imq Ingenieurbetrieb this method has been developed further in a way that standard defects on component surfaces may be caused in a defined way according to position and extension on the component and according to the defect level (change in residual stress, tempering zone, new hardening zone) and even containing similar physical effects as the real defects do (see figure 2).

Figure 2: Fabrication of artificial inhomogeneities/ standard defects by means of LASER radiation and circular standard defects d = 1.2 mm on a camshaft

The principal focus was hereby laid on the reproducibility of the properties such as lateral and depth extension of the artificial inhomogeneity. Thus, for example tempering zones may be fabricated adhering to a replicate precision concerning lateral extension of +/- 0.10 mm and according to depth extension of +/- 0.02 mm.

The method has been recently developed in a way that now even customer requirements such as circumferential standard defects on rotationally symmetric parts as well as standard defects on curved surfaces or standard defects of larger lateral extension can be fabricated. Figure 3 shows an example of such artificial inhomogeneities fabricated by imq.

Figure 3: **Circumferential standard defect on a gear rack, extensive standard defect on a roller bearing ring d = 250 mm and standard defect on the curved surface of a threaded nut (images below: cross sectional cut through the standard defects)**

Another considerable aspect in fabrication of reference bodies concerns the referencing of the produced inhomogeneities and the monitoring of the test medium “reference body”. During fabrication of the reference bodies standard defects are initially produced under identic conditions on at least two parts. Afterwards eddy current testing is performed with the master part as well as with the reference part. Figure 4 shows the testing signals which were received on a tempering zone resp. a tempering and new hardening zone by means of an absolute probe.

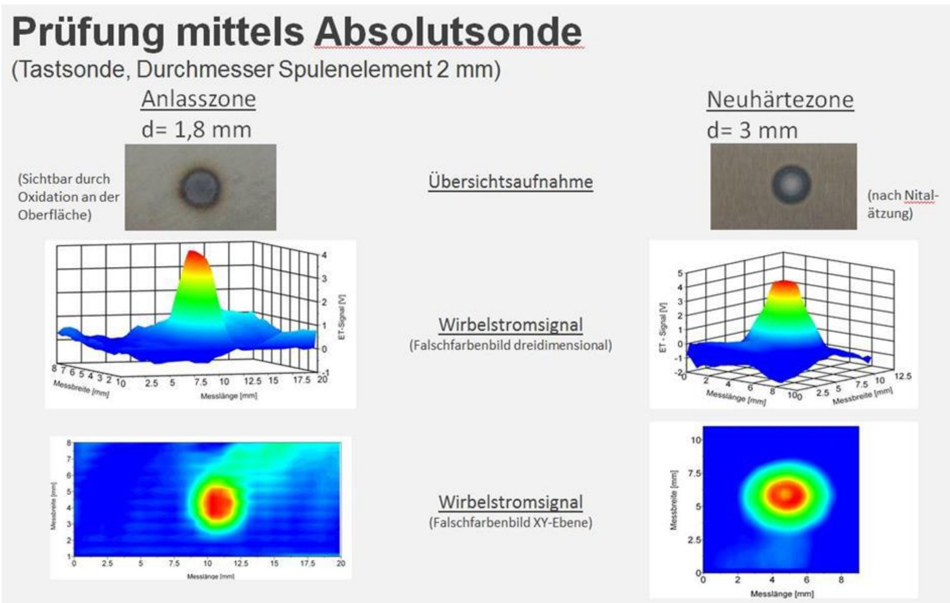


Figure 4: **Eddy current scan of a tempering zone (left) and of a tempering and new hardening zone (right)**

In case that both signals correspond within the scope of measuring accuracy the standard defect in the reference part is examined metallographically or by means of a residual stress measurement. Then the customer receives a certificate containing the properties of the reference body. During test medium monitoring the reference bodies are supposed to be checked concerning surface defects such as scratches or notches since they may as well have an effect on the testing result. By means of eddy current testing it may be examined whether the standard defect has changed itself.

In the meantime, E DIN SPEC 4882:2015-05 provides a draft of a standard which was developed by the DIN standard committee in charge and which defines standards within the fields of application and the reference body requirements in non-destructive grinding burn detection (figure 5). This draft is now publicly displayed for assessment.

Figure 5: Contents of E DIN SPEC 4882:2015-05 (draft)

Figure 6: NE Testing Set reference bodies for monitoring nital etching; www.imq-gmbh.com

For monitoring nital etching according to ISO 14 104 reference bodies have been developed as well (figure 6).

3. Reference bodies containing defined cracks

Currently, for non-destructive crack detection reference bodies are applied where defects have been inserted to in the form of saw cuts or eroded notches (figure 7). The width of these standard defects is usually between 1 mm and 0.05 mm. The gap width of cracks, however, is just about a few µm.

Figure 7: Reference body for eddy current testing containing inserted notches; Product ID: 3-Notch Eddy Current Standard, 4340 Steel; Notch depth: 0.2; 0.5; 1.0 mm; Width 0.1 to 0.12 mm; PH Tool Pipersville, PA 18947 USA

Figure 8 shows the results of eddy current testing of a ferro-magnetic steel part containing inserted notches of 0.2 mm width compared to the same parts containing real cracks of almost similar depth. The signals considerably differ in their amplitude whereby the real cracks cause significantly higher signal amplitudes.

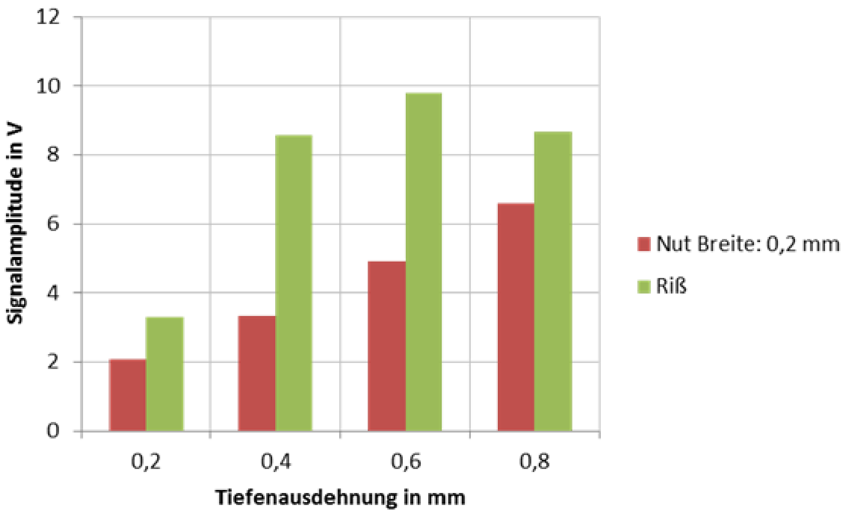


Figure 8: Comparison of signal amplitudes of natural cracks and eroded notches exemplified by locking sleeves made of MW 700L (micro-alloyed fine-grained steel) according to /5/

The acquainted reference bodies containing artificially caused cracks (figure 9) are intended for magnetic powder testing and penetration testing. In this case, the cracks arise more or less randomly resp. in an applied Ni-Cr layer. Therefore, they are not suitable to serve as reference bodies in eddy current testing and ultrasonic testing.

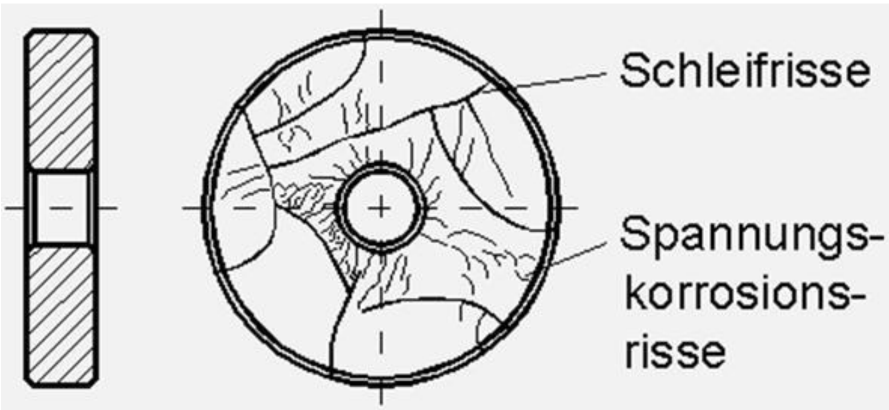


Figure 9: Reference body containing cracks for magnetic powder and penetration testing

At the moment imq Ingenieurbetrieb is working on a process which allows the fabrication of cracks of defined extension in length and depth in steel reference bodies. In the following the results shall be presented for the first time.

In the beginning, the examinations were carried out on flat specimen made of Q & T steel. Figure 10 shows the simulated stress curve in a flat specimen which had been locally treated thermally in the centre and then statically stressed on bending until the crack occurs.

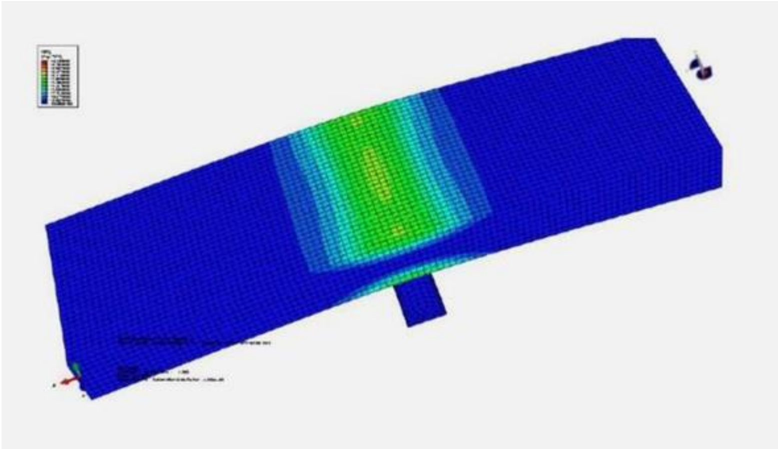
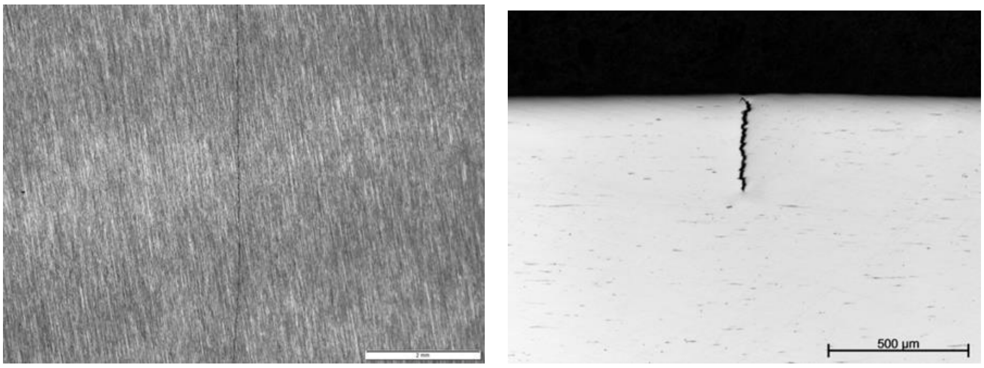


Figure 10: Simulation of a stress curve in test specimen LxWxD = 110x30x8 mm

Figures 11 and 12 show recordings of the occurred cracks. The presented crack has a width of only few µm on the surface and has a depth of 0.5 mm. The macro-image of a fractured surface emphasizes that the crack has a consistent depth all over its total length of about 10 mm (Fig. 12).



a) **b)**

Figure 11: Displays of fabricated cracks in test specimen a) plan view b) cross section

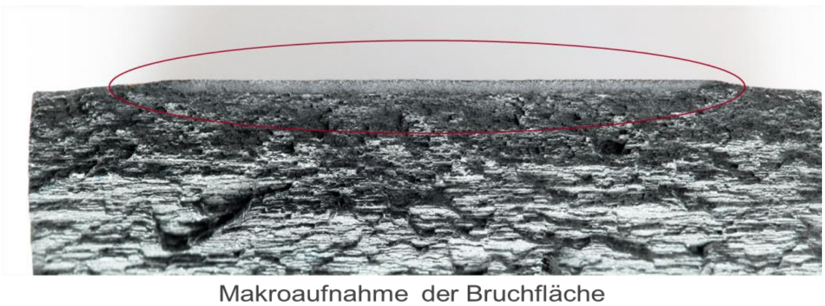


Figure 12: Macro-image of a fractured surface

The following figures 13 to 16 show the results of testing such reference bodies by means of eddy current testing, ultrasonic testing, magnetic powder testing and penetration testing.

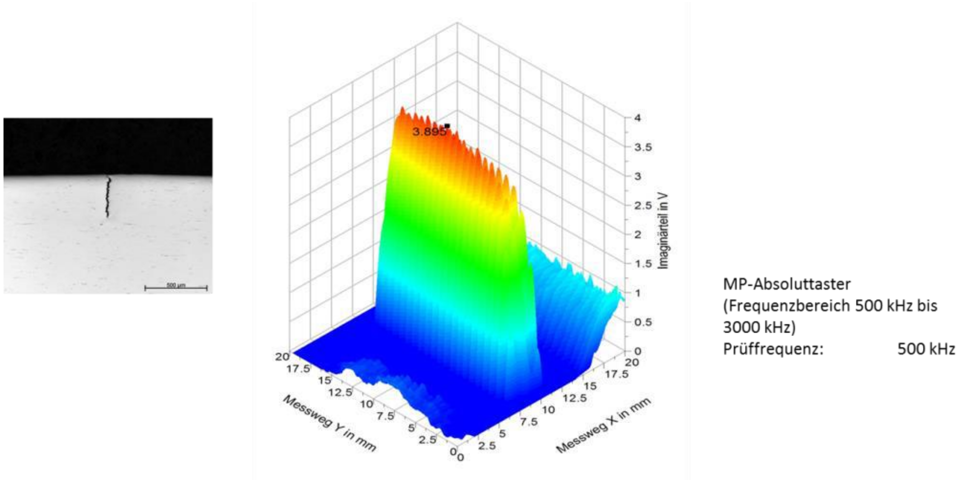


Figure 13: Eddy current scan over an artificially fabricated crack (depth 0.5 mm) in a flat specimen

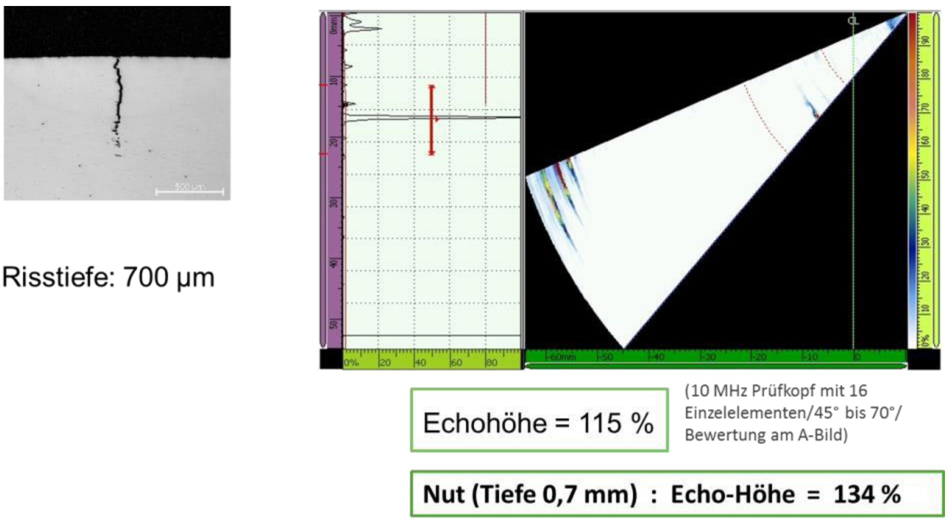
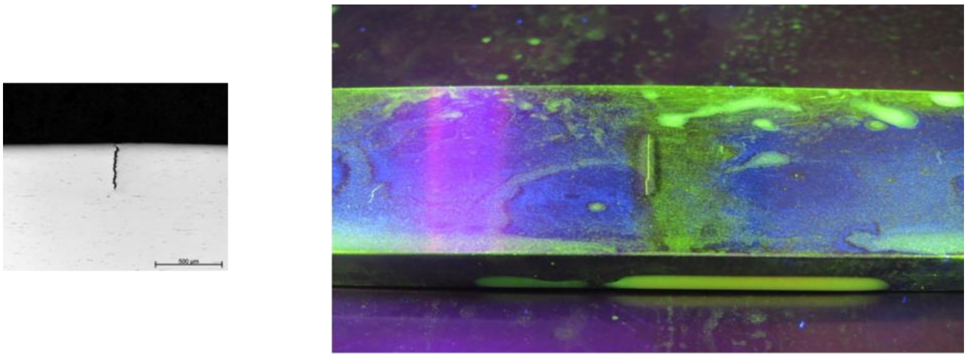


Figure 14: right image: Cross section left image: A - Image of an artificially fabricated crack (depth 0.7 mm) recorded by means of ultrasonic testing (Phased Array)



Tiede Universalfluxbank 900 WE2
Längsmagnetisierung: 5,0 KAW
Kreismagnetisierung: 0,6 KA
Bestrahlungsstärke UV-A Lampe: größer
10 W/m² (siehe Norm DIN EN 571-1)

Figure 15: Magnetic powder testing of an artificially fabricated crack (depth 0.5 mm)

Red-White- Procedure **Fluorescent penetrant**

Rot-Weiß -Verfahren Fluoreszierendes Eindringmittel

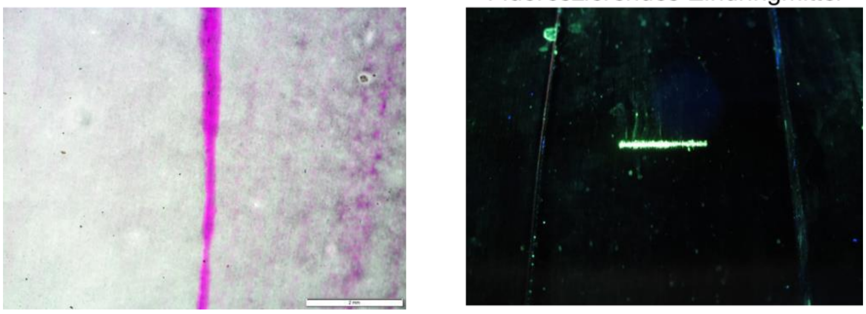


Figure 16: Detection of an artificially fabricated crack (depth 0.5 mm) by means of penetration test

In all methods the fabricated cracks are clearly displayed. In the ultrasonic test the crack emitted a slightly lower echo response compared with a notch of equal height.

4. Conclusion

The laser process is particularly well suited for the fabrication of reference bodies containing artificial inhomogeneities for grinding burn detection. This technology was advanced by imq Ingenieurbetrieb and allows from now on the reproducible fabrication of standard defects on curved surfaces, of circumferential standard defects and extensive standard defects as well. For test medium monitoring eddy current testing by means of absolute probe is applicable. The current standard draft E DIN SPEC 4882:2015-5 defines fields of application and reference body requirements for non-destructive grinding burn detection.

Furthermore, a nital etching Test Set containing reference bodies for monitoring nital etching was developed by imq as well. By means of combining local thermic treatment and mechanical stress, cracks of defined measurements are produced in steel parts. So far, this has been tested in plate-shaped components made of Q & T steel. The depth of these cracks varied from 0.1 mm up to 0.7 mm. Such fabricated reference bodies are suitable for application in numerous NDT methods.

5. Literatur

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