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Editorial

Special Issue: Novel Approaches for Nondestructive Testing and Evaluation

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1. Introduction

Nondestructive testing and evaluation (NDT&E) is one of the most important techniques for determining the quality and safety of materials, components, devices, and structures. NDT&E technologies include ultrasonic testing (UT), magnetic particle testing (MT), magnetic flux leakage testing (MFLT), eddy current testing (ECT), radiation testing (RT), penetrant testing (PT), and visual testing (VT), and these are widely used throughout modern industries. However, some NDT processes, such as cleaning specimens and removing paint, cause environmental pollution and must be inspected in limited environments (time, space, and sensor selection). Thus, NDT&E is classified as a typical 3D (dirty, dangerous, and difficult) job. In addition, the NDT operator judges the presence of damage by experience and subjective judgment, so in some cases, a flaw that exists may not be detected during the test. Therefore, to obtain clearer test results, a means for the operator to determine the flaw more easily should be provided. In addition, the test results should be organized systemically, in order to identify the cause of the abnormality in the test specimen and to identify the progress of the damage quantitatively.

Thus far, from a total of 18 submitted papers to this Special Issue, 13 have been published. The next sections provide a brief summary of each of the papers published.

2. Ultrahigh Resolution Pulsed Laser-Induced Photoacoustic Detection of Multi-Scale Damage in CFRP Composites by Wang et al.

This paper [1] presented a photoacoustic nondestructive evaluation (pNDE) system with an ultrahigh resolution for the detection of multi-scale damage in carbon-fiber-reinforced plastic (CFRP) composites. The pNDE system consisted of three main components: a picosecond pulsed laser-based ultrasonic actuator, an ultrasound receiver, and a data acquisition/computing subsystem. During the operation, high-frequency ultrasound was generated by a pulsed laser and recorded by an ultrasound receiver. By implementing a two-dimensional back-projection algorithm, pNDE images could be reconstructed from the recorded ultrasound signals, to represent the embedded damage. Both potential macroscopic and microscopic damages, such as surface notches and delamination in CFRP, could be identified by examining the reconstructed pNDE images. Three ultrasonic presentation modes, i.e., A scan, B scan, and C scan, were employed to analyze the recorded signals for the representation of the detected micro-scale damage in two-dimensional and three-dimensional images, with a high spatial resolution of up to 60 μm. Macro-scale delamination and transverse ply cracks were clearly visualized, identifying the edges of the damaged area. The results of the study demonstrate that the developed pNDE system provides a nondestructive and robust approach for multi-scale damage detection in composite materials.

3. Fast Terahertz Coded-Aperture Imaging Based on Convolutional Neural Network by Gan et al.

Terahertz coded-aperture imaging (TCAI) has many advantages such as forward-looking imaging, staring imaging, low cost, etc. However, it is difficult to resolve the target under a low signal-to-noise ratio (SNR), and the imaging process is time consuming. In this study [2], the authors provided an efficient solution to tackle this problem. A convolution neural network (CNN) was leveraged to develop an off-line, end-to-end imaging network whose structure is highly parallel and free of iterations. Additionally, it can simply have a general and powerful mapping function. Once the network is well trained and adopted for TCAI signal processing, the target of interest can be recovered immediately from the echo signal. Additionally, the method to generate training data was shown, and the authors found that the imaging network trained with simulation data was of good robustness against noise and model errors. The feasibility of the proposed approach was verified by simulation experiments, and the results show that it has a competitive performance with state-of-the-art algorithms.

4. Indirect Method for Measuring Absolute Acoustic Nonlinearity Parameter Using Surface Acoustic Waves with a Fully Non-Contact Laser-Ultrasonic Technique by Jun et al.

This paper [3] proposed an indirect method to measure absolute acoustic nonlinearity parameters using surface acoustic waves by employing a fully non-contact laser-ultrasonic technique. For this purpose, the relationship between the ratio of relative acoustic nonlinearity parameters measured using the proposed method in two different materials (a test material and a reference material) and the ratio of absolute acoustic nonlinearity parameters in these two materials was theoretically derived. Using this relationship, when the absolute nonlinearity parameter of the reference material was known, the absolute nonlinearity parameter of the test material could be obtained using the ratio of the measured relative parameters of the two materials. For experimental verification, aluminum and copper specimens were used as reference and test materials, respectively. The relative acoustic nonlinearity parameters of the two materials were measured from surface waves generated and received using lasers. Additionally, the absolute parameters of aluminum and copper were measured using a conventional direct measurement method, with the former being used as a reference value and the latter being used for comparison with the estimation result. The absolute parameter of copper estimated by the proposed method showed good agreement with the directly measured result.

5. Proposal of UWB-PPM with Additional Time Shift for Positioning Technique in Nondestructive Environments by Huyen et al.

The ultra-wideband (UWB) technology has many advantages in positioning and measuring systems; however, the powers of UWB signals rapidly reduce while traveling in propagation environments; hence, detecting UWB signals are difficult. Various modulation techniques are applied for UWB signals to increase the ability for detecting the reflected signal from transmission mediums, such as pulse amplitude modulation (PAM), pulse position modulation (PPM), etc. In this paper [4], the authors proposed an ultra-wideband pulse position modulation technique with an optimized additional time shift (UWB-PPM-ATS), to enhance the accuracy in locating buried objects in nondestructive environments. Moreover, the Levenberg–Marquardt–Fletcher algorithm (LMFA) was applied to determine the medium parameters and buried object location simultaneously. The influences of the proposed modulation technique on determining the system's parameters, such as propagation time, distance, and properties of the medium were analyzed. Calculation results indicate that the proposed UWB-PPM-ATS provided higher accuracy than conventional methods such as UWB-OOK and UWB-PPM, in both homogeneous and heterogeneous environments. Furthermore, the LMFA approach with the proposed UWB-PPM-ATS outperformed the LMFA with the traditional modulation method, especially for unknown propagation environments.

6. An Attention-Based Network for Textured Surface Anomaly Detection by Liu et al.

Textured surface anomaly detection is a significant task in industrial scenarios. In order to further improve the detection performance, the authors of this study proposed a novel two-stage approach with an attention mechanism [5]. Firstly, in the segmentation network, the feature extraction and anomaly attention modules were designed to capture detailed information as much as possible and focused on the anomalies, respectively. To strike dynamic balances between these two parts, an adaptive scheme in which learnable parameters are gradually optimized was introduced. Subsequently, the weights of the segmentation network were frozen, and the outputs were fed into the classification network, which was trained independently in this stage. Finally, the proposed approach was evaluated on the DAGM 2007 dataset, which consists of diverse textured surfaces with weakly labeled anomalies; the experiments revealed that this method can achieve 100% detection rates in terms of true-positive rate (TPR) and true-negative rate (TNR).

7. A Comparison of Power Quality Disturbance Detection and Classification Methods Using CNN, LSTM, and CNN-LSTM by Garcia et al.

The use of electronic loads has improved many aspects of everyday life, permitting more efficient, precise, and automated processes. As a drawback, the nonlinear behavior of these systems entails the injection of electrical disturbances on the power grid that can cause distortion of voltage and current. In order to adopt countermeasures, it is important to detect and classify these disturbances. To this end, several machine learning algorithms are currently being exploited. Among them, for the present work [6], the long short-term memory (LSTM), convolutional neural networks (CNNs), convolutional neural network–long short-term memory (CNN-LSTM), and the CNN-LSTM with adjusted hyperparameters were compared. As a preliminary stage of the research, the voltage and current time signals were simulated using MATLAB Simulink. From the simulation results, it is possible to acquire a current and voltage dataset with which the identification algorithms are trained, validated, and tested. These datasets include simulations of several disturbances such as Sag, Swell, Harmonics, Transient, Notch, and Interruption. Data augmentation techniques were used in order to increase the variability of the training and validation dataset, to obtain a generalized result. Afterward, the networks were fed with an experimental dataset of voltage and current field measurements containing the disturbances mentioned above. The networks were compared, resulting in a 79.14% correct classification rate with the LSTM network versus 84.58% for the CNN, 84.76% for the CNN-LSTM. and 83.66% for the CNN-LSTM with adjusted hyperparameters. All of these networks were tested using real measurements.

8. Leaky Lamb Wave Radiation from a Waveguide Plate with Finite Width by Park et al.

In this paper [7], leaky Lamb wave radiation from a waveguide plate with finite width was investigated to gain a basic understanding of the radiation characteristics of the plate-type waveguide sensor. Although the leaky Lamb wave behavior has already been theoretically revealed, most studies have only dealt with two-dimensional radiations of a single leaky Lamb wave mode in an infinitely wide plate, and the effect of the width modes (that are additionally formed by the lateral sides of the plate) on leaky Lamb wave radiation has not been fully addressed. This work aimed to explain the propagation behavior and characteristics of the Lamb waves induced by the existence of the width modes and to reveal their effects on leaky Lamb wave radiation for the performance improvement of the waveguide sensor. To investigate the effect of the width modes in a waveguide plate with finite width, propagation characteristics of the Lamb waves were analyzed by the semi-analytical finite element (SAFE) method. Then, the Lamb wave radiation was computationally modeled on the basis of the analyzed propagation characteristics and was also experimentally measured for comparison. From the modeled and measured results of the leaky radiation beam, it was found that the width modes could affect leaky Lamb wave radiation with the mode superposition, and radiation characteristics were significantly changed depending on the wave phase of the superposed modes on the radiation surface.

9. Evaluation of Cracks on the Welding of Austenitic Stainless Steel Using Experimental and Numerical Techniques by Berkache et al.

This paper [8] dealt with the investigation and characterization of weld circumferential thin cracks in austenitic stainless steel (AISI 304) pipe with eddy current nondestructive testing technique (EC-NDT). During the welding process, the heat source applied to the AISI 304 was not uniform, accompanied by a change in physical property. To take this change into consideration, the relative magnetic permeability was considered as a gradiently changed variable in the weld and heat-affected zone (HAZ), which was generated by the Monte Carlo method based on pseudo-random number generation (PRNG). Numerical simulations were performed by means of MATLAB software, using the 2D finite element method to solve the problem. To verify, results from the modeling works were conducted and contrasted with findings from experimental ones. Indeed, the results of the comparison agreed well. In addition, they showed that the consideration of this change in magnetic property allows distinguishing the thin cracks in the weld area.

10. Measurement of Thinned Water-Cooled Wall in a Circulating Fluidized Bed Boiler Using Ultrasonic and Magnetic Methods by Lee et al.

In this paper [9], a nondestructive inspection system was proposed to detect and quantitatively evaluate the size of the near- and far-side damages on the tube, membrane, and weld of the water-cooled wall in a fluidized bed boiler. The shape and size of the surface damages were evaluated from the magnetic flux density distribution measured by the magnetic sensor array on one side from the center of the magnetizer. The magnetic sensors were arrayed on a curved shape probe according to the tube's cross-sectional shape, membrane, and weld. On the other hand, the couplant was doped to the water-cooled wall, and a thin film was formed thereon by polyethylene terephthalate. Then, the measured signal of the flexible ultrasonic probe was used to detect and evaluate the depth of the damages. The combination of magnetic and ultrasonic methods helped to detect and evaluate both near and far-side damages. Near-side damages with a minimum depth of 0.3 mm were detected, and the depth from the surface of the far-side damage was evaluated, with a standard deviation of 0.089 mm.

11. Micromagnetic Characterization of Operation-Induced Damage in Charpy Specimens of RPV Steels by Rabung et al.

The embrittlement of two types of nuclear pressure vessel steel, 15Kh2NMFA and A508 Cl.2, was studied using two different methods of magnetic nondestructive testing: micromagnetic multiparameter microstructure and stress analysis (3MA-X8) and magnetic adaptive testing (MAT) [10]. The microstructure and mechanical properties of reactor pressure vessel (RPV) materials are modified due to neutron irradiation; this material degradation can be characterized using magnetic methods. For the first time, the progressive change in material properties due to neutron irradiation was investigated on the same specimens, before and after neutron irradiation. A correlation was found between magnetic characteristics and neutron-irradiation-induced damage, regardless of the type of material or the applied measurement technique. The results of the individual micromagnetic measurements proved their suitability for characterizing the degradation of RPV steel caused by simulated operating conditions. A calibration/training procedure was applied on the merged outcome of both testing methods, producing excellent results in predicting transition temperature, yield strength, and mechanical hardness for both materials.

12. Three-Dimensional Imaging of Metallic Grain by Stacking the Microscopic Images by Lee et al.

Three-dimensional observation of metal grains (MGs) has a wide potential application serving the interdisciplinary community. It can be used for industrial applications and basic research to overcome the limitations of nondestructive testing methods, such as ultrasonic testing, magnetic particle testing, and eddy current testing. This study [11] proposed a method and its implementation algorithm to observe metal grains (MGs) in three dimensions, in a general laboratory environment equipped with a polishing machine and a metal microscope. An image was taken by a metal microscope while polishing the mounted object to be measured. Then, the metal grains (MGs) were reconstructed into three dimensions through local positioning, binarization, boundary extraction, MG selection, and stacking. The goal was to reconstruct the 3D MG in a virtual form that reflects the real shape of the MG. The usefulness of the proposed method was verified using the carbon steel (SA106) specimen.

13. THz-TDS Techniques of Thickness Measurements in Thin Shim Stock Films and Composite Materials by Im et al.

Terahertz wave (T-ray) scanning applications are one of the most promising tools for nondestructive evaluation. T-ray scanning applications use a T-ray technique to measure the thickness of both thin Shim stock films and glass-fiber-reinforced plastic (GFRP) composites, of which the samples were selected because the T-ray method could penetrate the non-conducting samples. Notably, this method is nondestructive, making it useful for analyzing the characteristics of the materials. Thus, the T-ray thickness measurement can be found for both non-conducting Shim stock films and GFRP composites. In this work [12], a characterization procedure was conducted to analyze electromagnetic properties, such as the refractive index. The obtained estimates of the properties are in good agreement with the known data for polymethyl methacrylate (PMMA) for acquiring the refractive index. The T-ray technique was developed to measure the thickness of the thin Shim stock films and the GFRP composites. The study tests obtained good results on the thickness of the standard film samples, with the different thicknesses ranging from around 120 μm to 500 μm. In this study, the T-ray method was based on the reflection mode measurement, and the time of flight (TOF) and resonance frequencies were utilized to acquire the thickness measurements of the films and GFRP composites. The results showed that the thickness of the frequency samples matched those obtained directly by time-of-flight (TOF) methods.

14. Time-Resolved Neutron Bragg-Edge Imaging: A Case Study by Observing Martensitic Phase Formation in Low-Temperature Transformation (LTT) Steel during GTAW by Griesche et al.

Griesche et al. [13] used neutron imaging to visualize the sample remelting during the welding process. Polychromatic and wavelength-selective neutron transmission radiography were applied during bead-on-plate welding on 5 mm thick sheets on the face side of martensitic low-temperature transformation (LTT) steel plates using gas tungsten arc welding (GTAW). The in situ visualization of austenitization upon welding and subsequent α'-martensite formation during cooling could be achieved with a temporal resolution of 2 s for monochromatic imaging using a single neutron wavelength and of 0.5 s for polychromatic imaging using the full spectrum of the beam (whitebeam). The spatial resolution achieved in the experiments was approximately 200 μm. The transmitted monochromatic neutron beam intensity at a wavelength of $\lambda = 0.395$ nm was significantly reduced during cooling below the martensitic start temperature Ms since the emerging martensitic phase had a ~10% higher attenuation coefficient than the austenitic phase. Neutron imaging was significantly influenced by coherent neutron scattering caused by the thermal motion of the crystal lattice (Debye–Waller factor), resulting in a reduction in the neutron transmission by approx. 15% for monochromatic and approx. 4% for polychromatic imaging

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References

1. Wang, S.; Echeverry, J.; Trevisi, L.; Prather, K.; Xiang, L.; Liu, Y. Ultrahigh Resolution Pulsed Laser-Induced Photoacoustic Detection of Multi-Scale Damage in CFRP Composites. *Appl. Sci.* **2020**, *10*, 2106. [CrossRef]
2. Gan, F.; Luo, C.; Liu, X.; Wang, H.; Peng, L. Fast Terahertz Coded-Aperture Imaging Based on Convolutional Neural Network. *Appl. Sci.* **2020**, *10*, 2661. [CrossRef]
3. Jun, J.; Jhang, K.-Y. Indirect Method for Measuring Absolute Acoustic Nonlinearity Parameter Using Surface Acoustic Waves with a Fully Non-Contact Laser-Ultrasonic Technique. *Appl. Sci.* **2020**, *10*, 5911. [CrossRef]
4. Huyen, N.T.; Le Cuong, N.; Thanh Hiep, P. Proposal of UWB-PPM with Additional Time Shift for Positioning Technique in Nondestructive Environments. *Appl. Sci.* **2020**, *10*, 6011. [CrossRef]
5. Liu, G.; Yang, N.; Guo, L. An Attention-Based Network for Textured Surface Anomaly Detection. *Appl. Sci.* **2020**, *10*, 6215. [CrossRef]
6. Garcia, C.I.; Grasso, F.; Luchetta, A.; Piccirilli, M.C.; Paolucci, L.; Talluri, G. A Comparison of Power Quality Disturbance Detection and Classification Methods Using CNN, LSTM and CNN-LSTM. *Appl. Sci.* **2020**, *10*, 6755. [CrossRef]
7. Park, S.-J.; Kim, H.-W.; Joo, Y.-S. Leaky Lamb Wave Radiation from a Waveguide Plate with Finite Width. *Appl. Sci.* **2020**, *10*, 8104. [CrossRef]
8. Berkache, A.; Lee, J.; Choe, E. Evaluation of Cracks on the Welding of Austenitic Stainless Steel Using Experimental and Numerical Techniques. *Appl. Sci.* **2021**, *11*, 2182. [CrossRef]
9. Lee, J.; Choe, E.; Pham, C.-T.; Le, M. Measurement of Thinned Water-Cooled Wall in a Circulating Fluidized Bed Boiler Using Ultrasonic and Magnetic Methods. *Appl. Sci.* **2021**, *11*, 2498. [CrossRef]
10. Rabung, M.; Kopp, M.; Gasparics, A.; Vértesy, G.; Szenthe, I.; Uytdenhouwen, I.; Szielasko, K. Micromagnetic Characterization of Operation-Induced Damage in Charpy Specimens of RPV Steels. *Appl. Sci.* **2021**, *11*, 2917. [CrossRef]
11. Lee, J.; Berkache, A.; Wang, D.; Hwang, Y.-H. Three-Dimensional Imaging of Metallic Grain by Stacking the Microscopic Images. *Appl. Sci.* **2021**, *11*, 7787. [CrossRef]
12. Im, K.-H.; Kim, S.-K.; Cho, Y.-T.; Woo, Y.-D.; Chiou, C.-P. THz-TDS Techniques of Thickness Measurements in Thin Shim Stock Films and Composite Materials. *Appl. Sci.* **2021**, *11*, 8889. [CrossRef]
13. Griesche, A.; Pfretzschner, B.; Taparli, U.A.; Kardjilov, N. Time-Resolved Neutron Bragg-Edge Imaging: A Case Study by Observing Martensitic Phase Formation in Low Temperature Transformation (LTT) Steel during GTAW. *Appl. Sci.* **2021**, *11*, 10886. [CrossRef]