NANO, MICRO OR MACRO PROBLEMS – THE KNOWLEDGE GAP IN NDE

Dr. Heinrich Heidt
BAM Federal Institute for Materials Research and Testing, Berlin, Germany

ABSTRACT
Non-destructive testing is aimed to improve the safety and usability of products and infrastructure. In most cases the planning of NDT is concentrated on rare but possible (expected) defects and inhomogeneity. Defect analysis after failure or accidents often shows that this approach is inadequate: the cause of the event may be an unexpected, a chain of quality or management deficiencies never before observed. NDT experts should be sensible to this experience and be aware of unexpected indications and deviations. Examples.

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INTRODUCTION
Non-destructive testing (NDT) has reached an impressive level of physical, technical and computational standards. Many NDT processes are automated from data acquisition to evaluation. The quality of NDT is recorded and optimized by test specimens with all possible, expected and ever observed failure modes. The high degree of automation may lead to a mental hubris on the side of engineers who are satisfied as soon as they have done “everything possible”. Let us have a look at reality!

The abilities of NDT
The use of additional and new physical principles has expanded the applicability of NDT to formerly impossible projects and specimens. Especially the development of new transducers and sensors (i.e. Phased Array in UT, Imaging Plates and Detector Arrays in RT, xx Cameras in Thermography, GMR in ET) and sources (i.e. Synchrotrons and Betatrons in RT and Diffraction) has driven NDT and NDE beyond former limits.

What are we looking for?
The requirements for NDT from the point of view of design and production engineers are mostly conventional: looking for cracks, pores, inclusions, corrosion, sometimes gluing and debonding. And the task is restricted to “fitness for purpose”: Make sure that the specimen fulfills all the requirements stipulated by standards, i.e. for pressure vessels or welds. This is not enough!

What are we really looking for?

-Safety
A very broad definition says: Safety is relative freedom from danger, risk, or threat of harm, injury, or loss to personnel and/or property, whether caused deliberately or by accident.

For the NDT engineer, a safe product has to fulfill much higher standards than just “fitness for purpose”. Even in the unlikely and unexpected case of an accident the product shall not impose any “harm, injury, or loss to personnel and/or property”! This is why we wear seat belts in cars, use multiple barrier safety concepts in nuclear plants and fire resistant structures in civil engineering.

-Lifetime
Lifetime of a product, plant or infrastructure is part of the expectations of the customer or user and the “fitness for purpose”. The lifetime is calculated for the intended use. In many cases the lifetime can be extended after NDT and replacement of worn or defect parts. It is evident that after many years of use even unexpected failures may occur. A low-profile NDT might overlook these defects and cause a severe safety and lifetime problem.

-Quality
We like the wise definition from the American Society for Quality.

“A subjective term for which each person has his or her own
definition. In technical usage, quality can have two meanings:

a) The characteristics of a product or service that bear on its ability to satisfy stated or implied needs;

b) A product or service free of deficiencies.”

While meaning a) reflects the “fitness for purpose” considerations, meaning b) is a clear mandate to the NDT inspector (and the producer): good quality means “free of deficiencies”!

Since “Quality” is a subjective term, NDT cannot be used to quantify quality, but NDT should provide a product free of any observed and relevant deficiencies.

What should we know?

As a “consulting partner” to the design engineer and the user/customer, the NDT expert must learn about all

- Critical conditions
- “Unlikely” events/scenarios
- “Impossible” causes of failures

From failure and defect analysis we learn that then – and only then – a responsible and final decision can be made about the inspections to be applied. In many cases it is sufficient to train the inspectors (or the evaluation software) to recognize and notify these indications. In other cases some additional test may be necessary to exclude the risk of unexpected sources of failure.

EXAMPLE AND DEMONSTRATION – THE ICE TRAIN AXLE ACCIDENT

- Assumptions and investigations from the design engineers

For metallurgical quality verification it is sufficient to analyze a cut-off section from the end of the axle. The results of this representative sample stand for the composition and mechanical properties of the whole specimen.

NDT (UT) is applied to the new full axle: volume defects (inclusions, pores …) with a sensitivity of 1 mm circular disk-shaped reflector and transverse defects with a sensitivity of 2 mm notch depth.

In-service inspection is applied to the possibly critical regions every 300,000 km for transverse defects (cracks) with a sensitivity of 2 mm notch depth (Figure 2).

- The accident
- Unexpected findings (“never seen before”)

Inclusions were found by Micro CT near the surface of the axle and verified by metallography.

Inclusions detected and localized by CT and verified by metallography ranged up to 930 µm in length. This exceeds
the permitted length of 176 to 261 µm for different types (sulfides, Al, Si) significantly. Inclusions of this size and type were not observed in a similar place of the axle series before.

The inclusions were not detectable at the first time by inspection (UT with a sensitivity of 1 mm). The growing crack was not registered by the in-service inspection approx. 150,000 km before the accident (UT with a sensitivity of 2 mm).

If design engineers and NDT experts were aware of these potential problems: are there NDT solutions for a volume inspection of inclusions of this size?

- **The current situation**

Since the growing crack was not detected by the UT inspection 150,000 km before the accident, the inspection interval was reduced to 30,000 km due to safety and fracture mechanics considerations. The axles are replaced by new parts made from a different material. The total cost of these measures will be approx. €350 million. There is ongoing research for a permanent online-inspection of the axles during use.
CONCLUSION

The cause of the ICE axle accident was not perceptible to the inspection personnel and the manufacturer of the axles. They have no personal legal responsibility; the prosecutor closed the proceedings in 2009.

But: The inspection procedures were limited to the causes and risks which were considered as possible. Some regions of the axles are inspected with high sensitivity, others obtained less attention. The permissible NDT indications for volume defects (inclusions) were not in line with the purity requirements for the material. The assumption that the sample from a cut-off end of the axle is representative for the full volume proved to be wrong in this case. A crack initiation from inside the volume was not considered.

Lessons learned

The initiation and growth of a failure can be different from all calculations and modeling performed before. It may stem from the micro or nano scale (material structure and chemical reactions) instead of a source on the surface. Similar scenarios are possible for reinforced materials, multilayer compounds, even concrete and other complex specimens, especially if uncommon environmental and stress exposures are applied.

NDT experts and inspectors must develop high awareness for the Unlikely and Unexpected. The registration levels for indications should be as low as technically possible; the discrimination (alarm) level must allow the treatment of “non-identified indications”. If affordable, the whole volume / surface of the specimen should be inspected with the same high sensitivity; only the alarm level should be adapted to the local stress / use.

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