Micro Non-Destructive Testing and Evaluation

Giovanni Bruno

BAM, Bundesanstalt für Materialforschung und -prüfung, Unter den Eichen 87, 12205 Berlin, Germany; giovanni.bruno@bam.de

1. Foreword

What is meant by ‘Micro Non-Destructive Testing and Evaluation’? This was the central subject of debate in this Special Issue.

At present, sub-millimeter-size components or even assemblies are pervading the industrial and scientific world. Classic examples are electronic devices and watches (as well as parts thereof), but recent examples encompass additively manufactured lattice structures, stents, or other microparts. Moreover, most assemblies contain micro-components. Testing such components or their miniaturized parts would fit well within the topic of micro non-destructive testing and evaluation.

In all cases, performance and integrity testing, quality control, and dimensional tolerances need to be measured at the sub-millimeter level (ideally with a spatial resolution of about a micron); most of the time, such features and components are embedded in much larger assemblies, which also need to be taken into account. The solution to this dilemma (i.e. measuring large parts with high resolution) depends on the part and on the problem under consideration.

Another possible definition of micro non-destructive testing and evaluation can relate to the characterization of micro-features (e.g., the microstructure) in much larger specimens, such as damage in concrete cores or porosity in additively manufactured components. A further aspect is the use of microscopic probes to evaluate macroscopic properties. This is the case, for instance but not at all exclusively, in the use of diffraction techniques to determine macroscopic stress.

The splits between testing and characterization at the micro-level (or of micro parts) from one side and handling of macroscopic assemblies on the other represent a great challenge for many fields of materials characterization. On top of that, including the use of microscopic methods to test integrity would add a further level of complexity.

Imaging, mechanical testing, non-destructive testing, measurement of properties, structural health monitoring, and dimensional metrology all need to be re-defined if we want to cope with the multi-faceted topic of micro non-destructive testing and evaluation.

The challenge has already been accepted by the scientific and engineering communities for a while but is still far from being universally tackled. This Special Issue yields an interesting answer to the questions posed above. It presents the progress made and the different aspects of the challenge as well as at indicates the paths for the future of NDT&E.

2. Introduction

With the increasing miniaturization of components, performance assessment, quality control, and structural health monitoring have expanded their toolbox of experimental techniques. Classically, non-destructive testing and evaluation (NDT&E) has included macroscopic probes such as radar, X-ray radiography, and ultrasound for structures or large components. Recently, other tools have been used to cope with the challenge of miniaturization. Such tools include not only spatially or temporally resolved techniques such as synchrotron radiation imaging but also investigation techniques, which in the past belonged more to the realm of materials science than to engineering (e.g., diffraction and
laser-induced breakdown spectroscopy). However, such ‘new’ tools can be and have also been applied to investigate large components: X-ray and neutron diffraction are currently used to determine the residual stress in safety-relevant components (nuclear industry and additive manufacturing) [1,2], and X-ray computed tomography is used to investigate the degradation of concrete cores [3,4]. The meaning of micro-NDT&E (µ-NDT&E) methods has, therefore, been extended from the use of NDT&E techniques on microscopic components to the use of microscopic techniques and to macroscopic components.

3. Summary of the Special Issue

This Special Issue shows that X-ray computed tomography is becoming a major tool for µ-NDT&E, being used for small and large components [3,5,6], and for sensitive materials [7]. Indeed, new methods are also being developed [6–8]. At the same time, optical methods are being perfected to tackle challenging problems at the micro and macro scales [9,10]. Moreover, magnetic methods are still very powerful for detecting defects in several materials and components [11–14], especially when talking about large components. Indeed, such methods are being further developed and extended to new materials such as concrete [15] and to applications such as residual stress determination [16].

From the materials point of view, it is clear that concrete plays an eminent role in the field of NDT&E. Its eternal youth and wide application fields render it always useful, so that new kinds of investigations are paralleled with new compositions and materials designs [17]. However, classic materials such as steels [13,18], novel metallic biomaterials [19], and additively manufactured metallic alloys and structures [5,10] are also at the top of the agenda.

4. Conclusions

From the discussion above, we conclude that, in general, NDT&E methods are of primary importance in the design, performance assessment, quality control, and structural health monitoring of materials and components (metallic or ceramic/cementitious). One could summarize the meaning of the contributions to this Special Issue in a nutshell by stating that, currently, there is no separation between micro-NDT&E and NDT&E, since the latter field already includes the first and the applications of NDT&E methods to miniaturized materials or to the microscopic scale (materials science and characterization) has already been happening for some time.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: All contributing authors and the editorial team of Materials are acknowledged for their continued support for this Special Issue.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Schröder, J.; Evans, A.; Mishurova, T.; Ulbricht, A.; Sprengel, M.; Serrano-Munoz, I.; Fritsch, T.; Kromm, A.; Kannengießer, T.; Bruno, G. Diffraction-Based Residual Stress Characterization in Laser Additive Manufacturing of Metals. Metals 2021, 11, 1830. [CrossRef]
2. Bruno, G. Relaxation of Residual Stress in as-welded and aged AISI 347 pipe by means of time-of-flight neutron diffraction. Z. Met. 2002, 93, 33–41.
3. Oesch, T.; Weise, F.; Bruno, G. Detection and Quantification of Cracking in Concrete Aggregate through Virtual Data Fusion of X-ray Computed Tomography Images. Materials 2020, 13, 3921. [CrossRef] [PubMed]
4. Powierza, B.; Stelzner, L.; Oesch, T.; Gollwitzer, C.; Weise, F.; Bruno, G. Water Migration in One-Side Heated Concrete: 4D In-Situ CT Monitoring of the Moisture-Clog-Effect. J. Nondestruct. Eval. 2019, 38, 15. [CrossRef]
5. Khrapov, D.; Kozadayeva, M.; Manabaev, K.; Panin, A.; Sjöström, W.; Koptyug, A.; Mishurova, T.; Evsevleev, S.; Meinel, D.; Bruno, G.; et al. Different Approaches for Manufacturing Ti-6Al-4V Alloy with Triply Periodic Minimal Surface Sheet-Based Structures by Electron Beam Melting. *Materials* **2021**, *14*, 4912. [CrossRef] [PubMed]

6. Evsevleev, S.; Mishurova, T.; Khrapov, D.; Pavleleva, A.; Meinel, D.; Surmenev, R.; Surmeneva, M.; Koptyug, A.; Bruno, G. X-ray Computed Tomography Procedures to Quantitatively Characterize the Morphological Features of Triply Periodic Minimal Surface Structures. *Materials* **2021**, *14*, 3002. [CrossRef] [PubMed]

7. Léonard, F.; Zhang, Z.; Krebs, H.; Bruno, G. Structural and Morphological Quantitative 3D Characterisation of Ammonium Nitrate Prills by X-Ray Computed Tomography. *Materials* **2020**, *13*, 1230. [CrossRef] [PubMed]

8. Linardatos, D.; Koukou, V.; Martini, N.; Konstantinidis, A.; Bakas, A.; Fountos, G.; Valais, I.; Michail, C. On the Response of a Micro Non-Destructive Testing X-ray Detector. *Materials* **2021**, *14*, 888. [CrossRef] [PubMed]

9. Özcan, B.; Schwermann, R.; Blankenbach, J. A Novel Camera-Based Measurement System for Roughness Determination of Concrete Surfaces. *Materials* **2021**, *14*, 158. [CrossRef] [PubMed]

10. Mahmood, M.A.; Chioibasu, D.; Mihai, S.; Iovea, M.; Mihaiescu, I.N.; Popescu, A.C. Non-Destructive X-ray Characterization of a Novel Joining Method Based on Laser-Melting Deposition for AISI 304 Stainless Steel. *Materials* **2021**, *14*, 7796. [CrossRef]

11. Chady, T.; Okarma, K.; Mikołajczyk, R.; Dziendzikowski, M.; Synaszko, P.; Dragan, K. Extended Damage Detection and Identification in Aircraft Structure Based on Multifrequency Eddy Current Method and Mutual Image Similarity Assessment. *Materials* **2021**, *14*, 4452. [CrossRef] [PubMed]

12. Chady, T.; Łukaszuk, R.D.; Gorący, K.; Żwir, M.J. Magnetic Recording Method (MRM) for Nondestructive Evaluation of Ferromagnetic Materials. *Materials* **2022**, *15*, 630. [CrossRef] [PubMed]

13. Chady, T.; Łukaszuk, R. Examining Ferromagnetic Materials Subjected to a Static Stress Load Using the Magnetic Method. *Materials* **2021**, *14*, 3455. [CrossRef] [PubMed]

14. Vértesy, G.; Gasparics, A.; Szenthe, I.; Bilicz, S. Magnetic Investigation of Cladded Nuclear Reactor Blocks. *Materials* **2022**, *15*, 1425. [CrossRef] [PubMed]

15. Frankowski, P.K.; Chady, T. Impact of Magnetization on the Evaluation of Reinforced Concrete Structures Using DC Magnetic Methods. *Materials* **2022**, *15*, 857. [CrossRef] [PubMed]

16. Mishurova, T.; Stegemann, R.; Liyamkin, V.; Cabeza, S.; Evsevleev, S.; Pelkner, M.; Bruno, G. Subsurface and Bulk Residual Stress Analysis of S235JR + C Steel TIG Weld by Diffraction and Magnetic Stray Field Measurements. *Exp. Mech.* **2022**, *62*, 1017–1025. [CrossRef]

17. Mishurova, T.; Rachmatulina, N.; Fontana, P.; Oesch, T.; Bruno, G.; Radi, E.; Sevostianov, I. Evaluation of the probability density of inhomogeneous fiber orientations by computed tomography and its application to the calculation of the effective properties of a fiber-reinforced composite. *Int. J. Eng. Sci.* **2018**, *122*, 14–29. [CrossRef]

18. Vértesy, G.; Gasparics, A.; Szenthe, I.; Rabung, M.; Kopp, M.; Griffin, J.M. Analysis of Magnetic Nondestructive Measurement Methods for Determination of the Degradation of Reactor Pressure Vessel Steel. *Materials* **2021**, *14*, 5256. [CrossRef] [PubMed]

19. Savin, A.; Craus, M.L.; Bruma, A.; Novy, F.; Malo, S.; Chlada, M.; Steigmann, R.; Vizureanu, P.; Harnois, C.; Turchenko, V.; et al. Microstructural Analysis and Mechanical Properties of TiMo20Zr7Ta15Six Alloys as Biomaterials. *Materials* **2020**, *13*, 4808. [CrossRef] [PubMed]