

ETNDT5

September 19-21, 2011
Ioannina, Greece

5th International Conference on Emerging Technologies in Non-Destructive Testing

+ *Technology Transfer and Business Partnership Event*

Technical Program & Book of Abstracts



Organized by:



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IOANNINA



Envirocoustics
Acoustic Measurement Technology



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The organising committee welcomes you to the **5th Conference on Emerging Technologies in Non Destructive Testing**, in Ioannina, Greece on September 19th-21st, 2011.

The aim of the conference series is to bring together colleagues from academia and industry in all novel NDT related research areas and applications. The 5th Conference is focusing on NDT and Safety of Civil Engineering Structures. Following the successful tradition of previously organised events, the Technology and Business Partnership Event, co-organised by the European Enterprise Network members Praxi/Help-Forward Network and the Chamber of Ioannina will provide opportunities for Business and Technology cooperations. Finally, the Conference Exhibition will host state of the art NDT related industrial products.

A.S. Paipetis, Associate Professor
Conference Chairman

T.E. Matikas, Professor
Conference Co-Chairman

Department of Materials Science and Engineering
University of Ioannina



Conference topics

- New NDT methodologies and techniques
- NDT and Safety of Civil Engineering Structures
- NDT for risk based inspection and fitness for service
- NDT and damage tolerance design
- On-line inspection
- Structural health monitoring
- Remote NDT
- Smart materials and Structures
- Quantitative NDT
- NDT related fracture mechanics problems
- Inverse problems and mathematical modelling in NDT/NDE
- Advanced Signal Processing for NDT
- Numerical simulation in NDT/NDE
- Advances in NDT instrumentation and transducers technology
- NDI of buildings in earthquake-stricken areas
- NDT applications in naval and aircraft structures
- NDT for electronics and photonic materials and devices
- NDT in Biomedicine and bio-engineering
- NDT in the nanoscale and beyond
- Reliability, accreditation, certification and standardisation

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Sunday 18/9/2011 (17:00-22:00 Registration)

20:00-22:00 Welcome Reception at Hotel du Lac

Day 1: Monday 19/9/2011 (08:00-08:30 Registration)

8:30-9:10 Opening ceremony

9:10-9:50 Plenary Session 1: G.Y. Baaklini Nondestructive Evaluation, Structural Health Monitoring & Optical Diagnostics at NASA Glenn

Session 1A: NDT in diagnostics & protection of Cultural Heritage I (chair: A. I. Moropoulou, V. Kostopoulos, N. Avdelidis)

9:55-10:25	A. I. Moropoulou	Keynote: NDT as a tool for the protection of Cultural Heritage: Detection of Wear & Degradation of Materials, & evaluation of compatible materials & processes
10:25-10:45	S. Cancellieri, M. Poggi	Contribution of NDT to the sustainable preservation of the Church of Santa Maria in Gradi, Viterbo – Italy
10:45-11:05	P. Negri	A New NDT Approach for Fragile Archaeological Finds
11:05-11:25	A. Doulamis & T. Varvarigou	Image Analysis for Artistic Style Identification: A Powerful Tool for Preserving Cultural Heritage

11:25-11:40 Coffee break

Session 2A: NDT in diagnostics & protection of Cultural Heritage II (chair: A. I. Moropoulou, V. Kostopoulos, N. Avdelidis)

11:40-12:00	L. Binda, L. Cantini, A. Saisi	Innovative investigation strategies for the diagnosis of historic structures
12:00-12:20	P. Kapsalas, P. Maravelaki-Kalaitzaki, M. Zervakis, E.T. Delegou, A. Moropoulou	A Non-Destructive Corrosion Evaluation Framework based on Morphological Detection & Clustering of the Decay Patterns
12:20-12:40	E. Cheilakou, N. Liarokapi, M. Kouli	NDT characterization of ancient glass objects from the Aegean with an approach of the manufacturing technique
12:40-13:00	E.T. Delegou, M. Krokida, N.P. Avdelidis, A. Moropoulou	The Use of Pulsed Infrared Thermography as a NDE tool for the Assessment of Cleaning Interventions on Marble Architectural Surfaces

13:00-14:00 Lunch

Session 3A: NDT in diagnostics & protection of Cultural Heritage III (chair: A. I. Moropoulou, V. Kostopoulos, N. Avdelidis)

14:10-14:30	C. Gentile, A. Saisi	Radar-based vibration measurement on historic masonry towers
14:30-14:50	A. I. Moropoulou, K. C. Labropoulos, N. S. Katsiotis	Application of ground penetrating radar for the assessment of the decay state of Hagia Sophia's mosaics
14:50-15:10	C. Gentile, A. Saisi	Dynamic testing of historic iron bridge at different levels of excitation
15:10-15:30	E.Z. Kordatos, D.A. Exarchos, C. Stavrakos, T.E. Matikas, A. Moropoulou	Application of IR Thermography to Damage Characterization of Structures & the Diagnosis of Historic Monuments
15:30-15:50	G. Mastrotheodoros, K. Beltsios, N. Zacharias	Iron based & other ancient pigments for pottery decoration
15:50-16:10	A. I. Moropoulou (Chair)	Discussion

16:10-16:25 Coffee break

Session 4A: Ultrasonics I (chair R. Kažys, B. R. Mabuza)

16:25-16:45	S. Pavlopoulou, W.J. Staszewski, C. Soutis & G. Manson	Structural health monitoring of repaired metallic structures by analyzing the instantaneous characteristics of Lamb waves
16:45-17:05	N. Netshidavhini, B.R. Mabuza	Detection & characterization of surface-breaking defects in metals using ultrasonic surface waves
17:05-17:25	R. Raišutis, E. Žukauskas, L. Mažeika	Application of ultrasonic guided waves for non-destructive testing of constructional materials of aircraft structures
17:25-17:45	L. Mažeika, R. Raišutis, R. Kažys, V. Samaitis, A. Jankauskas	Monitoring of composite components using ultrasonic guided waves
17:45-18:05	A. Babakhani, F. A. Mianji, A. Parish, M. Mozaffarian, A. Dadkhah	Work of Iranian ultrasonic testing system for fault diagnostic of CNG cylinders at production lines
18:05-18:25	A. Savin, P. Botez, M.L. Craus, R. Grimberg	Resonant Ultrasound Spectroscopy as a tool for noninvasive examination of Zirconia head of hip prosthesis

Day 1: Monday 19/9/2011 (continued)

Session 1B: SHM & Sensors (Chair: S. Ogin, J. Degriek)

9:55-10:25	S.L.Ogin , A.D.Crocombe, A.R.Sanders Y. Guo, T. F. Capell, S. C. Tjin, B. Lin	Keynote Lecture: The use of chirped fibre Bragg grating sensors to monitor delaminations in composite materials & structures
10:25-10:45	G. Luyckx	Cure monitoring of cross-ply composite laminates with residual strain induced birefringent fibre Bragg gratings
10:45-11:05	R. L. Rito, S. L. Ogin, A. D. Crocombe, Yalin Guo, T. F. Capell, A. R. Sanderson, S. C. Tjin, B. Lin	On the use of a CFBG sensor to monitor scarf repairs of composite panels
11:05-11:25	S. Daggumati, E. Voet, I. De Baere, W. Van Paepegem, , S. Lomov, I. Verpoest	In-situ local strain measurement in textile composites with embedded optical fibre sensors
11:25-11:40	Coffee break	

Session 2B: Acoustic Emission I (Chair A. Anastasopoulos, M. Forde)

11:40-12:00	N. Tsoelas, D. Kourousis, I. Ladis, D. J. Lekou, A. Anastasopoulos, F. Mouzakis	Health Monitoring of Operating Wind Turbine Blades with Acoustic Emission
12:00-12:20	D.Papasalouros, D.Kourousis, C. Ennaceur, A.Anastasopoulos, P.T. Cole	Real-Time Damage Location & Assessment in Composite Structures with Acoustic Emission
12:20-12:40	K. N. Bollas, D. G. Papasalouros, D. A. Kourousis, A. Anastasopoulos	Acoustic Emission Monitoring of Wheel Sets on Moving Trains
12:40-13:00	O.V Bashkov, S.V. Panin, R.V. Evdokimova, A.A. Popkova	Method of the complex analysis of thickness & properties of hardening coating with use acoustic emission testing & digital images correlation
13:00-14:00	Lunch	

Session 3B: Structural Health Monitoring (SHM) of aerospace components (chair: H. Pfeiffer, E. Ringgaard)

14:00-14:30	H. Pfeiffer , M. Patitsa, I. Pitropakis, M. Wevers	Keynote Lecture: Structural Health Monitoring in an operational airliner: results on the implementation of percolation sensors achieved within the European Project: "Aircraft Integrated Structural Health Assessment II"
14:30-14:50	W. Hillger, A.Szewieczek, J.Aldave, P.Venegas Bossom, L.V. Gonzalez	Advanced NDT Techniques for Damage Detection in a Honeycomb Composite Helicopter Tailboom
14:50-15:10	I. Pitropakis, H. Pfeiffer, M. Wevers	Crack detection in aluminium plates for aerospace applications by electromagnetic impedance spectroscopy using flat coil sensors
15:10-15:30	E.Ringgaard, T.Zawada, T. Porchez, N. Bencheikh, F. Claeysen	Multi-element piezo-composite transducers for structural health monitoring using Lamb waves
15:30-15:50	I. Pitropakis, H. Pfeiffer, M.Wevers	Impact damage detection in composite materials of aircrafts using a polarimetric fibre sensor
15:50-16:10	S. Creten, C. Glorieux, T. Porchez, E. Ringgaard	Detection of closed defects in vibrating structures with piezo-excited & detected acoustic waves
16:10-16:25	Coffee break	

Session 4B Signal & Data Processing I (chair: J. M. A. Rebello, R. Grimberg)

16:25-16:45	N.P. Avdelidis, C. Ibarra-Castaneda, X.P.V.Maldague	Thermographic signal reconstruction on pulsed thermography results for detection & characterization of defects on composites
16:45-17:05	W. Hufenbach, N. Modler, A. Winkler, R. Kupfer	Characterisation of the fibre volume content at the edge area of warm-formed holes in textile-reinforced thermoplastic components
17:05-17:25	R. Grimberg, M.L.Craus, A. Savin, R. Steigmann, M.C. Ruch	Noninvasive method for establish the diffused hydrogen content in Zirconium Alloy used in PHWR
17:25-17:45	J.M.A. Rebello, R.M. Almeida	Improving TOFD sizing of near surface defects by wavelet transform
17:45-18:05	D. Roulias, T.H. Loutas, V. Kostopoulos	The application of information processing techniques towards an effective on line prognostic scheme for rotating machinery
18:05-18:25	L. Zanzi	Modeling GPR data to understand the problems in rebar size measurements

Day 2: Tuesday 20/09/2011

8:30-9:10	Plenary session 2: M. Ohtsu, T. Sonoda& M. Yamada	Visualized Impact-Echo Technique for Defects in Concrete by SIBIE Procedure
Session 5A: Electrical & Optical Methods for NDE (chair: V. Kostopoulos, G. Dassios)		
9:15-9:45	V. Kostopoulos	Keynote Lecture: Dynamic fibre Bragg grating based health monitoring system for composite aerospace structures
9:45-10:05	G. Dassios	Electric & Magnetic Brain activity: Distinct or Common information
10:05-10:25	A. Baltopoulos, A. Vavouliotis, A. Ampatzoglou, V. Kostopoulos	Non Destructive evaluation of artificially induced damage in composite structures using Electrical Resistance/Potential Mapping
10:25-10:45	S.B. Lee J.W. Yi, S.K. Lee, J. H. Byun, E. T. Thostenson, T. W. Chu	Damage sensing of carbon nanotubes embedded glass fiber composites based on electrical resistance change
10:45-11:05	J.W. Yi, H.S. Choe, S.B. Lee, J.B. Kim, S.K. Lee, O.O. Park	Electromagnetic Wave Absorbing Properties of Composites with Hollow Magnetic fibers
11:05-11:20	Coffee break	
Session 6A: On-Site Measurement & Monitoring by NDT in Infrastructures I (chair: M. Ohtsu, D.G. Aggelis)		
11:20-11:50	T. Shiotani, Y. Oshima, S. Momoki	Keynote Lecture: Damage Identification of PC Cable Breakage by means of Acoustic Emission
11:50-12:10	D. G. Aggelis, D.V. Soulioti, N.M. Barkoula, A.S. Paipetis, T.E. Matikas	Influence of the fiber chemical coating on the fracture behavior of steel fiber concrete measured by acoustic emission
12:10-12:30	J. S. Clausen, N. Zoidis, A. Knudsen	Onsite measurements of concrete structures using Impact-echo & Impulse Response
12:30-12:50	G. Carpinteri, A. Lacidogna, Manuello, & G. Niccolini	The Asinelli Tower in Bologna (Italy): Acoustic Emission Monitoring under Environmental Actions
12:50-13:10	N. Zoidis, E. Tatsis, C. Vlachopoulos, T Matikas, A. Gotzamanis	Visual inspection & evaluation using NDT testing methods of industrial building after fire.
13:10-14:10	Lunch	
Session 7A: On-Site Measurement & Monitoring by NDT in Infrastructures II (chair: M. Ohtsu, T. Shiotani)		
14:10-14:30	M. Ohtsu, K. Akasaka & T. Matsuo	AE Monitoring of Shrinkage Process in Concrete
14:30-14:50	M. Forde	Estimating the ultimate load carrying capacity of concrete beams & steel bridge cables using AE
14:50-15:10	Y. Kawasaki, M. Kitaura, T. Kobarai, Y. Tomoda & M. Ohtsu	Evaluation of Acoustic Emission Behavior during Corrosion Process in Reinforced Concrete with EPMA
15:10-15:30	Y. Kobayashi	Mesh-Independent Ray-trace Algorithm for Concrete Structures
15:30-15:50	N. Zoidis, E. Tatsis, C.Vlachopoulos, J. S. Clausen, T. E. Matikas, D. G. Aggelis, A. Gkatzamanis	Visual Inspection & Evaluation using NDT testing methods of extensively cracked concrete floor.
15:50-16:10	M. Yamada, T. Sonoda & M. Ohtsu	Quantitative Evaluation of Impact Force on Impact-Echo Method
16:10-16:30	Coffee Break	
Session 8A: Imaging & Digital Methods (chair: G. Busse, D. Van Hemelrijck)		
16:30-16:50	P. Menner, G. Busse	Dynamic shearography for inspection of aerospace structures
16:50-17:10	J. Blom, J. Van Ackeren, B. Belkassen, J.Wastiels	Determination of linear thermal expansion coefficient by using digital image correlation
17:10-17:30	A. Stylianou, C. Politopoulos & D. Yova	Atomic Force Microscopy Quantitative & Qualitative Nanoscale Characterization of Collagen Thin Films
17:30-17:50	E.G.Profitis, E. Chatzitheodoridis, D. Xirouchakis	Digital methods for flakiness & shape index definition
17:50-18:10	I. De Baere, W. Van Paepegem, P. Lava, D. Debruyne, C. Cofaru, W. Philips, J. Degrieck	Experimentally induced errors in Digital Image Correlation measurement of small strains with large gradients

Day 2: Tuesday 20/09/2011 (continued)

Session 5B: Nonlinear NDT I (chair: V. Tournat, K. Van Den Abeele)

9:15-9:45	N.Chigarev, S.Mezil, J.Zakrzewski, V.Tournat, V. Gusev	Keynote Lecture: Remote nonlinear photoacoustic imaging of cracks
9:45-10:05	G. Petersen	Filters, transducers & receivers for nonlinear measurements
10:05-10:25	S. Delrue, K. Van Den Abeele	Finite element simulations of the nonlinear dynamic response of closed delaminations & surface breaking cracks in composite materials
10:25-10:45	B. Van Damme, K. Van Den Abeele	Defect localisation using the nonlinear impact modulation technique
10:45-11:05	N.Chigarev, P.Zinin, A.Bulou, A.Zerr, D.Mounier, L.C.Ming, G.Amulele, V.Gusev	Characterisation of metallic film in a high-pressure diamond anvil cell by a laser ultrasonic technique
11:05-11:20	Coffee break	

Session 6B: Nonlinear NDT II (chair: V. Tournat, K. Van Den Abeele)

11:30-11:50	E. Janssen, K. Van Den Abeele	Imaging multiple defects in solids by means of selective source reduction & time reversed acoustics
11:50-12:10	I. Solodov, G.Busse	Multi-frequency defect-selective nonlinear imaging & NDT
12:10-12:30	E. Janssen, K. Van Den Abeele	Exploiting time reversal principles for the accurate determination of material velocities
12:30-12:50	N.Chigarev, S.Mezil, V.Tournat, V.Gusev	Nonlinear frequency-mixing photoacoustic imaging of a contact
13:10-14:10	Lunch	

Session 7B: Electrical Methods for NDE (chair: P. Pissis, G. Psarras)

14:10-14:30	A. C. Patsidis, G. C. Psarras	Disorder to Order Transition & Functionality in Polymer Matrix – Barium Titanate Nanocomposites
14:30-14:50	C. Pandis, G. Georgioussis, P. Peoglos, A. Kyritsis, P. Pissis, P. Georgiopoulos, E.Kontou	Electrical resistance measurement for in situ health monitoring of carbon nanotube/polymer composites
14:50-15:10	C. Pandis, G. Georgioussis, P. Peoglos, A. Kyritsis, P. Pissis, P. Georgiopoulos, E.Kontou	Strain & damage sensing in carbon fiber polymer-matrix composite by electrical resistance measurement
15:10-15:30	A. Baltopoulos, N. Polydoridis, V. Kostopoulos	Electrical tomography as a tool for the damage assessment of composite structures
15:30-15:50	A. Ampatzoglou, A. Vavouliotis T. Loutas, V. Kostopoulos	On line monitoring of damage during fatigue loading of composite patch repair of composite structures.
15:50-16:10	S. A. Grammatikos, A. S. Paipetis	Electrical resistance response to strain and damage in multi phase composites
16:10-16:30	Coffee break	

Session 8B: Inspection Methods (chair: N.J. Siakavellas, T. Theodoulidis)

16:30-16:50	T. Theodoulidis, N. Poulakis, J.R. Bowler	Eddy current crack inspections at plate edges. Theory/experiment
16:50-17:10	N.J. Siakavellas, N. Tsopeles	Detection of radial cracks at fastener holes by either eddy current or line heating stimulated thermography
17:10-17:30	J. Skramlik, M. Novotny	Apparatus for measuring of liquid conductivity
17:50-18:10	G. S. Velev, A. G. Markovski, B. G. Velev	Automated System for Non-destructive Testing of Complex Structure & Mechanical Properties of Metallic Materials
17:30-17:50	S.S. Kalligeros	The Necessity of Lift Inspections in Greece

RILEM Technical Committee MCM

16:30	M. Ohtsu (chairman)	On-site measurement of concrete and masonry structures by visualized NDT
20:30	Official Conference Dinner at Frontzu Politia	

Day 3 Wednesday 21/09/2011

8:30-9:10	Plenary session: N. Meyendorf	Structural Health Monitoring for Aircraft, Ground Transportation Vehicles, Wind Turbines & Pipes – Prognosis
Session 9A: Ultrasonics II (chair: S. Vanlanduit, T. H. Loutas)		
9:15-9:35	P. Ruello, A. Lomonosov, C.Mechri, A.Ayouch, M. R. Baklanov, V.Gusev	Depth-profiling of the elastic & optical properties of submicrometer thick optically transparent films by picosecond ultrasonics inteferometry
9:35-9:55	A. Paipetis, D. G. Aggelis, N. -M. Barkoula, N. Melanitis	Damage Monitoring of composite laminates using Ultrasonics
9:55-10:15	R. Longo, S. Vanlanduit, A. Nila, P.Guillaume	Ultrasonic characterization of materials using Laser Doppler Vibrometer measurements: a multi-input approach
10:15-10:35	F. Bettayeb	Ultrasound NDT signal analysis & material microstructure information finding
10:35-10:55	M. Kersemans, W. Van Paepegem, F.Zastavnik, J. Gu, H.Sol, J.Degrieck	Experimental & numerical polar scans of several anisotropic materials using pulsed & harmonic ultrasonic beams
10:55-11:20	Coffee break	
Session 10A: Ultrasonics III (chair: B. R. Mabuza, Y. Kobayashi)		
11:20-11:40	Y. Gharaibeh, N. Lee	Ultrasonic Guided Waves Propagation in Complex Structures
11:40-12:00	B. R. Mabuza; N. Netshidavhini	Periodic nondestructive inspection for flaws in steel plates & weldments using ultrasonic testing method in combination with fracture mechanics
12:00-12:20	G. Asfis, P. Stavrou, M. Deere, P. Chatzakos, D. Fuloria	Defect detection & sizing for steel plates : an approach using long range ultrasonic tomography
12:20-12:40	M.S. Kovacevic, A. Mirceta, D. Marcic	NDT & safety of crude oil storage tanks
13:00-14:00	Lunch	
14:00-14:30	Special session: A. Dimitriadis	Funding opportunities for NDT Technologies & future prospects
Session 11A: Ultrasonics IV (Chair: S. Vanlanduit, T. H. Loutas)		
14:30-14:50	L. Mažeika, L. Draudvilienė, R. Raišutis, E. Žukauskas	The technique for estimation of the dispersion of phase velocity of ultrasonic guided waves
14:50-15:10	S. Vanlanduit, R. Longo, A. Nila, P. Guillaume	Visualization of ultrasound waves in non-destructive material characterization
15:10-15:30	C. Mechri , P. Ruello, V. Gusev, R. Yasinov, S. Berger.	Non-destructive testing of elastic properties of nanostructured anodized alumina film by picosecond acoustics methods
15:30-15:50	P. Fey, J. Frick, D. Döring, F. Grüner, I. Solodov, G. Busse	Preliminary results on non-contact characterisation of weathered mineral materials by surface acoustic waves
15:50-16:10	I. Solodov, M. Rheinfurth, G.Busse	New opportunities for ultrasonic characterization of stiffness anisotropy in composite materials
16:10-16:30	Closing Ceremony	

Day 3 Wednesday 21/09/2011 (continued)

Session 9B: Signal & Data Processing II (chair: O. Bashkov, K. Beltsios)

9:15-9:35	C. Spiessberger, A. Gleiter, G. Busse	Data fusion for Lockin-thermography
9:35-9:55	A. G. Monsalve, H. Rohling	Signal Feature Extraction Approach for Automatic Defect Detection using Active Thermography
9:55-10:15	O.V Bashkov, V.A. Kim, A.A. Popkova, R.V. Evdokimova	Method of digital processing of images metallographic microstructures in MATLAB environment
10:15-10:35	S.S. Hakim, H.A.Razak	Damage Identification in Beam Structures using Modal Parameters & Artificial Neural Networks

10:55-11:20 Coffee break

Session 10B Acoustic Emission II (chair: A. Anastassopoulos, M. Shiwa)

11:20-11:40	T. Kek, J. Grum	AE monitoring at laser cutting
11:40-12:00	M. Shiwa, H. Masuda, H. Yamawaki, K. Ito, M. Enoki	In-situ Observation & Acoustic Emission Analysis for Corrosion Pitting of MgCl ₂ Droplet in SUS304 Stainless Steel
12:00-12:20	C. Ioannou, A. Iliadou, D.G. Aggelis, N.M. Barkoula, T.E. Matikas	Fracture properties of nanosilica-based cement mortars monitored by acoustic emission
12:20-12:40	T.I. Bashkova, O.V. Bashkov, R.V.Evdokimova, A.A. Popkova	Method of Acoustic Emission testing at crystallization of Sn-Pb Alloys
12:40-13:00	P.P. Nomikos, K.M. Sakkas, G. Papandonopoulos, A.I. Sofianos,	Acoustic emission of marble measured in the laboratory

13:00-14:00 Lunch

Session 11B: In service/strain/damage monitoring (chair: N.-M Barkoula, K. G. Dassios)

14:30-14:50	H. Monajemi, H. Abdul Razak, Z. Ismail	Damage detection of frame structures based on dynamically measured flexibility matrix
14:50-15:10	I. Garcia de Carellan, P. Catton, C. Selcuk, T.-Hean Gan	Methods for detection & cleaning of fouling in pipelines
15:10-15:30	A.Gkotzamanis, N. Zoidis, T. E. Matikas, E. Tatsis, C. Vlachopoulos	Concrete compressive strength estimation in situ using direct & indirect testing methods according to EN 13791
15:30-15:50	M. Mohammadhassani	An Experimental study on the strain contribution of horizontal & vertical web reinforced bar of High Strength Concrete Deep Beams
15:50-16:10	O. V. Bashkov, E. E. Parfenov, T. I. Bashkova, Y.V. Van-Di, A.A. Popkova, R.V. Evdokimova	A Soft & Hardware Complex for Recording & Processing of Acoustic Emission Signals & for Location & Identification of Their Sources

PROGRAM OVERVIEW

Sunday 18/9/2011 (17:00-19:00 Registration)		
Welcome Reception at Hotel Du Lac (19:00-21:30)		
Day 1: Monday 19/9/2011 (08:00-08:30 Registration)		
Opening ceremony (8:30-9:10)		
Plenary session 1: Nondestructive Evaluation, SHM & Optical Diagnostics at NASA Glenn (9:10-9:50)		
Session 1A (09:55-11:25) NDT in diagnostics & protection of Cultural Heritage I	Session 1B (09:55-11:25): SHM & Sensors	
Coffee break (11:25-11:40)		
Session 2A (11.40-13:00): NDT in diagnostics & protection of Cultural Heritage II	Session 2B (11:40 -13:00): Acoustic Emission I	
Lunch (13:00-14:00)		
Session 3A (14.10-16.10) NDT in diagnostics & protection of Cultural Heritage III	Session 3B (14.00-16.10): SHM of aerospace components	
Coffee break (16:10-16:25)		
Session 4A (16:25-18.25) Ultrasonics I	Session 4B (16:25-18.25): Signal & Data Processing I	
Day 2: Tuesday 20/9/2011		
Plenary session 2: Visualized Impact-Echo Technique for Defects in Concrete by SIBIE Procedure (8:30-9:10)		
Session 5A (09:15-11:05) Session 9: Electrical Methods for NDE I	Session 5B (09:15-11:05) Nonlinear NDT I	
Coffee break (11:05-11:20)		
Session 6A (11.20-13.10): On-Site Measurement & Monitoring by NDT in Infrastructures I	Session 6B (11.30-12:50) Nonlinear NDT II:	
Lunch (13:10-14:10)		
Session 7A (14.10-16.10): On-Site Measurement & Monitoring by NDT in Infrastructures II	Session 7B (14.10-16.10): Electrical Methods for NDE II	
Coffee break (16:10-16:30)		
Session 8A (16:30-18:10): Imaging & Digital Methods	Session 8B (16:30-18.10): Inspection Methods	(16:30): RILEM COMMITTEE MCM MEETING
Official Conference Dinner at Frontzu Politia (20:30)		
Day 3: Wednesday 21/9/2011		
Plenary session 3: SHM for Aircraft, Ground Transportation Vehicles, Wind Turbines & Pipes – Prognosis (8:30-9:10)		
Session 9A (09:15-10:55) Ultrasonics II	Session 9B (09:15-10:55): Signal & Data Processing II	
Coffee break (10:55-11:20)		
Session 10A (11.20-12.40) Ultrasonics III	Session 10B (11.20-13.00): Acoustic Emission II	
Lunch (13:00-14:00)		
Special session: Funding opportunities for NDT Technologies & future prospects (14:00-14:30)		
Session 11A (14.30-16.10) Ultrasonics IV	Session 11B (14.30-16.10): In service/strain/damage monitoring	
Closing Ceremony (16:10-16:30)		

HALL A

HALL B

HALL C

8:50-9:30 Plenary Session 1**Nondestructive Evaluation, Structural Health Monitoring and Optical Diagnostics at NASA Glenn**

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The Optical Instrumentation and NDE branch's mission is to compete to be the customer's first choice within NASA for innovative instrumentation and cost effective solutions to research and development challenges in optical/photonics measurement systems, in space and airborne flight electronics and mobile sensor platforms, and in nondestructive evaluation and propulsion health monitoring methods. Our data leads to improved designs, validation and verification of systems performance, increased safety and security and reduced design cycle times for core technologies developed at Glenn Research Center (GRC) & NASA. Focusing on optical flow path measurements, optical surface measurements, propulsion health monitoring and NDE methods development our selected accomplishments include but are not limited to the following:

- State-of-the-art thermal, ultrasonics, and X-ray & THz tomography methods
- Self-indicating thermal barrier coatings for damage assessment in materials & component
- Self-diagnostics accelerometers and microwave sensors for structural health monitoring
- High temperature fiber optic sensors to 1000 °C
- Up to 1400 °C temperature sensitive sensors
- Optical diagnostics: density, temperature & velocity measurements systems
- Mass flux and shock sensors for turbulence measurements in sub- and super-sonic jets

In this plenary lecture few technologies pertinent to ETNDT5 with some emphasis on seedling ideas that progressed from the development in the lab to real time aerospace applications will be highlighted and discussed. For more in depth details and expert personnel contacts the reader is directed to the following URL:
<http://www.grc.nasa.gov/WWW/OptInstr/>

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Session 1A: NDT in diagnostics & protection of Cultural Heritage I

Keynote Lecture:

Non Destructive Testing as a tool for the evaluation of degradation and compatible materials and processes for the protection of Cultural Heritage

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Protection of Cultural Heritage is a multidisciplinary field that attracts considerable scientific and economic interest from sectors ranging from tourism to construction materials industry. In fact, for certain European countries such as Greece, cultural heritage has been a significant contributor to a country's GDP, and thus, the sustainable maintenance, preservation and revitalization of cultural heritage, and in particular historic sites and monuments, has been the focus of significant efforts from the scientific and technical community. In the past, decisions regarding conservation interventions and protection of monuments were largely based on prior experience, limited and non-systematic identification of the prevailing problems and available technology. This approach has been shown to have limited the effectiveness of any interventions implemented and in some cases even threatened the preservation state of the monuments. In addition, the sensitivity that characterizes the accessibility of monuments, does not allow use of instrumental techniques typically employed in other materials related applications.

Recent technological developments in the field of non-destructive techniques, have enhanced their usefulness in the field of Cultural Heritage protection, and have made them an indispensable tool for the characterization of materials, detection of wear and degradation of materials, assessment of interventions' effectiveness and evaluation of compatible materials and processes applications. State-of-the-art techniques such as ultra-sonics, infra-red thermography, fibre-optic microscopy, endoscopy, ground penetrating radar and their respective signal and image analyses, validated by instrumental analyses, allow the successful implementation of an integrated approach for the protection of monuments. Such an approach, is based first on a non-destructive decay diagnosis, in which NDTs are utilized for characterization of materials, evaluation of previous interventions and assessment of the environmental impact. The identification of the problem is then followed by assessment of pilot interventions, in which NDTs are utilized in quality control of restoration materials, assessment of pilot applications of conservation interventions and performance / compatibility evaluation of pilot applications in lab scale and in-situ. Both functions (decay diagnosis and assessment) provide essential scientific support to decision making regarding monument's protection.

In conjunction with instrumental methods and strategic planning tools, Non-destructive Techniques provide quality control of materials and evaluation of the available technologies for the manufacturing of advanced materials, compatibility assessment of the conservation materials and the effectiveness of conservation interventions in the scale of architectural surfaces and historic masonries, strategic planning of conservation interventions, integrated environmental management, and strategic urban planning. Rapid technological development and further integration of IT, will make non-destructive techniques even more effective and user-friendly, and enhance their applications in the field of cultural heritage protection.

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Contribution of NDT to the sustainable preservation of the Church of Santa Maria in Gradi, Viterbo – Italy

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Introduction : In this abstract an integrated methodology concerning the diagnosis, based on ND testing and techniques, is presented in order to better investigate materials and structures of historic importance. This because the culture of sustainability, directly connected with the Restoration and Preservation policies of architectural heritage, requires to minimize intervention in the original structures and to maximize the effects of those interventions. It is well known the Non Destructive Testing and Techniques & Evaluation methods offer advantages to architectural heritage preservation.

The synergy between traditional approaches and scientific applications allows to choose the most compatible and efficient solution with respect to the historic building current state. In an analogous way, the cooperation between the Institutions, such as the Ministry of Cultural Heritage and Cultural Activities, through the Local Roman Authority Soprintendenza and ENEA, has been demonstrated essential to the proper investigation of the important church of Santa Maria in Gradi, Viterbo.

Methodology aspects: For the investigation of the ancient structure of Santa Maria in Gradi an integrated methodology has been used, combining traditional investigations and different types of NDT analysis, such as: characterization of different period masonry materials, through maps of not homogeneous areas, i.e. areas with different type of bricks or stone blocks; discovery of hidden structural elements, such as arches, columns, choirs included in the existing masonry; the description of the original construction techniques and typologies; evaluation of structural performances through determination of damage in fractured masonries; the detection and classification of surface damage ; examination of structural vulnerability through investigation of physical/mechanical properties of mortars, stones and bricks; inspection of previous refurbishment and/or maintenance techniques (injections, stitching armed joints).

Diagnostic testing: The facade graphical representations have been realized, including the specific position of equipment for data acquisition. This has permitted to obtain quick output concerning the masonry and the structural integrity of the investigated area.

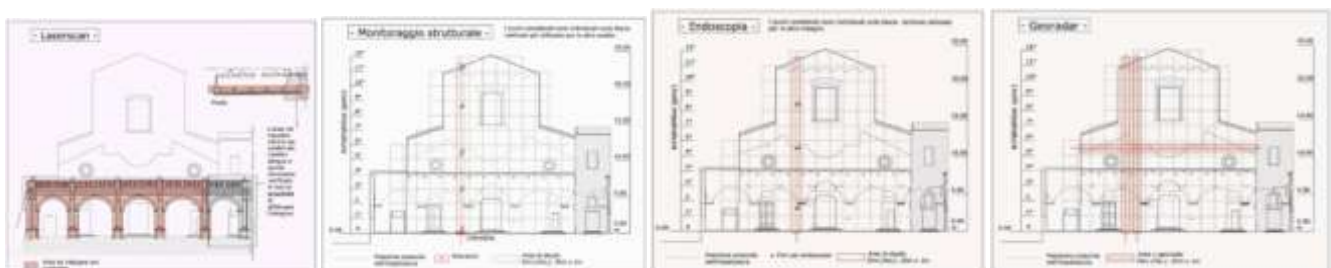


Fig.1: the spatial position of geometric and metric coordinates

In analogous way, to obtain quantitative, qualitative and comparative results, using the following technologies: Laser scanner technology: through the digital geometric description of the façade arcade has been described, through the spatial position of geometric and metric coordinates. The same technology has permitted to follow the ongoing deformative state, through consequent stages of digital description and data post processing analysis of the façade.

Structural monitoring: under static and dynamic regime, thanks to instruments such as exciters, accelerometers and data acquisition unit has been done. The obtained results have determined a different level of vulnerability of the masonry respect the dynamic input

Endoscopy: through a sequence of targeted stratigraphies has been detected the real morphological and functional nature of portions of the main facade (pockets, cavities, mixed materials) and the consolidation of previous interventions, which otherwise would be classified as homogeneous or mixed systems.

Georadar: through reliable scans to a depth of about 3 meters, it was found pre-existing elements under the nave, determining, also, some general characteristics of the church foundation. In addition, through an innovative antenna for detecting vertical scan, it was possible to identify hidden structural elements of floors, arches, pillars and choirs.



Fig. 2: geometric description of arcade with laser-scanner

Results of instrumental investigation: The results of instrumental investigation, together with historical and environmental information have allowed to obtain: Identification of the security and vulnerability of the structure. Determination of mechanical damage and control of the physical and mechanical properties of the masonry mortar (between stones and bricks). Determination of the causes of the deterioration of materials. Findings of adopted construction techniques.

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A New Non-Destructive Technological Approach for Fragile Archaeological Finds

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The sector of Cultural Heritage can take the advantages by the 3D virtual reconstruction and by application of Rapide prototyping also in the field of the conservation of the works of art. This can happen in accordance with the procedures laid down in the ENEA Laboratory.

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Image Analysis for Artistic Style Identification: A Powerful Tool for Preserving Cultural Heritage

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The recent advances in consumer electronics devices and image processing tools have stimulated museums to regularly assemble a vast amount of digital cultural content (i.e., paintings) in their collections. This, in the sequel, fires a cross-disciplinary interaction between image analysis researchers and art historians on developing new technological methods and solutions that supportively act towards art historian's mission of preserving paintings in addition to activities in image acquisition, storage, and database search. Preserving visual paintings and restoring damages is one of the most salient actions in conserving work arts and antiquities. In practice, professional restorers retouch a damaged painting by learning its original style and content features. More specifically, the preservation procedure often follows not only current knowledge of the artist's common practices but they also include a visual assessment of the presence of the artist's "handwriting" in the brushwork. This simply suggests that a computer vision analysis of a painting's digital representation could assist the art expert in the process of conservation.

However, it is true that art conservation is generally a subjective process which depends on art works, the artistic style and the restorers' attitude. Thus, it is quite possible a museum to follow different preservation methods for paintings of similar artistic styles than other museums/galleries. To harmonize preservation methods on the basis of a collaborative restoration procedure, we propose in this paper a new computer-vision based method that allow for an automatic identification of paintings artistic styles and then their classification into groups of similar artistic characteristics. This way, one can combine conservation procedures that are used in different museums and/or galleries with other techniques that are proposed for paintings of similar artistic styles and similar methods in brushing implying direct influence of an artist on another. The main concept is to harmonize art conservation on paintings that seems to follow similar artistic characteristics.

To achieve this, we initially analyze digital paintings in visual domain by extracting set of visual features, being invariant in scaling and orientation and being able to represent with high efficiency different artistic styles. Scale Invariant Feature Transforms (SIFT) and detection of digital corners can be used towards this purpose. In addition, feature related to brushstroke analysis can be considered very useful tool since this is directly related to the artistic style. Thus, a first step is to establish which parts of a painting should be discounted in an evaluation of brushwork, since they may not be due to the artist's hand. Then, non-linear classifiers are proposed to relate different visual paintings and classify them into common classes in terms of artistic styles. Feedforward neural network structures are considered as appropriate non-linear classifiers to achieve these goals. In this paper, we adopt a new retrainable learning strategy in estimating the network unknown parameters exploiting concepts of one of our previously work in artificial intelligence. Such selection is due to the fact that we can guarantee proper class creation even under a subjective artistic style interpretation.

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Session 1B: SHM & Sensors

Keynote Lecture:

The use of chirped fibre Bragg grating sensors to monitor delaminations in composite materials and structures

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Chirped FBG (CFBG) sensors embedded within composite materials have been shown in recent years to be able to monitor delamination growth in adhesively bonded lap-joints, whether the sensors are embedded within a composite adherend or within the adhesive bondline itself.

The relative ease of interpretation of CFBG reflected spectra with regard to delamination development is a consequence of the relationship between the spectral bandwidth of the reflected spectrum (typically 20 nm) and the sensor length (typically 60 mm). If the sensor is embedded in, or bonded to, a composite material subjected to a tensile uniform strain, all the grating spacings are increased and the entire spectrum shifts to higher wavelengths – just as for a uniform FBG sensor. However, if the strain field is perturbed by damage in the composite (such as a delamination), so that the smooth linear increase in the grating spacing is disrupted, then a perturbation appears in the reflected spectrum that can be used to monitor the physical location of the damage.

In this paper, recent results on monitoring delamination growth will be discussed, with particular reference to monitoring mode I cracks in double-cantilever beam specimens using a retro-fitted surface-bonded sensor.

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Cure monitoring of cross-ply composite laminates with residual strain induced birefringent fibre Bragg gratings

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In general, structural health monitoring (SHM) of composite structures is considered very valuable certainly in terms of determining a correct maintenance or repair services. SHM, however, can already start at the beginning of the production process! A very important aspect of the composite manufacturing process is the appearance of residual strains and stresses during the curing cycle.

Composites exhibit large residual strains after curing which vary dependent on the type of composite constituents, composite lay-up and manufacturing technology. The formation of thermal residual strains arise mainly from the difference in thermal expansion between the reinforcement fibres and the matrix (or resin) material but the origin of strain development is completely different than mechanical induced strains. Fibre Bragg grating are very well suited to serve as embedded strain sensor to monitor the internal strain state of composite structures. That is why, when embedded in a composite laminate, their spectral response (wavelength shift) will depend on external perturbations (or deformations) of the structure.

As mentioned above, the structure is already subjected to deformations (or residual strains) during its production. In this paper, the authors are investigating the possibility to estimate the residual strains during the autoclave manufacturing process of carbon fibre reinforced plastics.

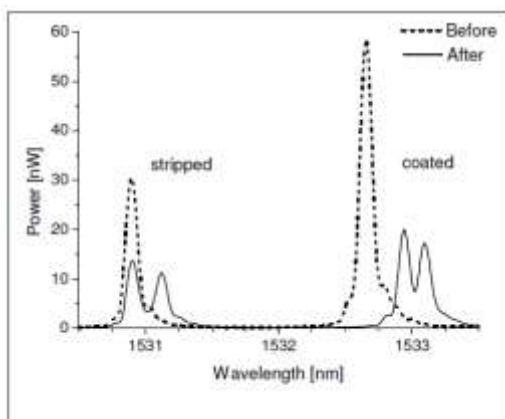


Fig.1: Spectra of the stripped and coated DTG® before and after curing.

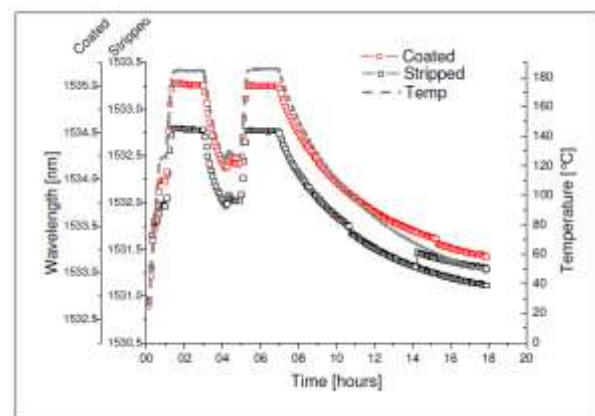


Fig.2: The wavelength evolution for a stripped and coated DTG®, during the curing cycle of a $[90_2,0_2]_{25}$ CFRP laminate

This has already been considered in literature, though, the focus here is on multi-axial strain monitoring, whereas the other authors tend to neglect the transverse strain components (in- and out-of-plane). In this paper, we prove that transverse effects should be considered as well and in many cases (dependent on the lay-up of the laminate) even will be the largest.

The multi-axial strain approach used in this paper is using the residual strain induced birefringence of FBGs. The measurement starts when the optical fibre is completely sealed within the material during curing and from that moment forces can be transferred from the matrix onto the embedded sensor. Multi-axial strain measurements during curing of a composite is found feasible with single-axial FBGs using residual strain induced birefringence! The strain readings of the FBG-sensors can potentially become an instrument to better understand the formation of residual strains in composite structures.

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On the use of a CFBG sensor to monitor scarf repairs of composite panels

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Scarf repairs are often used for damaged composite structures in order to recover the mechanical properties of the original structure. During service, there is the possibility that damage will occur in the repaired region and hence it would be useful to be able to monitor such repairs. This work investigates the possibility of using chirped fibre Bragg grating (CFBG) sensors to monitor the development of damage initiation and growth in the repaired region. The experimental part of the work uses a model system consisting of a scarf-repaired, transparent GFRP beam, fabricated using 8-harness satin fabric and epoxy resin, loaded in fatigue under four-point bending. The advantage of using this system is that the transparency of the material enables the development of damage associated with the repair to be observed directly.

During fatigue loading, damage in the form of cracks initiate at the interface between the scarf-repair and the parent material on the tensile face of the beam; these cracks grow progressively with fatigue loading with the consequence that the flexural modulus of the beam reduces. In the first part of the modelling work, FEA (finite element analysis) has been used to model the development of the damage observed experimentally. The repair and panel have been modelled using solid elements with orthotropic material properties relevant to the various plies.

Damage has been produced by explicitly uncoupling nodes. Reasonable agreement has been obtained between the stiffness reduction recorded experimentally and the FEA predictions for different crack lengths. In the second part of the work, the strains determined using the FE analysis for different degrees of damage have been input into a software package (OptiGrating[®]) to obtain predictions of the reflected CFBG spectra to be expected. As the damage develops within the scarf repair, the strains change and this modifies the reflected CFBG spectra. The results are discussed in the context of the feasibility of using a CFBG sensor for monitoring such repairs and the optimum positioning of such a sensor in relation to the repair.

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In-situ local strain measurement in textile composites with embedded optical fibre sensors

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To understand the local strains inside a textile composite, numerical simulations are typically done on the scale of one repetitive unit cell of the weaving pattern. Periodic boundary conditions are applied to the edges of the unit cell and different load cases can then be applied to the unit cell of the textile composite. Most often, the periodic boundary conditions are applied on all faces of the unit cell, which implies the assumption that the material is repeating itself over an infinite distance in all three orthogonal directions.

This assumption is more or less valid for the textile composite material in the midplane of thick laminates, where it is constrained by neighbouring material in all three directions. It is very difficult to validate such simulations, because local strain measurements inside a textile composite have rarely been done, and the interpretation is not straightforward.

This paper shows the successful use of embedded optical fibre sensors to measure the local strains inside a satin weave carbon/PPS composite (typically used in aerospace applications). The length of the Bragg grating inside the optical fibre sensor has been chosen such that it is longer than the length of one unit cell of the satin weave

architecture (7.4 mm). The read-outs of the optical fibre sensor give the minimum and maximum local strains that occur along the length of the Bragg grating. The correspondence with the developed numerical model is very good, and proves that the numerical modelling approach is valid for this textile composite.



Fig.1: Embedded optical fibre sensor in satin weave composite

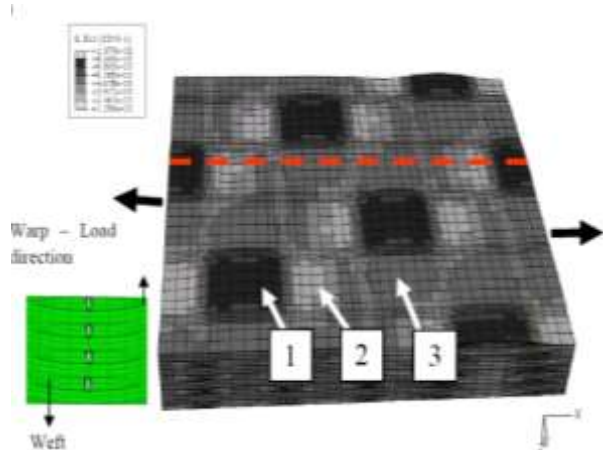


Fig.2: Numerical simulation of unit cell model with applied tensile loading and periodic boundary conditions

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Session 2A: NDT in diagnostics and protection of Cultural Heritage II

Innovative investigation strategies for the diagnosis of historic structures

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The safety assessment, and more in general the diagnosis, of historic buildings is a strategic issue, involving the systematic analysis of any risk factor that may affect the integrity of the buildings. Ancient buildings often show diffused crack patterns, which may be due to different causes in relation to their load history and to their construction technique, but also due to their function changes and historical vicissitudes. Conservation of historic buildings requires a deep knowledge of structures and materials, of their characteristics and potential state of damage and its causes; in fact, prevention and rehabilitation can be successfully accomplished only if the diagnosis of the state of preservation of the building has been formulated. The diagnosis should result from experimental investigation, both on-site and in laboratory, and, for the structural assessment, from the structural analysis based on appropriate mathematical models able to simulate the complex constructive process in a sequential-evolutionary analysis. This has a relevant importance in the structural and vulnerability analysis of historic buildings in seismic area.

The experimental phase is aimed to define the material properties, construction details, internal composition, general characteristics of the structure itself and localise eventual defects. The investigation also may require long-term monitoring of the structure.

Investigation procedures applied at different levels of complexity from monuments to "minor" historic buildings for several purposes are briefly outlined with particular interest in nondestructive techniques (NDT).

The solution of some difficult problems cannot be reached applying a single investigation technique, but by the complementary use of different techniques within a process accurately designed. This becomes a difficult task for the designer of the conservation project, who is asked to interpret the results and use them at least as comparative values between different parts of the same masonry structure or then to use different ND techniques. The diffusion of new investigation tools, enriches the number of available tests but often complicates the interpretation and the misunderstanding of the results, lacking addressed guidelines and suitable background.

The paper describes the designed process and the investigation strategies applied to several case histories, based on the Authors' expertise, in order to explore the most frequent problems affecting historic buildings, with special attention to the complementarity of different investigation techniques within a preservation project.

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A Non-Destructive Corrosion Evaluation Framework based on Morphological Detection and Clustering of the Decay Patterns

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This paper examines a novel approach of corrosion damage diagnosis and restoration based on image processing for quantitative evaluation of stonework degradation. This methodology can be applied in situ in association with a variety of non-destructive monitoring schemes, and on images acquired from several imaging modalities, capturing from micro- to macro-scale characteristics. Once corroded areas have been accurately detected, they are subsequently processed in order to extract some robust features indicating structural aspects of decay. The

extracted features are selected to form a multivariate feature space which in turn is clustered through unsupervised clustering techniques to obtain the different types of corrosion.

The degradation phenomena encountered on stonework form an aspect of high importance nowadays. Several investigations were carried out with the aim of studying the factors, extent and phenomenology of stone decay [1]. In a polluted environment, the most frequently observed decay phenomena on stone surfaces are the formation of black crusts. Thus the necessity of developing robust techniques of estimating the characteristics of corrosion is a prerequisite for determining accurate reconstruction strategies.

The methodology is tested across a large collection of images depicting corrosion damage of various phenomenologies which have been illustrated in terms of different monitoring modalities capturing from micro- to macro-scale characteristics. Further to evaluating the method accuracy in extracting corrosion topology and extent we also aim at quantizing the severity of degradation and the efficacy of cleaning interventions in terms of accurate statistical metrics based on multivariate tests of statistical significance.

In order to address the effective shape detection of decay spots, we tested a category of local morphological operators in combination with sensitive blob detectors to approach the exact topology of decay regions on the surface matrix. A further contribution of this work is finally that it attains to establish associations between the type of corrosion and the shape of the decayed regions obtained through our automated multivariate statistical testing framework [3]. Affine invariant shape features were extracted via considering the boundary cross-sections and evaluating the statistical norms on the cross-sections length distribution. Furthermore, we have also developed an automated framework for clustering the degradation type according to shape, colour and size features. For the classification and the formation of corrosion feature clusters we have employed the unsupervised clustering (un-supervised refers to the algorithm's ability to define the number of clusters without any prior knowledge regarding their shape, distribution etc) algorithm DBSCAN [3] based on forming clusters of arbitrary shape according to their proximity in the N-dimension feature space.

Our automated framework is tested through wide image datasets depicting representative decay effects. The directionality of corroded areas is studied through evaluating the standard deviation on the distribution of corroded areas orientations. Larger values of standard deviation reflect corroded areas encountered at arbitrary orientations with respect to the surface axes.

On the other hand, low values of standard deviation represent corroded regions directed at specific orientations. Compactness, eccentricity and higher order boundary moments were also studied in association with the severity of degradation and the type of corrosion. Summarizing the results derived by series of experiments, it was assessed that the decay patterns detected on more severely corroded surfaces tend to be more compact than decay regions remaining after the cleaning interventions or decay regions encountered on rain-washed surfaces. Thus, decay areas detected on untreated surfaces tend to form patterns of circle-like shape while the shape of decay regions detected on treated surfaces deviate significantly from circle. The tendency of decayed particles to attain a spherical shape can be adequately explained on account of the second thermodynamic law.

[1] Kapsalas P., Maravelaki-Kalaitzaki P., Zervakis M., Delegou E.T & Moropoulou A. (Sep. 2007). Optical Inspection for Quantification of Decay on Stone Surfaces, *NDT&E International*, 40(1), pp.2-11.

[2] Kapsalas, P., Zervakis, M. & Maravelaki-Kalaitzaki, P., (Jul. 2007). Evaluation of Image Segmentation Approaches for Non-Destructive Detection and Quantification of Corrosion Damage on Stonework, 49(1), pp. 4415-4442.

[3] M. Ester, H.-P. Kriegel, J. Sander, and X. Xu. "Density-Based Clustering in Spatial Databases: The Algorithm GDBSCAN and its Applications." *Data Mining and Knowledge Discovery*, An International Journal 2(2): 169-194, June 1998. Kluwer Academic Publishers, Norwell, MA.

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NDT characterization of ancient glass objects from the Aegean with an approach of the manufacturing technique

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The aim of the present work is the application of the non destructive techniques of Fiber Optics Microscopy (FOM) and Environmental Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (ESEM-EDX), for the characterization of decorated colored glass objects, with relation to the manufacturing technique. All the glasses are in the form of small fragments, which have come to light at archaeological excavations in the area of Dodecanese in Greece and are dated at a period between the 5th and 4th century BC. Today they belong to the National Archaeological Museum of Athens. The great historical value and the very small size of the glass fragments did not allow any sampling or even any surface treatment. Therefore, for the microscopic observation of their manufacturing technique and the elemental compositional analysis, the FOM and ESEM-EDX non destructive techniques were used. The compositional data obtained led to significant results on the level of the adopted glass technology, suggesting an identification of the main coloring agents used for the production of the glass objects colorations. The presence of C, O, Si, Ca, Na, Fe as major components was indicated in the bulk glass of the examined items, characterized also by low Al, K, Mg contents, allowing to classify them as soda – lime-silica ($\text{Na}_2\text{O} - \text{CaO} - \text{SiO}_2$) glass. Pb and Sb were found to be the responsible colorants for the opaque yellow decorations, while only Sb for the white ones. The green coloration was attributed to high Fe content. Co was indicated as the responsible coloring agent for blue glass. In this work, the results obtained from the microscopic examination provided significant information on the level of the employed glass manufacturing technique used, allowing us to assume that the core –forming was the main technique used for the production of the glass artifacts. Finally it is concluded that the employed techniques proved efficient to provide in a consistent way characterization of the Aegean colored glass objects. Thus, it is proposed from these results that FOM and ESEM-EDX could be used as valuable and appropriate non destructive techniques for the investigation and characterization of ancient glass artifacts, where no sampling is allowed.

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The Use of Pulsed Infrared Thermography as a NDE tool for the Assessment of Cleaning Interventions on Marble Architectural Surfaces

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In this work, pulsed infrared thermography (PT) was applied on marble samples collected on site before and after pilot cleaning interventions. An integrated pulsed thermographic system employing a medium wave infrared camera that uses a cooled indium antimonide detector with a frame rate of 60 Hz, a focal plane array pixel format of 320 (H) x 256 (V) and an optical lens of 13 mm focal length was utilised for the pulsed thermographic analysis. The system has an integrated power flash heating system with a power output of 2KJ in 2-5 ms. Temperature – time plots, displaying the intensity of pixels against time were plotted from the acquired pulsed thermographic images. Moreover, the rate of the emitted infrared radiation of the investigated samples was studied. It is shown that the cooling rate of the investigated samples is described by a first order kinetic model, where the time constant of the cooling rate is an exponential function of marble surface microstructure and its luminosity. In particular, marble surface microstructure was expressed by the near-surface fracture density (FD) of the stone which is a measure of the fraction of the stone volume filled by fractures, crevices, and pore space. The FD values resulted by digital image processing of SEM images using the EDGE program which was developed by the US Geological Survey. Luminosity L^* values were recorded by the application of the NDE technique of colorimetry in situ on the investigated marble surfaces according to CIE Lab Uniform Colour Space.

It is concluded that the pulsed infrared thermography can be a skilful means of inspecting marble architectural surfaces, before and after cleaning, using the suggested empirical mathematical model.

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Radar-based vibration measurement on historic masonry towers

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The microwave remote sensing is emerging as an innovative technique, suitable to the non-contact vibration monitoring of large structures. The combined use of radar interferometry and high resolution waveforms and has led to the development of portable radar systems, apt to simultaneously measure the (static or dynamic) deflection of several points on a large structure with high accuracy. The main ideas of the microwave-based measurement of deflections are: (1) to employ high resolution electromagnetic waveforms to take consecutive images of the investigated structure, with each image being a distance map of the intensity of radar echoes coming from the reflecting targets and; (2) to evaluate the displacement of each target detected in these images from the phase of the back-scattered electromagnetic waves collected at different times (microwave interferometry).

The practical implementation of the above principles in a sensor prototype was carried out by the Italian company IDS (Ingegneria Dei Sistemi, Pisa, Italy), in collaboration with the University of Florence, within the framework of a research project funded by the Italian Government. Subsequently, a joint research started between IDS and the Department of Structural Engineering of Politecnico di Milano, mainly aimed to validate the results of the microwave interferometer, named IBIS-S (Image By Interferometric Survey of Structures) and to assess the equipment performances in ambient vibration testing of full-scale bridges.

The application of microwave remote sensing to the measurement of vibrations on historic structures is in principle very attractive, although characterized by some potential issues: (a) the electromagnetic reflectivity of masonry is rather low; (b) the actual displacement of the surveyed historic structure needs to be larger than the radar sensitivity (0.02 mm).

The paper first describes the radar equipment and its technical characteristics, in order to highlight advantages and potential issues of the new technology. Subsequently, the application of microwave remote sensing to the measurement of deflections on an historic masonry bell-tower, instrumented also with conventional accelerometers, is presented and discussed. Two series of data were collected, with the excitation being provided by the wind and the micro-tremors only and by the swinging of bells, respectively.

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Session 2B: Acoustic Emission I

Health Monitoring of Operating Wind Turbine Blades with Acoustic Emission

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Wind turbine blades are one of the most exposed parts of a wind turbine since, due to the nature of the wind, they are subject to aerodynamic loads with great variability, strong gusts of wind, and occasionally sustain severe weather conditions while rotating. Furthermore, the structural integrity of the composite material blades is critical to the entire wind turbine for safety reasons as well as for increased efficiency. However, inspection of installed blades during operation, or even during off-line mode presents practical difficulties due to accessibility restrictions, nature of the material, size of the blades, complicated geometry, etc. Acoustic Emission (AE) has proven to be highly effective in detecting and identifying damage in wind turbine blades and generally composites under load through numerous laboratory tests including full scale blade tests. However attempts for in-service monitoring of wind turbine blades are limited. In the present paper, AE measurements acquired with an on-line health monitoring system for rotor blades, installed inside the hub of an operating wind turbine, will be presented. AE features, like signal amplitude, duration, energy, average signal level etc. of signals acquired during wind turbine operation are being analyzed with advanced data analysis techniques in order to emphasize on useful data and identify trends within the enormous amount of AE data acquired. Results indicate the feasibility of monitoring rotating blades with AE and reveal multiple correlations between the acquired AE data rate and the wind turbine operating conditions such as rotor speed, wind speeds, torque, etc.

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Real-Time Damage Location and Assessment in Composite Structures with Acoustic Emission

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The use of composites has been steadily increasing over recent years with significant applications for many divergent industries. Composite materials intrinsically possess certain advantages such as higher strength to weight ratios, improved fatigue properties and a natural corrosion resistance offering a viable and cost effective alternative for many engineering applications. Their over increasing demand in industries such as marine, automotive, surface transport and aerospace, as well as the highly non linear behaviour under dynamic loading, are offering the opportunity for novel non destructive testing and evaluation techniques to be developed and studied.

Acoustic Emission has proven to be a superior global, non destructive inspection technique with highly detailed dynamic defect detection capabilities in both metal and composite structures. Within the scope of EU funded COMPAIR research project, the capabilities of Acoustic Emission are studied and subsequently fine-tuned in order to maximize its potential of real time damage detection and assessment in FRP structures used in the transportation industry. In the present paper, experimental results of real-time damage detection and assessment on GFRP coupons are presented. Ten coupons were tested up to failure under various tensile loading conditions in order to successfully locate and assess the damage accumulation in the various stages of the dynamic loading. Further analysis has been performed in all acquired Acoustic Emission data sets using specialized pattern recognition and DSP software, in order to accomplish a more detailed study of the characteristics of the dynamic

damage mechanism for the specific FRP material. Results show a very detailed agreement between the real time software-located AE events and the actual damaged area verifying the great potential of Acoustic Emission to be used in real time monitoring of composite structures in various industries.

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Acoustic Emission Monitoring of Wheel Sets on Moving Trains

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Recent work in Acoustic Emission monitoring of wheel sets on moving trains and trams using AE sensors mounted on the rails, has verified the great potential of the method in detecting geometric defects such as flat surfaces on wheel circumference. To achieve optimum results, multi-dimensional analysis has been performed, combining Time Driven Data (TDD), Hit Driven Data (HDD) and long waveform streams acquired simultaneously. High frequency AE sensors proved to be adequately sensitive to flat defects, and the received AE signal level fluctuations were in agreement with the single defect rotational frequency. Combined analysis of all available types of AE data in the time and frequency domain with specialized software reveals the full potential, of the method in providing high accuracy defect detection.

The present paper presents the results of AE measurements performed during train passes, with different speeds & directions, where wagons without any wheel defects and ones containing known artificial flats were moving along the rails. AE features, like signal amplitude, duration, energy, average signal level etc. of AE signals are being analyzed and compared. Digital Signal Processing, post-test AE feature extraction and time measurements performed on acquired waveform streams that contain the total continuous acoustic emission during each pass for verification. The results clearly show repeatable indications on trains having defected wheels.

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Method of the complex analysis of thickness and properties of hardening coating with use acoustic emission testing and digital images correlation

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Results of researches of influence of thickness of a strengthening layer of samples of stainless 12Cr18Ni10Ti (321 H) steel specimens in a condition of delivery and with a nitrated superficial layer are submitted to deformation and destructions with use of a method of acoustic issue (AE) and to correlation of digital images. Criteria of identification of sources AE connected to plastic deformation and fragile destruction are used, on the basis of the analysis of parameters of registered signals With use of the new approach to identification of sources AE, based on the analysis of spectral factors and energy of : wavelet-spectra of signals AE comparison of activity of sources of various type at different stages of development of deformation is carried out. Characteristic stages allocated by the analysis of the schedule of factor of deformation hardening from a degree of deformation.

1. It is shown, that, as against not nitrated sample, cracking a nitrated layer causes increase of quantity of stages in samples with a covering thickness 10-14 microns up to five, and in a sample with the strengthened superficial layer 30 microns up to six. Thus to each of stages there corresponds change of activity AE of sources that is the additional basis for identification of stages. Change of quantity of stages is connected to distinction in character and formation of a layer of a substrate of strips of the located shift and mesovolume in the form of trihedral prisms.

2. In work additional confirmation of the fact of generation AE of signals already at a stage of elastic deformation is received, and sources AE at the given stage can be and microcracks. To increase in thickness of the strengthened layer there is a monotonous increase in the total account and energy AE, radiation sources such as the macrocracks, arising in result cracking a superficial layer.

3. With increase in thickness of the strengthened layer up to threshold value the total account and energy AE of sources dislocation type and sources such as microcracks increase, and after achievement of a threshold the total account and energy AE of sources dislocation type are reduced. For sources such as microcracks the total account and energy AE essentially do not change, that is proved by increase in speed of local deformation and energy AE in places of formation of cracks, groups of dispositions, not having time to be redistributed, pass in the category microdiscontinuity flaw (microcracks).
4. With increase in thickness of the strengthened layer the contribution to total account AE of sources dislocation type decreases, and sources of type micro- and macrocracks increases. Besides increase of thickness of a nitrated layer causes reduction of the contribution to total energy AE of sources dislocation type and microcracks while the contribution to energy of sources such as macrocracks grows.
5. The method of correlation of digital images allows integrated to reveal the stages connected to formation in the nitrated layer of microcracks, however localness of supervision does not allow to reveal precisely characteristic stages of deformation and destruction just as it is realized in method AE and at the analysis of diagrams load.

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Session 3A: NDT in diagnostics and protection of Cultural Heritage III

Application of ground penetrating radar for the assessment of the decay state of Hagia Sophia's mosaics

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The church of Hagia Sophia in Istanbul, is a world heritage monument that epitomizes the byzantine ecclesiastic architecture. The church is decorated with mosaics dating back to the fourth century, however, throughout its history the building has been damaged by earthquakes, vandalism, and has been the subject of various interventions. Regarding the mosaic decorations, a significant portion of the mosaic decoration that has survived through centuries, has been covered during the conversion and subsequent use of Hagia Sophia as a Mosque. Since 1935, when Hagia Sophia was converted into a museum, conservation of the remaining non-covered mosaics has begun, but this includes also mosaics that have been revealed from areas where the plaster was removed during the conservation process of the building.

In the framework of a bilateral Greek-Turkish cultural cooperation agreement the decay state of the mosaics at the south upper gallery was assessed using an array of non-destructive techniques. Ground penetrating radar at 1.6GHz and 2.3GHz was employed at mosaic areas where the Ottoman period plaster has been removed during recent conservation interventions. In addition, ground penetrating radar was employed at areas where the plaster has been partially removed, in order to examine the possibility of underlying mosaics being still present nearby. Regarding the mosaics' preservation state, ground penetration radar revealed in some areas the possibility of partial mosaic detachment, a situation that requires careful consolidation and conservation interventions. In other areas the base mosaic plaster adheres adequately with the masonry.

This study has shown that ground penetrating radar can be successfully employed to assess the decay state of mosaics and allow effective conservation interventions to be selectively applied.

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Dynamic testing of historic iron bridge at different levels of excitation

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The paper focuses on the dynamic investigation of an historic bridge, performed in operational conditions under different levels of ambient excitation, aimed at obtaining an assessment of the bridge structural health condition by checking the invariance of the dynamic characteristics (i.e. natural frequencies and mode shapes) with increasing excitation amplitude. The investigated structure is the San Michele bridge, an iron arch bridge that crosses the Adda river, linking the small towns of Calusco d'Adda and Paderno, about 50 km far from Milan. The bridge was built between 1887 and 1889 by the Società Nazionale delle Officine di Savigliano (SNOS) to complete one of the first Italian railway lines and to comply with the needs of the rapidly growing industrial activities in the Lombardia region at the end of XIX century.

The historic infrastructure, protected by the Italian Ministry of Cultural Heritage since 1980, is the most important monument of XIX century iron architecture. The main structural elements of the bridge are a parabolic iron arch, with a span of 150 m, and a truss-box metal girder, 266 m long, resting on nine equally spaced bearings; four of these bearings are supported by the arch, directly or through metallic piers, while the remaining ones are supported by three iron piers and by the abutments.

Notwithstanding the lack of maintenance and the poor state of preservation of the structure, significantly damaged by corrosion, the bridge is still used as a combined road and rail bridge, with the top deck of the truss-box girder carrying one lane of alternate road traffic and the bottom deck housing the tracks of a single-line

railway. Within the dynamic tests performed on the historic infrastructure since June 2009 to address a Structural Health Monitoring program, the bridge response at selected points was continuously recorded for 15 hours. The extraction of modal parameters from the collected data clearly highlighted slight variations in time of natural frequencies and mode shapes and the dependence of the bridge dynamic behaviour on the amplitude of excitation/response.

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Application of IR Thermography to Damage Characterization of Structures and the Diagnosis of Historic Monuments

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Infrared thermography is a real-time method based on monitoring the temperature variation on the surface of materials and structures. This method identifies and interprets the surface temperature differences in the material, leading to the evaluation of damage distribution and accumulation. Infrared thermography is a non-destructive, full field and non-contact method allowing characterization of degradation in historic monuments without causing further damage to them. This work presents recent results of infrared thermographic inspection of murals at the “Monastery of Molivoskepasti” in the Ioannina region. Three different thermographic techniques have been used and compared for their efficiency in detecting hidden letters in sub-surfaced donors inscriptions.

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Iron-based and other ancient pigments for pottery decoration

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47 samples of Archaic pottery excavated in Thebes (central Greece) were examined by means of Optical Microscopy, SEM-EDAX and XRD in order to investigate the nature of the decorative pigments on their surfaces. Black-colored pigments were identified as especially refined iron-rich clays; shiny black surface could be achieved by treating those clays in a multistep firing (Oxidizing-Reducing-Oxidizing). Red pigments were also iron-rich clays, in most cases significantly coarser than those used for the creation of black surfaces. As regards yellowish pigments, they were found to be mainly calcium- or/and magnesium-rich clays while purple pigments exhibited unexpectedly high iron content and intriguing micromorphology. In order to fully understand the nature of purple pigments, several natural and artificial iron-based materials were subjected in thermal and grinding treatments. The products were studied in means of SEM-EDAX and XRD and it was concluded that purple hue may be obtained by firing iron precursors in high temperatures (>900 °C): this treatment causes the formation of hematite particles with diameter >1 µm which exhibit the characteristic hue. More generally it was demonstrated that a range of colors usually associated to natural ochres and their processing could be obtained from iron sources familiar during antiquity and other than natural ochres via a simple adaptation of the vinegar treatment route which was widely used during antiquity for the production of verdigris and lead white. Hence a new question is posed: Do all decorative ancient ochres originate from natural ochres?

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Session 3B: Structural Health Monitoring (SHM) of aerospace components

Keynote Lecture:

Structural Health Monitoring in an operational airliner: results on the implementation of percolation sensors achieved within the European Project: “Aircraft Integrated Structural Health Assessment II (AISHAII)”

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Fig.1 The applicability of the system was shown in a relevant lab-environment, and the sensor is in the meanwhile implemented in an operational airliner (Boeing 737). The sensor network will provide first data on the presence of corrosive liquids in a relevant environment.

The European project AISHA II focuses on the structural health monitoring technologies for planes and helicopters to achieve a relatively high Technology Readiness Level (TRL). The full-scale parts considered are floor structures composed of aluminium alloy floor beams and composite floor plates, slat-tracks made of maraging steel and helicopter tailbooms made from aluminium alloy and sandwich CFRP. The non-destructive techniques applied are based on ultrasonics as well as on electrical and electrochemical impedance measurements. Due to the dominance of plate-like structures in aircraft, ultrasonic guided waves are used for damage detection. For impact damage detection with Lamb waves, mode conversion effects are exploited and the detection is performed by appropriate sensor arrays. Another concept applied is the high-accuracy time-of-flight detection of Lamb waves using the chirp technology. Another successfully applied idea is the interruption of electrical conductivity by fatigue cracks (slat tracks and aluminium sheet structures) or by leaking liquids (floor beams, hydraulic pipes). Simple impedance measurements using dedicated gauges allow conclusions on structural damage and leakage. The main focus for all investigations is the durability and robustness of the technologies proposed. For instance, sensors are presented that are based on the collapse of percolation conductivity of a conducting composite when a target liquid enters the sensing zone. From one of the sensing materials developed, a floor beam sensor was designed to determine the presence of corrosive liquids in floor structures (see picture on the left). The sharp increase of resistance due to ingress of liquids can be monitored, but it is possible to read out data during maintenance.

The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n°212912.

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Advanced NDT Techniques for Damage Detection in a Honeycomb Composite Helicopter Tailboom

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Honeycomb sandwich components are high tech materials for primary aerospace components; however their impact sensitivity requires a reliable non-destructive testing (NDT). A part of the EU-AISHA II project is the detection of damages caused by impacts in a complex EC 135 helicopter Tailboom structure. An on-board Structural Health Monitoring (SHM) System with attached sensors could check the interiority not only at Letter-Checks but also at any time.

Lamb waves can penetrate large areas with low attenuation and interact with defects. An SHM-system based on Lamb waves enables in principle damage detection in large components without time consuming scanning. However, in minimum two dispersive Lamb wave modes exist and their interaction with defects is very complex. Therefore the receiver signals are very difficult to interpret and it is important to have complementary NDT methods such as ultrasonic inspection techniques and Infrared Thermography (IT).

Ultrasonic inspection testing is usually applied with squirter technique; transmitter and receiver are situated on opposite sides. After optimization of test parameters it was possible to have a one sided access, and an additional evaluation of the frequency spectra enables more detailed information about the interior for the visualisation of inserts, and lightning protection foils.

Infrared Thermography (IT) inspections, based in Infrared (IR) radiation detectors and joined to specific excitation techniques, allow fast, precise and non-hazardous inspections. Different excitation techniques shall be applied according to the defect to be detected. Furthermore, Pulsed and Lock in techniques have their specific advantages in different inspection fields. Finally, a mathematical analysis, based on algorithms, highlight the encountered defects.

Real conditions to be applied on the component under study is a must, therefore, high efforts have to be made in order to ensure that the conditions applied are accurate and close enough to the real conditions. However, there are several standards that define these test parameters.

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Crack detection in aluminium plates for aerospace applications by electromagnetic impedance spectroscopy using flat coil sensors

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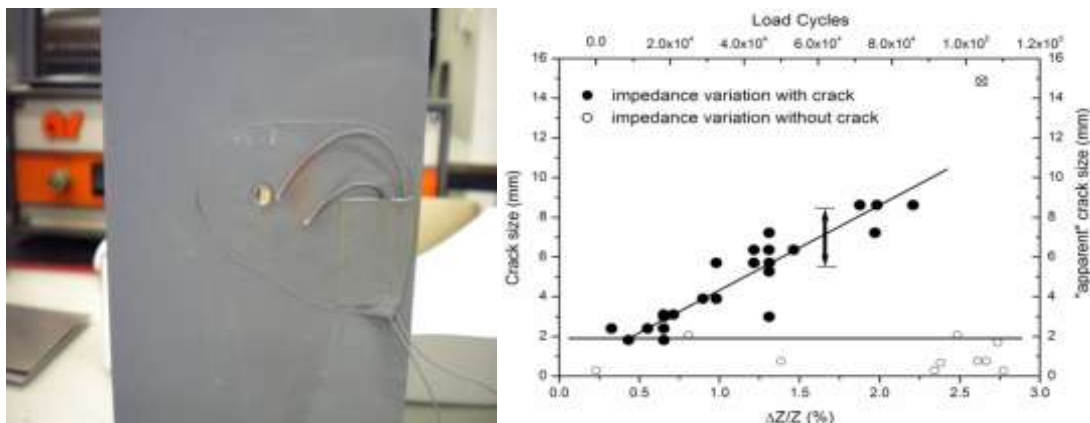


Fig 1: Embedded flat coil sensor and impedance variation vs. crack size

A flat coil sensor based on eddy-current technology has been developed for the non-destructive testing (NDT) of aluminium plate-like structures for aerospace applications. Structural health monitoring (SHM) is a rather new and growing technology and the implementation of its techniques is receiving a high level of interest from the aviation industry. Aircraft manufacturers and airlines are interested in SHM not only for safety reasons but also for more efficient maintenance. Nowadays, eddy-current sensors are the main detection systems for fatigue cracks in various critical points of an aircraft. These critical points can be found primarily in plate-like aluminium parts where small holes or rivets are present. In this research, a high-cycle fatigue test was performed in order to monitor cracks in thin Al 2024-T3 plates using a flat coil sensor. For the initiation of the cracks a hole was artificially created in the middle of the plate. Results showed that this type of sensor was able to detect the crack growth by electromagnetic impedance measurements and due to its flexible and thin design it can be used as an embedded sensor between the primer and top-coating of the aluminium plate like structures.

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Multi-element piezo-composite transducers for structural health monitoring using Lamb waves

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One of the well-established techniques used for Structural Health Monitoring (SHM) is based on the propagation of ultrasonic waves through a structure in order to assess its structural integrity. The common solution relies on the use of piezoelectric transducers to emit and receive ultrasonic waves. However, because of the high number of echoes and possible propagation modes within the structure, those applications require very extensive signal processing.

In this work we present an approach involving piezo-composite transducers dedicated to SHM in combination with specific electronics that has been developed and successfully tested for reducing the complexity of the detection schemes. This has been achieved by selecting the mode and direction of the Lamb waves. The array transducer comprises a row of eight independently driven PZT elements integrated in a polymer matrix, effectively forming a 2-2 composite. Dielectric and piezoelectric characterisation is presented and the obtained results confirm an excellent uniformity and performance of the tested devices. Moreover, additional results of Finite Element Method modelling are given. Functional characterisation at the system level shows that it has been possible to successfully distinguish waves propagating at different velocities, confirming the concept of mode selectivity using piezoelectric arrays. This result is very promising for applications of SHM on complex structures.

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Impact damage detection in composite materials of aircrafts using a polarimetric fibre sensor

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There is for the moment an increasing use of composite materials in aerospace industry. For the safe operation of aircrafts, engineers therefore also need to investigate new techniques to assess impact damage. In the last years, there is an increasing interest in structural health monitoring systems based on optical fibres to be used for composite materials in aircrafts. This paper presents how optical polarimetric fibre sensors can work as line-integrating sensors and how they can be used to detect impacts. The aircraft materials investigated in this paper are simple composite plates as well as a tailboom of a helicopter, the latter representing a full-scale part. Optical fibre sensors were mounted on the composite material by appropriate adhesives. The impacts were detected due to the modulation of the light propagating in the optical fibre, which resulted from the elastic pressure waves of the impact. The change in the light propagation can be detected along the whole length of the active fibre sensor.

The results from the optical fibres are very similar to those obtained using piezo-electric sensors and show the potential for further development in aerospace non-destructive technology when non-electric sensors for online impact detection are needed.

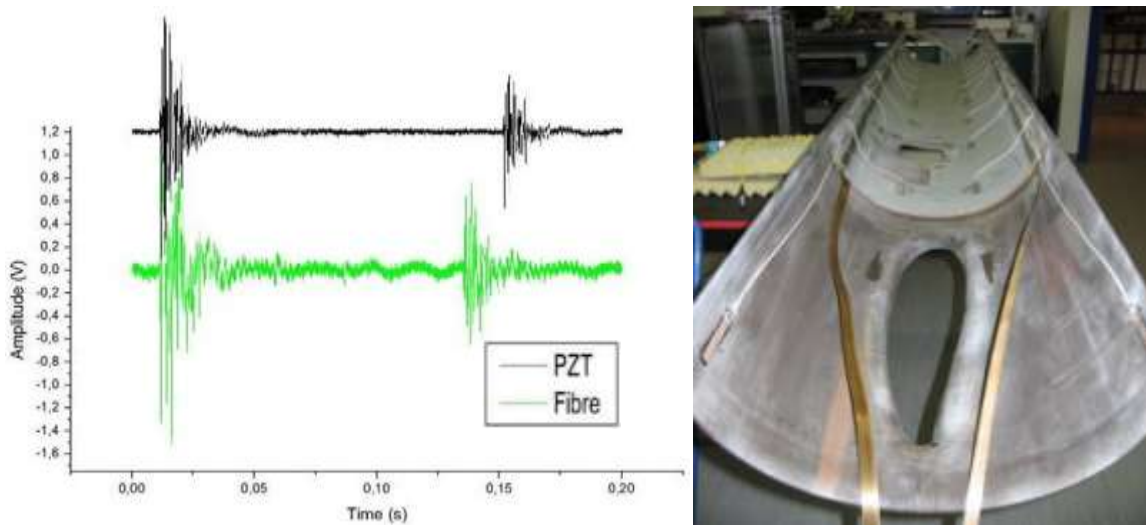


Fig.1: Signal comparison with PZT and SM optical fibre (left), optical fibres inside EC 135 Tailboom (right)

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Detection of closed defects in vibrating structures with piezo-excited and detected acoustic waves

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Inspection of civil structures and aircrafts is time-consuming and costly. In most of the cases inspection requires to take the vehicle out of circulation, and it also requires a large amount of manpower. On-line structural health monitoring (SHM) can offer a significant reduction of this cost and time. For this purpose a variety of different testing techniques needs to be developed. In this work a SHM system to detect closed cracks in vibrating structures is developed making use of piezoelectric excitation and detection in combination with dedicated signal analysis. This online technique will allow to automatically inspect critical structures that are subject to heavy loads without taking them out of operation, saving costly man-hours and down time. When a dynamically varying defect is present in a vibrating structure, the waves traveling through the defected region are modulated due to (typically low frequency) vibration induced temporal variations of the defect impedance. By monitoring this modulation and investigating the correlation with the (low frequency) vibrations of the structure defects can be detected. To obtain reliable results all the different aspects of this process have to be optimized. An important feature of the concept is the use of a one dimensional piezo-arrays that are able to perform mode selection and direction selection, thus enhancing the transmitted waves of interest to preferentially travel through the region of interest towards the receiver array, and reducing unwanted reflections reaching the receiver array.

A second way to enhance the selectivity of signal features induced by defects in the region of interest is related to the signal analysis. In the followed approach, the measured receiver signal is split into a low and a high frequency part. The low frequency part corresponds with the environmentally induced vibrations of the part under inspection. The high frequency part is demodulated by a lock in detector, resulting in a signal that represents the defect-induced modulations of transmitted probing waves due to the dynamic loading induced transmission modulation by the defect. The magnitude of the demodulated signal and its correlation with the low frequency vibration reveals the severeness and nature of the defect.

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Session 4A: Ultrasonics I

Structural health monitoring of repaired metallic structures by analyzing the instantaneous characteristics of Lamb waves

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Life extension of ageing aircraft with adhesively bonded repair patches has lately received a lot of attention with a significant number of applications both in metallic and composite structures [1, 2]. In these systems, repair monitoring is a major priority which will ensure the effectiveness of the repaired region and the continuous in-situ monitoring of its structural integrity. Inspection with Lamb waves is one of the most widely used damage detection technique based on ultrasonic waves [2]. The majority of the signal processing techniques which has been developed for the extraction of signal features related to damage, focus on amplitude analysis. However these techniques can be easily influenced by non damage related parameters like temperature or moisture effect and lead to false alarms. The current analysis will demonstrate the inspection of a repaired aluminium plate with an external patch using Lamb waves. The aim of the study is the damage assessment and feature extraction by analyzing the instantaneous characteristics of Lamb waves through the Hilbert transform.

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[2] Pavlopoulou, S., Soutis, C. and Manson, G.. Proceedings of the 9th International Conference on Durability of Composite Systems, Patras, Greece, 12-15 September 2010.

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Detection and characterization of surface-breaking defects in metals using ultrasonic surface waves

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This paper discusses the capability and reliability of surface (Rayleigh) waves in terms of detecting and characterizing surface-breaking defects. The surface waves belong to the group of traveling waves. A good understanding of which defect characteristics affect detection and characterization is essential when using ultrasonic testing method. According to Lord Rayleigh surface waves propagate along the solid surface and their wave motion is confined to a region near the surface whose depth is comparable to the wavelength. Surface waves can be diffracted, scattered and reflected by surface-breaking defects according to the size of the defect relative to the wavelength. Surface waves can be used for detection and characterization of surface and near-surface defects. Deliberately created and welding defects have been systematically detected. Specially designed sample work pieces were also considered for defect detection and characterization. The detection probabilities and characterization of defects have been discussed. Surface waves are compared with other kinds of traveling waves and the requirements for surface wave propagation are discussed. The experimental results show that this method is effective and reliable for detection and characterization of the surface-breaking defects.

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Application of ultrasonic guided waves for non-destructive testing of constructional materials of aircraft structures

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The modern composites, such as fibre metal laminates, honeycombs, glass or carbon fibre reinforced plastics (CFRP) are used as lightweight, high tension and compression strength, thermally stable and corrosion resistance materials in various axially loaded aircraft structures (covering panels of fuselage, stiffeners and stringers of the wings, spar caps and longerons). For example, in order to build the arbitrary spar profile the small diameter composite rods are used as constructional elements which are glued together in epoxy-filled matrix. The dynamic loads and external forces, shear stress caused by torsion deformation of the wing, continuous vibrations, fatigue, harsh environmental media and the exploitation conditions can weaken the strength of the overall component in the case when the defective rods are used. The expected defects are break of fibres, reduction in density or multiple delaminations. Therefore, the quality control of constructional elements like individual rods must be performed during manufacturing, as repairing procedure of the finally assembled structure is very complicated. Therefore, in order to apply the NDT technique for on-line testing of CFRP rods during manufacturing, it was necessary to develop the ultrasonic non-contact testing method suitable to detect internal non-homogeneities in the case of a single side access.

The regularities of ultrasonic guided waves (GW) propagation along the regular shape composite rods in cases of defect-free and defective regions were analysed using the semi analytic finite element (SAFE) and the finite element (FE) techniques. The interaction mechanisms of GW with defective regions were investigated experimentally also. It was determined that, taking into account such interaction mechanisms (reflection back, scattering over defect and mode conversions) and using the special orientation of ultrasonic transducers, not only presence of the defective regions are being detected efficiently, also their parameters such as the length of delamination can be estimated with a sufficient for practical applications accuracy. On the basis of these investigations two NDT methods were proposed: the immersion and the air-coupled. The immersion NDT of the circular-shape rod is based on exploitation of the L (0, 1) mode, because the flexural F (1, 1) mode is completely suppressed not far away from the excitation region due to huge leakage losses. The immersion technique is less sensitive to variations of the S/N ratio; however excitation of the L (0, 1) mode is efficient only from the edge of CFRP rods and therefore is not very attractive for on-line applications. In the case of the air-coupled approach it was found that for a continuous quality monitoring of square-shape CFRP rods the F₁ mode may be efficiently exploited due to asymmetric excitation/reception of GW having only a single side access to the rod. It was demonstrated that in the both cases damages of CFRP rods may be easily detected and their dimensions estimated.

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Monitoring of composite components using ultrasonic guided waves

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In the recent years a wide spread of non-destructive inspection and monitoring techniques based on the application of ultrasonic guided waves is observed. Especially such techniques are attractive in the case of monitoring of composite components. However, complexity of guided waves and phenomena such as dispersion, presence of multiple modes and anisotropy create obstacles on the way of new developments. The problems are met both in the modelling and experimental investigations due to a big size and complicated geometry of the components to be inspected. One of the main problems is a lack of the knowledge for interpretation of multimodal and multi-reflected signals. As a result usually only the fastest modes are used in analysis and as a consequence an essential part of information contained in the signals is lost or not used. The objective of the work presented was to investigate application of the guided waves for monitoring of the composite components and to develop such models and signal processing techniques which enable to detect and monitor evolution of various defects. The analysis demonstrated that most important parameters influencing quality of the monitoring are the number and position of the transducers necessary to achieve the required coverage, the sensitivity to

evolution of the defects and possibility to estimate the defects parameters – at least their location and the size. It was shown that there are several important differences between the non-destructive inspection and monitoring approaches. The disadvantage of the monitoring with respect to the detectability of defects is in the fact, that the number of embedded transducers and as a consequence of the number of measurement positions is limited. On the other hand the signals in the case of monitoring are more stable as the transducers are embedded into a structure under a test and there is no influence of the signals variations caused by the acoustic coupling, what can be observed in the case of a contact type scanning during a conventional inspection. It was demonstrated that due to this fact even very small variations of the signal shape can be detected and measured. In order to determine what changes and where they can be observed in the signal, the model was developed which takes into account the excitation and propagation parameters of guided waves. Using this model and the proposed signal analysis technique in the case of a glass fibre (GFRP) rectangular plate it is possible to achieve a complete coverage of the object even with a small number of embedded ultrasonic transducers if not only the fastest modes, but also multiple reflections are analysed. The experiments carried out have shown that the proposed approach enables to monitor evolution of the defects or variations of the elastic properties at arbitrary positions of the plate.

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Work of Iranian ultrasonic testing system for fault diagnostic of CNG cylinders at production lines

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Design and manufacturing an automatic ultrasonic testing system for flaw detection of compressed natural gas (CNG) cylinders is explained on this paper. Ultrasonic scanners have been installed on 5 different CNG production lines in the territory. A fast and reliable test of cylinders is done with capability of logging results as per customer demands. The paper explains both machine specification and challenges faced during manufacturing and starting up. A questionnaire has been designed for different operators to know their opinions about handling and performance. The ultrasonic machine could identify defects caused in different stages of CNG production line especially in heat treatment furnace. The knowledge of ultrasonic interpreting has been transferred to operators and they have earned enough capability to distinguish between flaw and noise signals.

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Resonant Ultrasound Spectroscopy as a tool for noninvasive examination of Zirconia head of hip prosthesis

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This paper proposes to use Resonant Ultrasound Spectroscopy for evaluation of monoclinic phase condition appeared in Yttria stabilized polycrystalline tetragonal zirconia (Y-TZP) ball head of hip prosthesis. Monoclinic phase can appear due to mechanical stresses from femoral head. The ceramic ends with diameters of 28 mm and 32 mm, which were artificially fatigued in accordance with ASTM F2345-03, have a monoclinic phase content varying from 2.9wt% to 66wt%, determined by X ray diffraction. These modifications were emphasized by modification of resonant ultrasound spectroscopy spectrum.

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Session 4B: Signal & Data Processing I

Thermographic signal reconstruction on pulsed thermography results for detection and characterization of defects on composites

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Active thermography has been extensively investigated in the past few years for the nondestructive evaluation of different types of materials. Composites in particular have received considerable attention given that active thermography has shown to be well suited for the detection and characterization of most kinds of defects typically found in these materials such as impact damage, delaminations, disbonds and inclusions. Pulsed thermography (PT) is one of the many, but nonetheless effective, active thermography techniques on composites inspection. Nonetheless, signal processing is a necessary step of the inspection process, especially if defect characterization is required. A wide variety of techniques have been developed from the classical thermal-based techniques to signal transformation algorithms (adapted from the area of machine vision) on which temporal data is transformed to a different domain (frequency, principal components, high-order moments, etc.) with the purpose of simplifying data analysis. In this paper, thermographic signal reconstruction (TSR) is presented and exemplified using various composite specimens after they have been tested by PT.

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Characterisation of the fibre volume content at the edge area of warm-formed holes in textile-reinforced thermoplastic components

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Textile-reinforced thermoplastics (TRTP) gain increasing relevance for lightweight structures in high volume applications due to their excellent mechanical properties and high potential for efficient manufacturing processes. For the assembling of TRTP components with other structural parts, high strength joints, e.g. bolts or rivets, are often necessary. The required holes are usually cut into the joined structures by drilling which leads to a local interruption of fibre reinforcement and thus to a reduction of the load bearing capacity in the joining zone. To avoid such a weakening, a special hole moulding technology was applied within the Collaborative Research Center (SFB) 639 which realigns the fibre architecture to the edges of the hole rather than disrupting it. As a consequence, remarkable improved mechanical properties are measured in joining zones with such moulded holes. In case of woven fabrics, the hole moulding process causes a characteristic fibre rearrangement with changing fibre orientations and an increased fibre volume content nearby the hole.

As the material properties of TRTPs are highly depending on the fibre orientation and fibre volume content, further research is necessary to understand the effects which lead to enhanced mechanical characteristics in the joining zones. For a precise representation of the material configuration, high resolution analysis of the gradual fibre volume content (FVC) nearby the holes was performed. FVCs are usually determined by cross-sectional microscopy, by wet chemical analysis, and by ignition loss. However, methods like the wet chemical analysis or ignition loss are limited to relatively large specimens to determine the fibre volume content. Other methods like the cross-sectional microscopy require large efforts on the preparation of the specimens. Novel testing methods concerning the determination of the fibre volume content by computer tomography (CT) are known for a couple of years but can't be considered as standard yet.

To determine the local FVC at the edge areas of a moulded hole with a high resolution, a study was carried out simultaneously using microscopy analysis, CT analysis and the ignition loss method by thermogravimetric analysis.

Therefore, 4 mm thick glass fibre reinforced polypropylene specimens with holes of 8 mm diameter were exemplarily investigated. The obtained data of the microscopy and CT analysis was evaluated by specific image processing algorithms. A comparison of the FVC determination methods shows that similar local FVC values and resolutions can be obtained with the CT and microscopy analysis. The local FVC determined by ignition loss also shows similar FVC values but a lower resolution. However, in terms of specimen preparation, the CT analysis is significantly effortless compared to both microscopy and thermogravimetric analysis.

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Noninvasive method for establish the diffused hydrogen content in Zirconium Alloy used in PHWR

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Pressurized Heavy Water Reactors (PHWR) contains a horizontal cylindrical vessel, named Calandria vessel, filled with D₂O used as neutrons moderator. The normal temperature of the moderator is 70°C. The ends of the vessel have holes in which fuel channels are inserted. One fuel channel is made from two concentric tubes:

- internal tube named pressure tube is made from Zr 2.5%Nb with 6.3m length, 105mm inner diameter and 4.15mm wall thickness
- external tube named calandria tube is made from Zircalloy 2.

Inside of the pressure tube the fuel bundle are inserted and between them D₂O circulates as coolant fluid with the maximum temperature of 270°C. The concentricity of the tubes is assured by 4 garter springs.

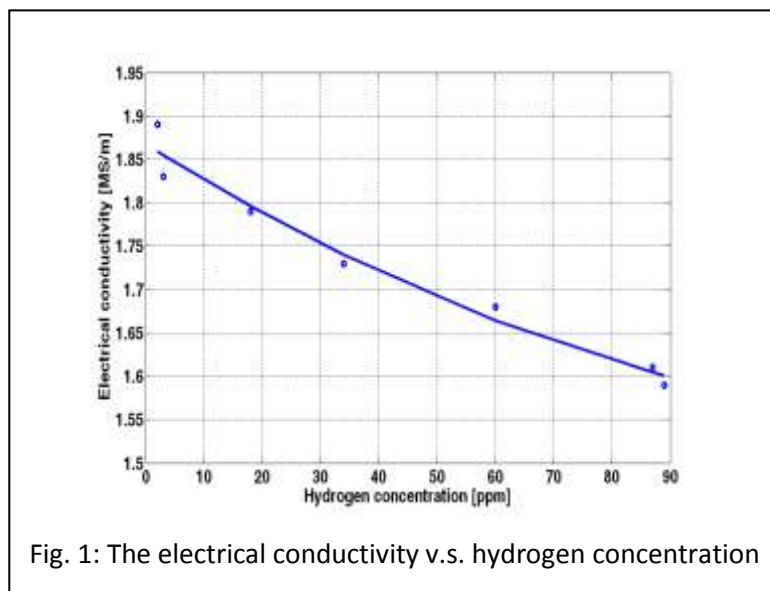
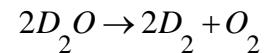


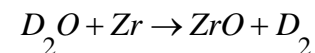
Fig. 1: The electrical conductivity v.s. hydrogen concentration

Two mechanisms of deuterium (hydrogen) apparition are possible:

- radiolysis of heavy water:



- corrosion of Zr 2.5%Nb alloy:



deuterium appeared may diffuse in the pressure tube's wall from the "hot" internal surface (270°C) and the "cold" (~100°C) external surface. If the deuterium concentration exceeds a certain threshold, the deuterium chemical combines with Zr: $Zr + D_2 \rightarrow ZrD_2$, resulting zirconium hydrides.

For determination of D₂(H₂) content for Zr

2.5%Nb alloy, an electromagnetic method has been proposed. This method determines the conductivity of Zr alloys with different quantities of absorbed hydrogen, the correlation between the electrical conductivity and hydrogen concentration being experimentally established. For a circular coil with rectangular cross section, closed form solution for the impedances are given in [1]. The ohmic resistance of the coil will be neglected. If Z_{air} is the reactance of the coil in air and Z is the reactance of the same coil placed at height h over an amagnetic conductive plate with H thickness and having local conductivity $\sigma(x_0, y)$

$$\delta Z(k) = \left(\sigma - \sigma_0 \right) \frac{\partial \theta(x_0, y_0, k)}{\partial \sigma} \Big|_{\sigma=\sigma_0} \quad (1)$$

where $\delta Z(k)$ the Fourier transform of the variation of the impedance.

$$\theta(x_0, y_0, k) = \frac{(\gamma^2(x_0, y_0) - k^2)(1 - e^{-2\gamma(x_0, y_0)H})}{(\gamma^2(x_0, y_0) + k^2)(1 - e^{-2\gamma(x_0, y_0)H}) - 2k\gamma(x_0, y_0)(1 + e^{2\gamma(x_0, y_0)H})} \quad (2)$$

Take inverse Fourier transform of (1), we can write

$$\delta z = U \delta \sigma \quad (3)$$

By inversion of (3) we can determine the local modification of the electric conductivity of material.

10 coupons from pressure tubes with 28x28x4.18mm³ have been taken into study with hydrogen content between 2 and 89ppm. In figure 1 is presented the electrical conductivity of samples in function of hydrogen content. When $\sigma \leq 1.68 \text{ Ms/m}$, the development of the Zr hydrides oriented after a circumferential direction of pressure tube wall is possible. When $\sigma \leq 1.61 \text{ Ms/m}$, the Zr hydride start to change orientation after radial direction. In this situation blisters and hydrogen cracking is possible to appear.

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Improving TOFD sizing of near surface defects by wavelet transform

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It is well known the limitation of the TOFD technique in accurately sizing near surface defects, since the longitudinal diffracted echo from the defect tip superimposes with the lateral or the back wall wave. Indeed, in the cases where there is not enough time resolution between the lateral wave and the diffracted crack tip close to the specimen surface accurate defect sizing is difficult and even uncertain. This same reasoning can be applied to the defect with bottom tip close to the opposite back wall surface. In literature, it is usually assumed that when the material under test contains defects, there will be a 180° phase difference between the diffracted signal at the top of the defect and the lateral wave as well as a 180° phase difference between the diffracted signal from the bottom of the defect and the back wall reflected wave. These ideas led us to suppose that application of the Wavelet Transform could be an efficient tool to separate these two waves enabling a more accurate defect sizing. In order to confirm these suppositions the ultrasonic spectral analysis of echoes from the lateral, back wall and diffracted crack tip waves where experimentally obtained and compared. We observed that the general aspect of the frequency spectrum distribution was clearly different for each echo, supporting our assumption that Wavelet Transform could be applied with some chances of success to solve the above mentioned problem.

The experimental part of this work is twofold. In a first approach we employed 25mm steel butt welds containing lack of fusion defects inspected by an ultrasonic TOFD technique using two broad band 70° 10MHz transducers. Several A-scan signals were acquired in the defective region and the Fast Fourier Transform was applied. As expected, the four waves analyzed: lateral, back wall, upper and bottom crack tips diffraction waves exhibited a clear difference in their frequency spectra. Then a complete ultrasonic TOFD inspection was simulated using the CIVA software. The virtual solid was a butt weld, 25mm thick, containing a 4 mm vertical near bottom surface defect. The defect/surface ligament was small enough to prevent that the bottom crack tip defect and the back wall signals could be separated in the TOFD image. A routine was developed using the Matlab Wavelet Toolbox. The Wavelet Transform was applied to a set of simulated A-scan signals obtained by scanning the entire defective area. The “Discrete Meyer” wavelet displayed the best results in the CIVA scenario, enabling a complete separation of the two waves. To validate this simulation, a real steel butt weld containing a root defect, whose signal was unable to be separated from the back wall one was employed, in a real regular TOFD inspection. Again the Wavelet Transform using the “Discrete Meyer” mother wavelet was successfully applied to clearly separate the root defect from the bottom plate surface in the TOFD image.

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The application of information processing techniques towards an effective on line prognostic scheme for rotating machinery

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The scope of this study is to examine the prognostic capability of multisensory and multiparametric monitoring of rotating machinery. The experiments were performed on a back to back test gear pair which was run continuously from an initially healthy condition until its complete breakdown. The multisensory data collected included an oil debris sensor recordings that measured the quantity of iron particles inside the lubricant, vibration and acoustic emission sensor recordings. The combination of the latter has provided a single hyper-parameter with prognostic capabilities.

Consequently several approaches are considered in order to assess the potential of one and three step-ahead prediction of the level of the hyper-parameter based on approaches that can cope with the non-stationary, non-linear stochastic nature of this hyper-parameter. These include the application of stochastic AR/GARCH modeling, and Artificial Neural Networks. The ability of each method to model and consequently follow the time evolution of this hyper parameter is assessed.

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Comparison of synthetic and real data to understand the problems in measuring the reinforcement diameter with high-frequency GPR

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According to some authors, high-frequency GPR can provide on-site non-destructive measurements of the diameter of concrete reinforcements. The procedure should be based on the analysis of radar energy scattered by reinforcements when illuminated with parallel and perpendicular polarization. The theory of Radar Cross Section (RCS) supports this assumption. However, laboratory test performed on concrete specimens indicate that many practical problems must be solved to obtain reliable and stable measurements from real data. Synthetic data were used to analyze the problem in order to determine the most critical issues that affect the whole measurement procedure. The data processing sequence was accurately studied to obtain the best fit between synthetic results and theoretical expectations. Later, the same processing sequence was applied to real data collected on laboratory specimens. Results were less encouraging. The comparison with synthetic data was essential to understand that background subtraction is the most critical issue. Unfortunately, the methodology needs radar data in the frequency range of 1-2GHz. In this range, the background wave is still disturbing the radar signal scattered by the target. As a result, background subtraction is absolutely essential and extremely delicate. According to simulations, this problem is of larger importance than the fact that commercial GPR systems generate wide band radar pulses while RCS theory is frequency dependent.

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8:30-9:10 Plenary Session 2

Visualized Impact-Echo Technique for Defects in Concrete by SIBIE Procedure

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In the impact-echo method, spectra analyzed often contain so many peak frequencies that it is fairly difficult to identify resonant frequencies associated with locations of defects in practical applications. Stack Imaging of Spectral Amplitudes Based on Impact-Echo (SIBIE) is developed to improve the impact-echo method and to visually identify locations of defects in concrete. Case studies of the SIBIE procedure are presented and discussed for on-site measurement in concrete structures. To identify ungrouted post-tensioning ducts in prestressed concrete, a feasibility study was conducted in model structures. For voids and surface cracks in delaminated zones between concrete piers and pre-stressed concrete panels covered, on-site measurement was successfully performed. For the case of surface cracks sealed, both depths of repaired layer and existing cracks could be identified. All results demonstrate that defects in concrete structures can be visually identified with reasonable accuracy by the SIBIE procedure.

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Session 5A: Electrical & Optical Methods for NDE

Keynote Lecture:

Dynamic fibre Bragg grating based health monitoring system for composite aerospace structures

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The needs for Structural Health Monitoring (SHM) in the aerospace industry are rapidly increasing due to demands to improve safety, reduce cost and inspection time, while maintaining structural integrity and reliability. The main purpose of the present work is to develop an innovative system for structural health monitoring of aerospace composite structures based on real-time dynamic strain measurements. The dynamic response of typical aerospace structures (stiffened aircraft panel, composite sandwich panel and space lightweight antenna sub-reflector) measured using fiber Bragg grating (FBG) dynamic sensors. Damage is simulated by slightly varying locally the mass of the structures at different zones, or by introducing a real damage in the form of delamination and/or fiber breakage.

Finite element model of the structures has been developed to simulate the dynamic behavior based on the modal superposition principle. The numerical model was calibrated against experimental results, and it was used for the optimization of the placement of the FBG sensors. The proposed damage detection algorithm utilizes the collected dynamic response data, and through various levels of data processing, an artificial neural network identifies the damage size and location. Feature extraction is the first step of the algorithm. Novel digital signal processing techniques, such as the wavelet transform, are used for feature extraction. The extracted features are effective indices of damage location and its extension. The classification step comprises a feed-forward back propagation network, whose output determines the simulated damage location. Finally, dedicated training and validation activities are carried out by means of numerical simulations and experimental procedures. Potential applications for the proposed system are for SHM during operation as well as during ground qualification extensive tests of space structures and during the mission, for the spacecraft monitoring. Furthermore, embedded FBGs have been used in the case of composite plates, in order to explore the combined capabilities of the proposed system to address the curing monitoring of the composite plate, to perform the qualification/approval tests and to monitor the integrity of the structure during its operating life.

It has been proven that dynamic FBGs can serve with success the full span of composite panels monitoring needs, from the manufacturing stage, until the end of its life.

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Electric and Magnetic Brain activity: Distinct or Common information

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Electroencephalography (EEG) and Magnetoencephalography (MEG) provide the two basic methods for the study of the functional brain. A fundamental question, that was open for a long time, concerns the independence of the information carried by these two methods. An answer to this question is reported here. In fact, based on the mathematical analysis of the corresponding models, we show that complete independence appears only in the unrealistic spherical model, while in any other realistic geometry fitting the human brain, there is a partially overlapping information. A probable cause of this ambiguity of overlapping information is the fact that in most clinical applications the spherical model is used, although the actual data never come from a perfect sphere. On the other hand, there is no case where either of the two sets of data is recoverable from the other. That is the data are at least partially independent. The analysis is based on appropriate expansions of the neuronal current in vector spherical harmonics, in terms of which the necessary techniques become simple and clear.

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Non Destructive evaluation of artificially induced damage in composite structures using Electrical Resistance/Potential Mapping

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Since delaminations of composite laminates are usually invisible or difficult to detect by visual inspections, delamination causes low reliability for primary structures. Automatic systems for delamination identifications in-service are desired in order to improve this low reliability. At the present work electrical potential technique was applied to detect and locate artificial damage in carbon fiber reinforced polymer (CFRP) patched plates. The potential distribution across the surface of the laminates was measured using a grid pattern of 117 electrical contacts on several topologies. A constant current of 1 A was applied to the plate, and the changes in the potential distribution between the virgin plate and five scenarios of damaged plates documented and presented graphically in order to find out the best topology. Simultaneously a finite element study realized for the same scenarios and using a fine-tuned Matlab visualization code we were able to identify the location and geometry of the artificial damage for all damaged scenarios.

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Damage sensing of carbon nanotubes embedded glass fiber composites based on electrical resistance change

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Application of composites in the primary structural parts such as aircrafts or wind turbine blades involves a great deal of mechanical joining to form a final structure. Therefore, it is essential to monitor the critical status of the joints related to the overall durability and performance of the structure. Carbon nanotubes acting as an electrical conductive network is utilized to detect the damage evolution and state in unidirectional glass fiber reinforced composite joints. In order to sense the damage evolution in the matrix, the double-lap tension test with two different electrode configurations in the longitudinal direction (LD) and transverse direction (TD) was performed. There are three stages in the change in resistance before the peak load. Initially the resistance change increase

steadily, then rapidly and back to a steady increase. These steps correspond to the elastic deformation, the microcracks initiation/growth in matrix, and the saturation of crack density.

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Electromagnetic Wave Absorbing Properties of Composites with Hollow Magnetic fibers

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Hollow magnetic fibers with different lengths were successfully prepared by an electroless plating method and a proper heat treatment process. The hollow structure lowers an apparent density of composite absorbers when the fibers are added at the same volume fraction as conventional solid magnetic fibers. Therefore, these fibers can be utilized as effective filler for the lightweight electromagnetic (EM) wave absorbing materials. The characterization of surface morphology, fiber length and elemental compositions were performed by SEM and EDS analysis. The result showed that the fibers which mainly consisted of nickel, iron and cobalt had a diameter of about 3.5 μm and a shell thickness of approximately 1 μm . The fiber length was controlled by varying a length of substrate polymeric fibers using a fiber cutting machine. Composite absorbers including the hollow fibers with different fiber lengths were fabricated and the complex permittivity and permeability of composite absorbers will be investigated using a network analyzer in the range of several GHz frequencies. Through the result, optimal design for the high reflection loss (dB) will be carried out to achieve an efficient EM absorbing performance. In addition, simulation results and experimental measurement of reflection loss will be compared.

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Session 5B: Non-linear NDT I

Keynote Lecture:

Remote nonlinear photoacoustic imaging of cracks

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In the most common form of photoacoustic imaging, the light intensity is modulated periodically and the acoustic signal is detected at one of the frequency components of the modulation spectrum. We have recently described [1-3] a particular realization of photoacoustic imaging based on the detection of such frequency components of the acoustic signal which are absent in the spectrum of the light intensity envelope, and can be generated only due to some nonlinear processes contributing to the photoacoustic conversion. We term this microscopy “nonlinear photoacoustic imaging”. The nonlinear processes can be caused by the dependence of the physical parameters of the system on laser intensity, material temperature and material deformation.

Correspondingly, the contrast in nonlinear photoacoustic imaging is due to inhomogeneity in nonlinear physical parameters based on intensity, strain or temperature derivatives [4-6]. In the first experiments [1,2] the nonlinear frequency-mixing photoacoustic imaging of cracks through excitation of acoustic waves by two lasers intensity-modulated at two different fundamental frequencies, combined with piezoelectric detection of acoustic waves at mixed frequencies has been achieved. By exploiting the strong dependence of the photoacoustic emission efficiency on the state—open or closed—of the contacts between the crack faces, remarkably enhanced image contrast is observed, ~ 20 times higher than linear photoacoustic images at the highest of the fundamental frequencies. The threshold nonlinear acoustic phenomena were observed [2] similar to those, that have been earlier documented in purely acoustic experiments in cracked glass [7]. The one-dimensional theory attributing the experimental observation of the large number of nonlinear acoustic spectral components (mixed frequencies) to strong bimodular nonlinearity of the crack has been developed [8]. In this communication we present experimental results demonstrating for the first time that nonlinear photoacoustic imaging can be accomplished remotely (opto-acousto-optically) by performing both generation and detection of acoustic waves by lasers. We demonstrate that for the excitation of the acoustic waves, a single laser could be modulated independently at two different frequencies without spurious cross-talk.

We demonstrate how the observed phenomena of the oscillating dependence of the amplitude of the mixed-frequency acoustic components on laser intensity can be understood qualitatively in the frame of the simplest theory [8]. We present a possible extension of the theory [8] to the three-dimensional case, which is necessary for the adequate description of the frequency-mixing phenomenon in case of sharp focusing of the laser radiation, and also in order to extract, quantitative information on the parameters of the crack.

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Filters, Transducers, and Receivers for Nonlinear Measurements

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Measurements of the nonlinear properties of materials frequently require examining very small amplitude harmonics in the presence of a large amplitude fundamental frequency. This requires careful control of the receiving system to maximize the signal-to-noise ratio and reject the fundamental frequency. This can be accomplished by using transducers made from linear materials such as Lithium Niobate, appropriate rigid bonds for both transmit and receive transducers, carefully designed filters, a frequency selective receiver, and either digital or analog signal processing techniques. The advantages and difficulties of implementing each of these methods is discussed and examples are given.

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Finite element simulations of the nonlinear dynamic response of closed delaminations and surface breaking cracks in composite materials

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Early stage delaminations in composite materials tend to be closed at rest. Inspection with traditional linear ultrasonic techniques generally fails to diagnose and locate such imperfections. However, if undetected and left untreated, incipient defects may gradually grow within the material and eventually lead to the failure of the component. Kissing bonds or clapping contacts inherently demand a nonlinear diagnostic method, applying a finite excitation amplitude that is able to overcome an activation threshold to open and close the contact.

In order to obtain a better understanding and analysis of the macroscopic nonlinear behavior that can be observed at the component level, we developed and investigated the results of a finite element model for a composite material containing a delamination. The model makes use of local node splitting and the non-linear constitutive behavior is implemented by means of spring-damper elements with local activation thresholds at the delamination interface. Numerical experiments show that subharmonics and harmonics of the excitation frequency are generated by the clapping delamination if the excitation amplitude is large enough to overcome the local activation threshold. The results of an intensive parametric study also show that the shape, position, depth and orientation of one or multiple delaminations can be determined by studying the excited subharmonic and harmonic frequencies and the corresponding amplitude patterns. To increase the signal-to-noise ratio of the detected nonlinear contributions, sweep signals can be used in combination with the scaling subtraction method. Moreover, the model can be easily adapted to consider the influence of e.g. surface breaking cracks instead of delaminations.

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Defect localisation using the nonlinear impact modulation technique

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In materials with defects, the defect zone can be considered as a source of nonlinear wave propagation. As a result of the local nonlinearity in the stress-strain relation at the position of the defect, (sub)harmonics of the fundamental source frequencies are being developed. Other effects may include amplitude dependent resonance frequency shifts and attenuation. Further, when two frequencies are emitted, nonlinearity will cause inter-modulation components that appear in the spectrum as sidebands (sum and difference frequencies). As –in practice- the appropriate choice of the two emitted frequencies is sometimes difficult, an alternative consist in the combination of an excitation of the sample by an impact and a simultaneous probing by a high frequency CW signal. The impact excitation results in the activation of a set of resonance modes with characteristic stress-

patterns. If the anti-nodes of the stress pattern of a particular mode coincide with the defect zone, and the amplitudes are large enough to activate the nonlinearity of the cracks, the high frequency probing signal will be modulated by this particular mode, and sum and difference frequencies will appear in the spectrum of the received signal. The effective level of nonlinearity for the different modes can be analyzed using a moving window analysis of the low frequency, sideband and high frequency components for various levels of high frequency probing energy. As not all excited resonance modes activate the cracked zone in the same manner, the measured level of nonlinearity depends on the mode structure. A weighted sum of the stress-patterns of the resonance modes by means of the nonlinearity sensitivity provides an indication of the location of the defect. Preliminary experimental evidence of the use of this global technique to engender localization of defects will be provided.

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Characterisation of metallic film in a high-pressure diamond anvil cell by a laser ultrasonic technique

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The evaluation of elastic properties of the materials under high pressures in a diamond anvil cell (DAC) is necessary for the industrial, geophysical and astrophysical applications. Meanwhile, the use of piezoelectric transducers in a DAC is quite complicated task due to relatively small volume of the sample under study and the presence of confining medium, i.e. diamond anvils. For this reason, laser optoacoustic technique [1, 2], allowing the excitation and the detection of ultrasound directly in the sample under high pressure without mechanical contact, looks very promising [3-6].

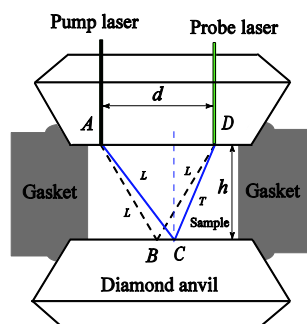


Figure 1. Scheme of the LU-DAC technique. The rays ABD and ACD correspond to longitudinal and longitudinal mode-converted into shear acoustic pulses propagation.

The acoustic echoes are excited by the laser pulses of 750 ps duration (Fig. 1). Contactless detection of acoustic pulse is achieved using 1 GHz bandwidth photo-detection of reflected CW probe laser radiation. The signals are visualised with an oscilloscope of 3 GHz bandwidth. Loading of the sample surfaces by diamond increases both the efficiency of laser-induced thermoelastic generation of acoustic waves and the efficiency of their acousto-optic detection at iron/diamond interfaces. In comparison with picosecond laser ultrasonics [6], our realisation of laser ultrasonic technique provides important opportunities in the measurements of the velocities of shear acoustic waves and of the sample thickness.

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Session 6A: On-Site Measurement and Monitoring by NDT in Infrastructures I

Keynote Lecture:

Damage Identification of PC Cable Breakage by means of Acoustic Emission

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Corrosion-induced cables' breakage reported frequently in post-tensioned PC structures, sometimes leading to eventual failure. As deterministic investigation techniques have yet to be proposed, the authors propose one strategic way based on acoustic activity. When the cable ruptured, elastic energy could be released as elastic waves: namely acoustic emission (AE). Identification of the breakage could be carried out with detecting AE waveforms, by implementation of source location algorithm. As for the existent breakage, the location could be determined by extracting the secondary AE activity as well. In the present study, these AE activities i.e., primary and secondary AE activities are experimentally produced systematically using a full scale PC beam. Thus, the fracture/ fractured areas are quantitatively identified by AE activities. In the experiment, tensile stress applied to PC cables was reduced in sequence, where AE activity and source-location were monitored in time domain. As a result, the fractured zone is specified, as well as fracturing areas with time. Subsequent to the stress release from each of the cables, the beam was subjected to four-point bending with an incremental cyclic manner. The broken areas are estimated by the secondary AE activity generated due to friction between cables and grout agent. In addition, AE parametric features relating closely to the fracturing behavior are discussed to apply the proposed AE technique to in-situ investigation.

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Influence of the fiber chemical coating on the fracture behavior of steel fiber concrete measured by acoustic emission

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Inclusion of steel fibers is an effective way to reinforce the brittle nature of concrete. In order to achieve maximum mechanical properties and especially toughness, chemical coating of the fibers is applied. Suitable agents improve the bonding between the stiff fiber and matrix enabling more efficient stress transfer. In the present study specimens with different shape of plain and chemically coated steel fibers are subjected to four-point bending with concurrent monitoring of their acoustic emission (AE) activity. Specific AE parameters demonstrate that coating offers distinct characteristics to the interphase especially after the maximum load has been reached. Parameters like average frequency (AF) and the rise angle of the waveforms, which are used for cracking mode classification, indicate that the post peak behavior of specimens with chemically coated fibers is more closely related to matrix cracking, while uncoated exhibit clear shear behavior due to pull-out. It is concluded that coating effectively contributes to the deflection of the cracks from the fiber-matrix interphase into the concrete matrix, increasing the absorbed fracture energy as revealed by the increased mechanical toughness of the coated fiber specimens. AE analysis sheds light into the fracturing behavior of concrete in real time, in a way that is not possible by any other conventional measurement.

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Onsite measurements of concrete structures using Impact-echo and Impulse Response

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Concrete structures deteriorate, often unnoticed, and in worst case the damages are visible until it is too late for a repair or the repair will be extensive and costly. The use of NDT technology can provide valuable information of the current condition of a concrete structure and can be a valuable help planning the maintenance of a structure.



Figure 1. Impulse Response Testing on Evripos Bridge, Greece (left) and Impact-Echo, Demark (right)

The use of NDT can also be a strong tool during the construction phase for quality assurance of the structure. Especially for complex or hidden or embedded structures as e.g. control of the injection quality of cable ducts. Hidden faults or flaws can be detected early and can be remedied while access to the structure is still possible without major inconvenience for the future users.

Special inspections combining a visual survey and various NDT techniques such as e.g. the Impulse Response or Impact-Echo can disclose problems at an early state and provides valuable information of the actual condition of the structure. The use of NDT cannot be used to evaluate a structure without a thorough calibration of the equipment onsite e.g. by drilling of cores. This operation is a vital part of performing NDT.

This paper presents some typical testing cases where NDT has been used on bridges and buildings with emphasis on the advantages and limitations of the techniques. See Figure 1. The cases show how flaws and faults on bridges such as poor bonding at interfaces between, asphalt, membranes and concrete on bridge decks or between the original concrete can be discovered as well as the presence of ASR. Also how quality assurance of injected cable ducts can be conducted.

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The Asinelli Tower in Bologna (Italy):

Acoustic Emission Monitoring under Environmental Actions

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This study concerns the structural stability of the famous “Torre degli Asinelli” in Bologna. This building is the tallest and, with the Garisenda tower, the most undisputed symbol of the City. Asinelli tower is 97.30 m tall, and has a square section vertically tapered, with sides of about 8.00 m at the base, and 6.50 m at the highest level. The wall thickness ranges from 3.00 m at the foundation level to 1.00 m at the top. The tower can be divided in elevation into four sections depending on the type of masonry. The bearing walls consist of solid masonry at the base and at the highest level, while in the middle section it is *a sacco*. The tower leans of 2.23 m towards west, for this reason it is known as the Italy’s highest leaning tower.

The preservation issues of the Italian cultural heritage monuments, and particularly those related to the masonry towers, were often linked to an extensive and heated debate involving the public authority, specialists in structural and geotechnical disciplines, scientists in theories and techniques of restoration. Assessing the structural safety of these constructions is a complex problem, which must be addressed by interpreting their environmental and loading conditions and the constituent materials characteristics. In this connection, greater importance is attached to the adoption of innovative and highly advanced monitoring techniques.

To analyze the stability conditions of the tower the Acoustic Emission (AE) technique was used. This approach is particularly effective when it is necessary to analyze the influence of repetitive or impulsive phenomena – such as the vehicles traffic actions, or the effect of wind and earthquakes – on the damage evolution of a structure. The AE monitoring began on September 23, 2010 and ended on January 28, 2011. Six AE transducers were applied in the south-east corner of the tower, at an height of about 10.00 m from the ground, just above the colonnade surrounding the tower, where the structural masonry is *a sacco*. Finally, to formulate a more comprehensive assessment of the tower conditions, the AE results were compared with those obtained by measuring the acceleration and the speed of vibration generated by vehicle traffic. Their nonuniform movements, with alternation of acceleration and deceleration can amplify the effect of vibrations and generate damage in the masonry.

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Visual inspection and evaluation using NDT testing methods of industrial building after fire

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The object of the present study was the evaluation of the condition of an industrial building, after a fire, and the assessment of the damages that were caused by the fire to the concrete elements of the support structure. The purpose of the study was the determination of the extent of the damages that were caused by the fire and the estimation of the condition of the structural elements after the fire. For this purpose, all the structural elements

of the building were visually inspected. Afterwards, taking into consideration the observations of the visual inspection, further tests were carried out, using direct and indirect ultrasound velocity measurements, reinforcement cover depth measurements and concrete cores cutting. The objective of the study was the evaluation of the condition of the elements that appeared seriously damaged and were considered dangerous for the structural integrity of the construction and the confirmation of the good condition of the elements that appeared to have minor damages by the fire.



Fig. 1: Direct ultrasound pulse velocity measurement (left) and reinforcement cover depth measurement (right)

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Session 6B: Non-linear NDT II

Imaging multiple defects in solids by means of selective source reduction and time reversed acoustics

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Time reversal techniques are routinely used to identify sources of energy and/or scattering in medical applications, seismology and linear acoustics NDT. Inherent limitations of the traditional time reversal process in the case of multiple sources or scatterers make it difficult to distinguish the scattering sources individually. The selective source reduction (SSR) method employs a subtraction technique to selectively suppress in amplitude (and ideally eliminate) a time reversed focal signal that is masking another focus. In previous work, Scalerandi et al. and Anderson et al. successfully applied the SSR method to identify masked primary sources in a fully linear medium. Here, we extend the capabilities of the SSR method to deal with 1) secondary sources (for example scattering caused by embedded defects) and 2) nonlinear scattering generated during the ultrasonic wave propagation as well. We call this new method SSR-NLTRA (Selective Source Reduction based on Nonlinear Time Reversed Acoustics). In the extended approach, the contribution of all primary sources is first eliminated by means of the scaling subtraction method. Subsequently, the SSR-TRA method is applied to the remaining nonlinear content of the signals. We show by means of 2D wave propagation simulations that the new method can be applied iteratively to successfully image multiple masked nonlinear defects.

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Multi-frequency defect-selective nonlinear imaging and NDT

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The nonlinear approach to ultrasonic NDT (NNDT) is concerned with nonlinear response of defects, which results in frequency conversion up- and down the spectrum of the original input signal. These spectral changes are caused by anomalously high nonlinearity of micro- and macro-scale defects. The intact parts of the material outside the defect vibrate linearly, i.e. without frequency variation in the output spectrum. Thus, in NNDT, a small cracked defect (transparent in a linear ultrasonic NDT) behaves as an active radiation source of new frequency components rather than as a passive scatterer in conventional ultrasonic testing. This makes NNDT a unique defect-selective instrument for localising and imaging of nonlinear flaws. The latter include a numerous class of contact defects, scaled from dislocations (nano-scale) to fatigue (micro-) cracks and macro-debonds in joints.

In this paper, basic mechanisms responsible for frequency conversion by nonlinear defects are discussed and major features of the nonlinear spectra demonstrated. Experimental methodologies of nonlinear scanning laser vibrometry (NSLV) and nonlinear air-coupled emission (NACE) are used to study nonlinear elastic wave-defect interactions. An inherent multi-frequency capability of the nonlinear spectra is applied to automation and NSLV image processing. New opportunities of air-coupled ultrasound in nonlinear acoustics of defects are shown by using experimental methodology of NACE. The major features of the NACE radiation patterns are revealed in experiments and supported by a 2D-theoretical model. The benefits of feature extraction from nonlinear acoustic images of defects are demonstrated in 3D-NACE experiment. Applications for defect-selective imaging and NNDT are demonstrated for a series of hi-tech materials and industrial components.

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Exploiting time reversal principles for the accurate determination of material velocities

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In view of applying hybrid numerical-experimental NDT techniques (for instance 'time of flight diffraction', or 'phased array' studies) some particular object and material parameters need to be identified. Apart from the density and the geometry, it is critical to know the velocities and/or velocity distribution of the sample under consideration.

Based on traditional time reversal (TR) principles, and the signal dilatation and contraction method developed by Griffa and Scalerandi, we developed a new automatic procedure for the determination of the (isotropic) longitudinal and shear material velocities. The method requires a single recorded signal as input, together with a (crude) estimation of the longitudinal velocity. Density and geometry are assumed to be known exactly, as well as the position of excitation and recording. Iteration of this TR based procedure allows to determine velocities with an accuracy better than 0.5%. Results are presented for a 3D numerical "blind" test case and for an application involving experimentally recorded data.

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Nonlinear frequency-mixing photoacoustic imaging of a contact

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The first nonlinear frequency-mixing photoacoustic experiments with cracks [1, 2] have provided very promising results for the purpose of non-destructive testing. Meanwhile, the parameters of naturally produced cracks, necessary for the testing of the theoretical models [3] are usually unknown. To avoid this problem, we propose here to use the contact between a cylindrical lens and a light-absorbing plate and its edges for mimicking some of the crack features. The variable forces applied to the lens allow us to change the parameters of the contact (Fig. 1a). The nonlinear photoacoustic imaging is performed using heating of the of the contact zone by two cw laser beams modulated at very different frequencies ($f_L \ll f_H$). The acoustic waves at mixed frequencies $f_H \pm n f_L$ ($n=1,2,\dots$) are then detected by an accelerometer connected to a spectrum analyser.

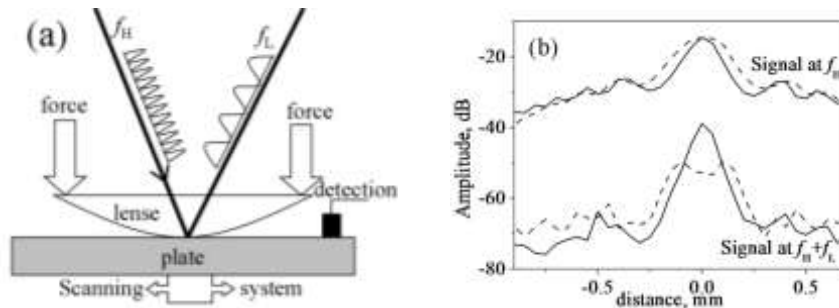


Fig. 1 (a): Experimental set-up; (b) Photoacoustic signals at f_H and $f_H \pm f_L$.

1D imaging of the contact zone at fundamental component f_H and first sidelobe $f_H + f_L$, is achieved by the displacement of the plate (Fig. 1b) relative to the laser beams. The spatial resolution is limited by the size of laser focal spot. The contrast of an image at $f_H + f_L$ is about 10 dB higher than the one at f_H when the contact is practically unloaded (solid line). Significant drop of the photoacoustic signal amplitude in the central part of the image is observed when a force is applied (dashed line). This observation is in agreement with the theoretical expectations [3]. It is remarkable that the amplitude of the photoacoustic signal at f_H does not practically change during the application of the force.

The oscillations in the signal at f_H due to the optical interference at the surfaces of lens and light absorbing plate provide information about the distance between the walls of the contact. The width of the image at fundamental frequency should allow us to calibrate the value of the applied force. Studies on the influence of surface quality

on nonlinear photoacoustic frequency-mixing are planned. The knowledge of elastic, optical and geometrical properties of the plate and lens allows the characterization of the contact and the testing of various theoretical models of nonlinear photoacoustics phenomena through the quantitative comparison of the theoretical predictions with the experimental data.

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Session 7A: On-Site Measurement and Monitoring by NDT in Infrastructures II

AE Monitoring of Shrinkage Process in Concrete

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Shrinkage cracking is one of major problems in concrete structures at early ages. Although shrinkage is a well-known phenomenon in fresh concrete, early-age cracking is recently a great issue in Japan. It is found that the effect of aggregate is the key factor, because the constraint due to cement matrix should affect the volumetric change of aggregate. Accordingly, on-site monitoring of shrinkage cracking by nondestructive testing (NDT) is to be promptly developed. This is because shrinkage cracking is recently highlighted in Japan, because of the use of coarse aggregate of low quality.

Consequently, an application of AE monitoring to shrinkage process in concrete is studied. Two types of experiments were conducted. One is the monitoring of shrinkage process in concrete of three kinds of aggregate. These were granite of low porosity, weathered andesite of high porosity and simulated aggregate of alumina balls. Reasonable agreement is demonstrated between AE activity and shrinkage strain. In the other experiment, the shrinkage mechanisms are studied, applying AE-SiGMA analysis. Conducting experiments of shrinkage in concrete with steel-ball inclusion, the mechanisms are clarified as micro-crack evolution process

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Evaluation of Acoustic Emission Behavior during Corrosion Process in Reinforced Concrete with EPMA

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Deterioration of reinforced concrete (RC) due to salt attack is known as one of serious problems. Thus, development of non-destructive evaluation (NDE) techniques is important to assess the corrosion process. Reinforcing steel-bar (rebar) in concrete normally does not corrode because of a passive film on the surface of rebar. When chloride concentration at rebar exceeds the threshold level, the passive film is destroyed. In the case, maintenance is desirable at an early stage. In this study, to identify the onset of corrosion and the nucleation of corrosion-induced cracks in concrete due to expansion of corrosion products in rebar, continuous acoustic emission (AE) monitoring is applied to a cyclic wet and dry test of RC specimen. The AE parameter analysis such as RA value and averaged frequency and *I_b*-value is applied to AE parameter to evaluate the corrosion process in RC. Monitoring the corrosion process of rebar by AE, it is confirmed that the onset of corrosion and the nucleation of corrosion-induced cracks in concrete are successfully identified. Then, generating behaviors of corrosion process in concrete are evaluated by the AE parameter analysis. Additionally, cross-sections inside the concrete specimen are observed by an electron probe micro analyzer (EPMA). Results of AE parameter analysis are compared with the corrosion mechanisms observed at the inside of the specimen by EPMA. From these results, a great promise for AE techniques to evaluate corrosion process in concrete due to expansion of corrosion products at an early stage in RC structures is demonstrated.

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Mesh-Independent Ray-Trace Algorithm for Concrete Structures

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Seismic Tomography is one of the non-destructive techniques. This method intends to determine the material parameter distribution from differences of observed and theoretically computed information by an identification procedure. First travel time is frequently chosen as the information for the seismic tomography and a ray-trace algorithm is one of the methods to obtain it. Generally, the ray-trace algorithm needs to subdivide the structures into cells and associates material property to each cells or nodal points and represents ray-paths as straight lines that connect two nodal points. These facts reveal the resolutions of the ray-trace and the material parameter distribution depend on the mesh of the structures. The ray-trace gives more accurate result on fine meshes, however the number of degrees of freedom increases under fine meshes and consequently it causes over fitting of material parameters in identification procedure since the number of observation data is limited in general. This is a trade-off of the accuracy of ray-trace and identification, and it suggests that the result of the ray-trace can be independently improved by using mesh-independent ray-trace algorithm. Therefore, in this paper, mesh-independent ray-trace algorithm is introduced in two-dimensional manner. This method actualizes mesh-independency of the ray-trace by installing relay points in the cells. The relay points should be installed uniformly in the cell and isoparametric mapping of the cell coordinate is adopted to full fill the uniformity. Author has been studied ray-trace algorithm for the structures that have irregularity in its shape, and the coordinate system of individual cells are isoparametrically mapped to cells of regular shape such as square in the method to detect the intersection of the cells and ray-paths. This isoparametric mapping is commonly used for finite element analysis and the guarantee of the uniformity of the installation of the relay points are approximately fulfilled by placing the relay points regularly in the mapped cell. The number of the relay points can be controlled by a parameter and the resolution of the ray-trace can be determined individually in each cell. Furthermore, it is noteworthy that pre-processor for finite element analysis is available for preparing the mesh data in this algorithm since the same isoparametric mapping with finite element analysis has been adopted. This algorithm overcomes the limitation of the trade-off of the resolution of ray-trace and identification and the feature and applicability has been verified with some examples

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Visual Inspection and Evaluation using NDT testing methods of extensively cracked concrete floor

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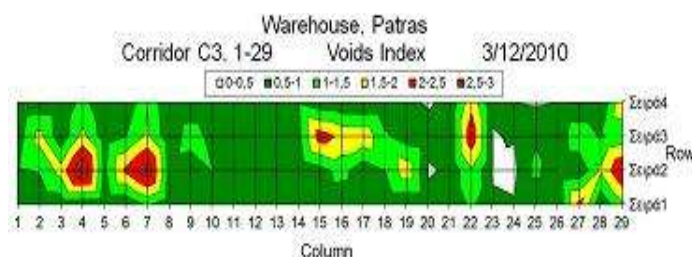


Fig.1. Impulse Response on Evripos Bridge, Greece (left) and Impact-Echo, Demark (right)

The scope of the present study was on one hand the estimation of the state of the cracked floor using nondestructive evaluation methods and on the other hand the inspection of the underlying layers of the where the floor was based. The study comprised: (i) Systematic recording of the cracks in terms of position, size and

width, (ii) definition of the crack depth using ultrasonics, (iii) existence of voids between the floor and the underlayer using the Impulse – Response method, (iv) definition of the floor thickness using the Impact – Echo method and (v) quality check of the condensation and the quality of the underlayer. The aim of the study was the investigation of the extensive cracking in order to define the optimum restoration strategy and predict where attention must be paid during the construction.

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Quantitative Evaluation of Impact Force on Impact-Echo Method

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The impact-echo method is very well-known as a non-destructive testing for concrete structures. It is based on the use of low-frequency elastic waves that propagate in concrete to determine thickness or to detect internal flaws in concrete. The impact echo method consists of three stages as applying the impact, detecting waves, and identifying peak frequencies. Each stage has an associated problem. The upper bound frequency due to Impact should be higher than resonance frequency due to defects. Secondly, the frequency response of receiving device of sensors should cover the frequency range. Thirdly, frequency spectrum normally contains many peak frequencies. In this study, the impact force caused by aluminum bullet and characteristic of acceleration sensor are identified by theoretical analysis based on Lamb's solution. In addition, results of SIBIE (Stack Imaging of spectral amplitudes Based on Impact Echo) analysis are discussed with respect to defect depths and the frequency range for the measurement.

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Session 7B: Electrical Methods for NDE

Disorder to Order Transition and Functionality in Polymer Matrix – Barium Titanate Nanocomposites

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Composite systems consisting of a polymer matrix with embedded ferroelectric ceramic particles represent a novel class of engineering materials, which recently receives an increasing research interest. This type of materials is considered as one of the most promising for applications where embedded capacitors are required. Ceramic particles exhibit high dielectric permittivity, while polymer matrix is characterised by ease processing, suitable mechanical properties, high dielectric strength, and low cost. The composite scheme of both materials provide a combination of their properties, which is desirable in many current emerging applications such as cellular phones, wireless personal digital assistants, packaging technologies, acoustic emission sensors, leakage current controllers, stationary power systems and hybrid electric vehicles. The ability to store and retrieve electric energy in a distributed network of micro-, or even better, nano-capacitors is the key feature of this scientific and technological effort. Further, employing ferroelectric ceramic particles, as the reinforcing phase, lend functional or self-tunable performance to the composite structures. Ferroelectric particles exhibit spontaneous polarization, below a critical temperature. Moreover, are characterized by a temperature dependant disorder to order transition, which in the case of barium titanate lies close to 140°C. In the present study composite systems of epoxy resin and barium titanate micro and/or nano particles have been prepared and studied varying the filler content. The morphological functionality of the embedded micro and/or nano particles was examined via x-ray diffraction, below and above the critical temperature. The dielectric response of the composite systems was studied by means of broadband dielectric spectroscopy in a wide frequency and temperature range. Dielectric permittivity and electric modulus formalisms were employed for analysing the obtained data. Dielectric results provide evidence that the occurred relaxation processes arise from the polymer matrix and the reinforcing phase. Finally, the functional behaviour of the composites and their efficiency of energy storage were investigated via the variation of polarization with temperature, and the dielectric reinforcing function respectively.

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Electrical resistance measurement for in situ health monitoring of carbon nanotube/polymer composites

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It is well established that conducting networks formed in an insulating polymer matrix can be utilized as highly sensitive sensors for detecting the onset, nature and evolution of damage in advanced polymer-based composites. In this work multiwall carbon nanotubes (MWCNTs) dispersed in a polymer matrix have been used for damage sensing of the resulting nanocomposite under tensile and cyclic loading. This was achieved by measuring the electrical resistance change in conductive MWCNT/polypropylene nanocomposites with 3% and 6% wt MWCNT content well above the percolation threshold. The samples were subjected to tensile loading and the longitudinal strain was measured very accurately, with a laser-extensometer which permits a non-contact measurement of the longitudinal deformation distribution of the sample. Simultaneously with the mechanical tests, the longitudinal electrical resistance of the specimen was monitored with the use of gold sputtered stripe electrodes equally spaced on the surface of the sample perpendicular to the loading direction. For the measurement of resistance a four-probe method was used by applying a known current through the two outer electrical contacts and measuring the voltage between the two inner electrodes. The mechanical tests showed the typical stress-strain behaviour of a ductile material where the linear elastic region is followed by the plastic

deformation region and a neck formation before fracture. The results concerning electrical measurements showed that resistance change $\Delta R/R_0$ increases linearly in the elastic region, whereas when entering the plastic region $\Delta R/R_0$ changes faster up to the fracture of the specimen. The latter behavior appears very promising for using the electrical resistivity method for detecting damage at an early stage before catastrophic failure of the specimen. The results during cycling loading tests showed a reversible change of resistance on every cycle and repeatability of resistance change. A small increase of resistance at zero stress after many cycles was observed. During this test a yield stress of 17 MPa was detected, which is lower than the one found in previous experiments with specimens with no loading history. By lowering CNT content (being above the percolation threshold) the relative change of resistance $\Delta R/R_0$ as a result of applying the same stress could be increased but there is a trade-off with the noise of the measurement. The increase of electrical resistance with strain could be explained as a result of destruction of percolating paths forming the conducting network. The results showed that MWCNTs dispersed in a polymer matrix forming a conductive network have a potential to be used as a sensitive network to monitor or predict the damage in polymer/carbon nanotube nanocomposites. Experiments with different polymer matrices are in progress.

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Strain & damage sensing in carbon fiber polymer-matrix composite by electrical resistance measurement

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The measurement of electrical resistance appears to be a valuable non-destructive technique that can be used to monitor the damage in carbon fiber reinforced polymers. In this work composites of polyetherethetketone(PEEK) with unidirectional carbon fibers at a content of 55wt% were tested. The samples were subjected to tensile loading in parallel to the fiber direction and the longitudinal strain was measured very accurately, with a laser-extensometer which permits a non-contact measurement of the longitudinal deformation distribution of the sample. The mechanical tests showed the typical stress-strain behaviour of a brittle material where a monotonic increase of stress until the fracture was observed while failure occurred quite sudden. Simultaneously with the mechanical tests, electrical resistance of the specimen was monitored with the use of gold sputtered electrodes on its surface. Different electrode configurations were used in order to measure longitudinal, through thickness or oblique resistance. In all cases a fixed current was applied and the resulting voltage drop was continuously monitored.

For the longitudinal resistance the four-wire method was chosen as preliminary tests showed that it is superior to the two-wire method. Except from the electrical resistance technique, the voltage technique was also investigated in the through thickness configuration by measuring the voltage away from contacts where the current was applied. The results showed that the through thickness and oblique resistance increases linearly with strain until fracture. The same was observed for longitudinal resistance but there were cases where a sudden increase of resistance before fracture was observed indicating fiber breakage before fracture. Furthermore, resistance changes immediately from minimum strain indicated the high sensitivity of the above technique. The tests were limited to samples of CFRP with UD fibers of one ply in which the monitoring of resistance changes served more for strain sensing rather than for damage sensing. Further tests on laminates with various lay-ups are in progress where the above configurations are believed to provide distinctive responses of the most common damages like delamination and intraply cracks.

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Electrical resistance response to strain and damage in multi phase composites

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The variation of the electrical properties of fibre reinforced polymers when subjected to load offer the ability of strain and damage monitoring. This is performed via electrical resistance and electrical potential measurements. On the other hand Carbon Nanotubes (CNTs) have proved to be an efficient additive to polymers and matrices of composites with respect to structural enhancement and improvement of the electrical properties. The induction of CNTs increases the conductivity of the matrix, transforming it to an antistatic or a conducting phase. The key issue of the structural and electrical properties optimization is the dispersion quality of the nano-scale in the polymer phase. Well dispersed CNTs provide an electrical network within the insulating matrix. If the fibres are conductive, the CNT network mediates the electrical anisotropy and reduces the critical flaw size that is detectable by the change in conductivity. Thus, the network performs as an inherent sensor in the composite structure, since every invisible crack or delamination is manifested as an increase in the electrical resistance. The scope of this work is to further exploit the information provided by the electrical properties with a view to identify strain variation and global damage via bulk resistance measurements. The aforementioned techniques were employed to monitor, strain and damage in fibre reinforced composite laminates both with and without conductive nanofillers.

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Electrical tomography as a tool for the damage assessment of composite structures

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As a means towards integrated smart composite structures, electrical sensing strategies have been proposed for damage identification. Most of the approaches have dealt with the existence of damage and mostly in near 1D cases. Some works have worked on the issue of locating the damage. Towards this direction, this work proposes the development of Electrical Tomography as a tool for damage assessment of composite structures. The technique utilizes electrical measurement strategies (currents and voltages) to assess the structural health of a composite. A theoretical investigation on current and measurement strategies will be presented and applied on realistic structural cases. Respective experimental results have shown that the technique is capable of identifying the presence of damage. Furthermore it can indicate the region where the damage is located. Until now, discontinuities as small as 0.1% of the inspected area can be sensed and located. Based on the latest results it is believed that Electrical Tomography could evolve as an integrated SHM or NDI technique, offline and online. Implementation aspects and development directions will also be discussed.

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On line monitoring of damage during fatigue loading of composite patch repair of composite structures

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Although aircraft composite repair is applied for more than thirty years, since it was initiated in Australia, a range of issues arises that pose technological challenges regarding the design, manufacturing and application of the composite. The ability to assess repair efficiency/integrity compromise a emerging need of the aeronautical composite industry that requires health monitoring capabilities during the service life of the repaired component / system. NDI techniques for repair integrity monitoring are required to (a) reliably detect flaws over a critical size, (b) be least affected by local geometry and property variations, and (c) operate fast and cost efficiently. Towards this end, electrical potential technique is proposed. The monitoring of composite patch integrity using the inherent electrical properties of the material is a technique that comes again in the forefront of research. In spite of its advantages, self-sensing has received less attention than the use of embedded or attached devices the last decades. Aim of this study was to investigate the possibility of using the electrical potential technique (EP) for the on-line monitoring of the damage during fatigue loading of composite patch repair of composite structures. Moreover Acoustic Emission (AE) Technique was also employed in order to access also its capabilities.

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Session 8A: Imaging & Digital Methods

Dynamic shearography for inspection of aerospace structures

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Interferometry is a well established technique for sensitive monitoring surface deformations on a scale that is given by the wavelength of light. If deformation is performed periodically e.g. by absorption of intensity modulated light while interferometric images of the inspected object are recorded continuously, a stack of images is obtained that contains information about the low frequency mechanical behaviour of the inspected object. After unwrapping the stack of fringe images, the local phase and amplitude of the periodical object displacement are extracted by a Fourier transformation at the low modulation frequency of the time dependent height change at each pixel. This principle is known from lockin thermography, and also here depth range depends on modulation frequency. However, it should be pointed out that here the mechanical response is involved in addition to the thermal wave effect. Hence the mechanical aspect of defects is shown. Our paper presents the principle and the performance of this technique on model samples and demonstrates the advantages of this new approach on aerospace structures. An example is the fibre reinforced horizontal stabilizer of a light aircraft where hidden structure is clearly revealed (Fig. 1).

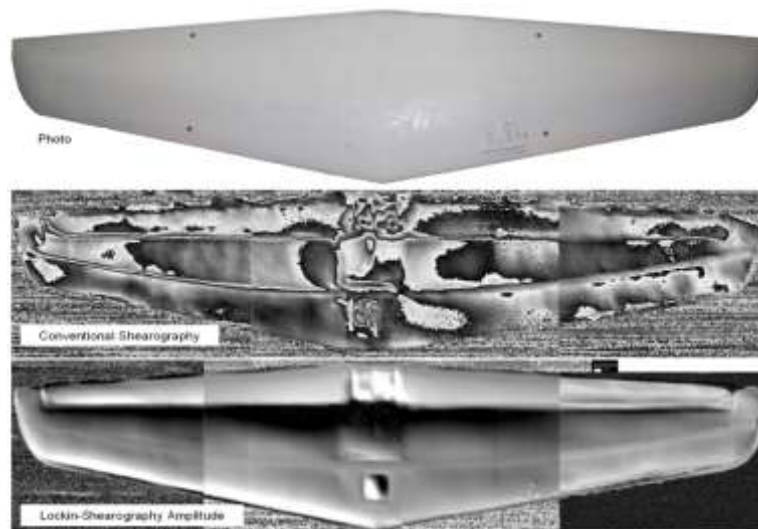


Fig. 1: Horizontal stabilizer of a light aircraft inspected with shearography: Conventional technique (middle) compared to Lockin-shearography amplitude image (bottom). Photograph shown on top. Sample kindly provided by Akaflieg of University Stuttgart.

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Determination of Linear thermal expansion coefficient by using digital image correlation

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Many materials and certain material applications require detailed preconditioning and specific thermal test schedules to be followed to obtain a correct evaluation of thermal expansion. Since a general test method cannot cover all specific requirements, details of this nature should be contained in the relevant material specification. The standard testing method to measure the linear thermal expansion is based on contact methods (ASTM E228-

95, Standard Test Method for Linear Thermal Expansion of Solid Materials with a Vitreous Silica Dilatometer). The Thermal Mechanical Analysis (TMA), measures the change of length of the specimen during heating by using a vitreous silica push-rod or tube dilatometer. A big disadvantage of this method is the restricted size of the specimens. When using the TMA method on fiber reinforced composites; the small specimens required (maximum 5 x 5 mm cross section) are not representative for the behavior of the composite, so the method is not applicable. In this paper the coefficient of linear thermal expansion will be determined by using a contact (TMA) and a non contact method based on digital image correlation (DIC). This full field optical non contact method measures the in-plane displacements of the object surface. The aim of this study is to use both testing methods on different material in order to calibrate and verify the usability of the method to determine the linear thermal expansion coefficient. As an example the results of the measurements on aluminum heated up to 300°C are shown in figure 1. The green curves represent the strain as calculated from the TMA data, while the red curves represent strain obtained from the DIC data.

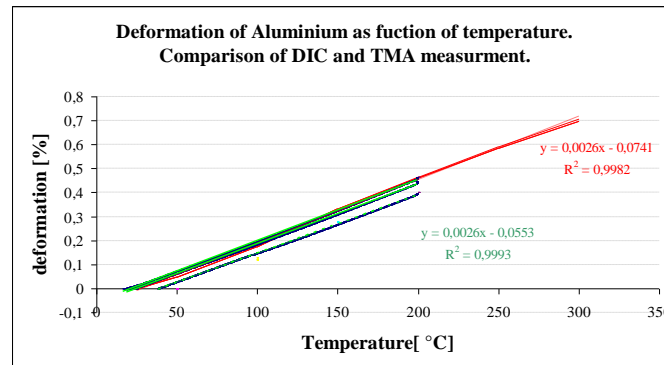


Figure 1- Deformation (strain) of aluminum as function of temperature

Results are compared with the TMA measuring technique. The reference measurements on aluminum and on pure IPC show that both techniques yield similar results, proving the usefulness of the proposed DIC technique for measuring the in plane deformation of a specimen at elevated temperatures. Results on textile reinforced IPC show the applicability of the DIC method for measuring macroscopic thermal expansion properties of fiber composite materials.

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Atomic Force Microscopy Quantitative and Qualitative Nanoscale Characterization of Collagen Thin Films

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Collagen is the most abundant protein in mammals and is a basic component of the extracellular matrix. Due to its unique properties it is widely used as biomaterial, scaffold and culture substrate for cell and tissue regeneration studies. As the majority of biological reactions occur on surfaces or interfaces and collagen fiber structure can trigger cell response it is of great importance to nanostructure collagen thin films. Collagen nanobiomaterials present improved surface characteristics and as a result they have wide applications in biomedicine, in fields where it is very critical to pre-determined the topography of the surfaces. Surface characterization in the nanoscale could be performed with Atomic Force Microscopy (AFM), which is a powerful tool and offers quantitative and qualitative information. Its ability of high resolution imaging and non destructive characterization under different conditions make it very attractive for biological samples investigation. The aim of this paper was to characterize the collagen fibers of the thin films formed on different substrates (glass, mica, polystyrene particle surfaces) and correlate their morphology with the characteristics of the used substrates, formation methodologies (spin coating, hydrodynamic flow) and the original collagen solution. The clarification of the role that deferent parameters play in the formation of the films will enable the design and control of collagen based nanobiomaterials with pre-determined characteristics. The results demonstrated that AFM can be used to characterize nanostructured collagen thin films which, under appropriate control of a number of parameters

(substrate, solution concentration, film formation procedure) it is possible to be formed with reproducible and pre-determined characteristics.



Fig. 1: AFM topographic images of collagen thin films and their substrates: Elongated fibers with random orientation on glass (A) and mica (B) with spin coating procedure. Oriented collagen fibers, formed by hydrodynamic flow of the collagen solution over the substrate (C), Polystyrene particle surface (D). The characteristic D-band of collagen fibers formed on polystyrene particle surface (E) and mica (F)

These nanostructured films and the offered information by AFM could be used in order to fully clarify the relationship between collagen surface nano-characteristics and cells behaviour. These films could be applied to direct cellular processes or cover non-biological surfaces, offering them biocompatibility, in a variety of research and later medical applications. Additionally, these nanostructured patterns could model collagen reach tissues and study their optical properties like Second Harmonic Generation.

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Digital methods for flakiness and shape index definition

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The mathematical software Matlab provides basic tools for image processing and for automated calculation of geometrical parameters of objects, such as orientation, perimeter, area, maximum and minimum length. The calculation of these initially requires processing and transformation of colored images to grayscale and finally to binary images. In this project we combine two different software tools, Matlab and a software tool that was developed in our laboratory using the Visual Basic programming language. The overall code automates a series of procedures that lead to the exact definition of the areas, perimeters, and the maximum and minimum lengths of limestone gravels. It concludes with the statistical processing of the results. Fig. 1 shows example histograms of the area and of maximum and minimum lengths, which constitute useful parameters for the flakiness and shape index of gravels. Image analysis is of course a non-destructive technique, with the advantage of analyzing fast a larger volume of sample, therefore resulting to better statistics. Furthermore, real time processing is possible during quality testing with significant reduction of costs. In addition, the method can perform cluster analysis for object separation at various scales, macroscopic or microscopic, such as crystal separation in rock thin sections) based on their color and/or their luminance (Fig. 2), and also to provide textural data (Fig. 3).

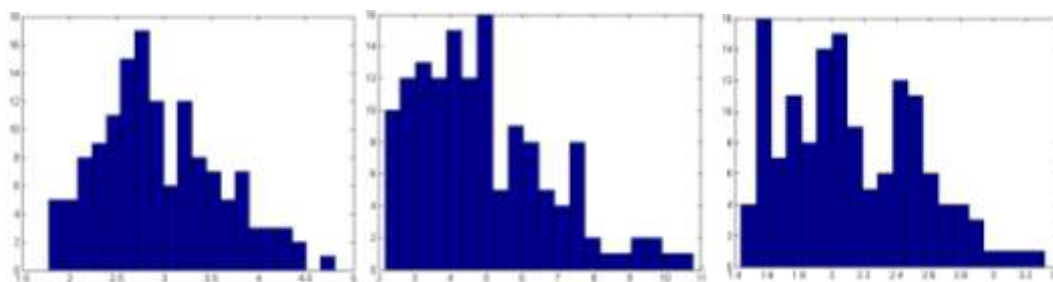


Fig. 1: Distribution area, maximum and minimum length histograms respectively

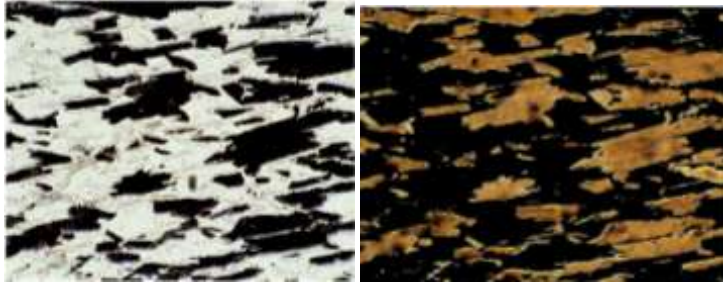


Fig. 2: Biotite grain separation from the main matrix (schist sample)

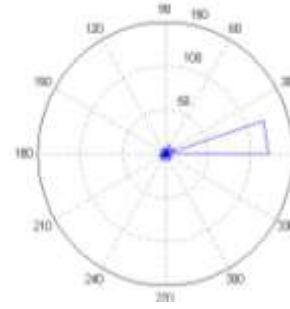


Fig. 3: Projection in circular histogram of biotite grain orientation (schist sample)

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Experimentally induced errors in Digital Image Correlation measurement of small strains with large gradients

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Digital Image Correlation or DIC is an already widespread and commonly used technique to perform full field strain measurements. Usually, a so called ‘speckle pattern’ is put on the specimen and then, pictures are taken first in the undeformed stage, which is the reference and then in various deformed states. The technique itself consists of comparing the image of a deformed pattern with a reference image and determining the displacements of the so called ‘subsets’. The mathematical algorithm eliminates rigid rotations of the subset and is able to determine the strain field. This technique was originally designed for large-strain measurements and as such, it works very well when large strains are present, but when determining (very) small strain fields, especially in combination with large (rigid body) deformations or large strain gradients, this technique becomes a lot more sensitive to the boundary conditions of the experimental setup.

This manuscript will illustrate the errors induced by experimental factors such as the speckle pattern and size, the gripping of the specimen, whether rotation of the grips is allowed or not, the subset size, camera lens induced deformation, ... on the eventual derived strain field. These parameters will be assessed on different types of experimental tests, ranging from uni-axial tensile tests to Double Cantilever Beam (DCB) Mode I tests on both isotropic and orthotropic materials.

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Session 8B: Inspection Methods

Eddy current crack inspections at plate edges. Theory/experiment

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Cracks tend to appear at places of stress concentration such as plate edges and the openings of boreholes. In these cases, eddy current nondestructive inspections are more difficult because of the large signal produced by the edge itself. In this work we study the interactions of eddy currents with edge cracks. Apart from using the Finite Element Method, we develop a fast and efficient Boundary Element Method model and we also perform precision measurements in the lab for verification purposes. Eddy current crack inspections are simulated either with differential (finite element) methods or with integral (boundary element and volume element) methods. Differential methods are quite universal but computationally intensive since in eddy current testing configurations the problem to be solved is multi-scalar: large modeling area with just a small perturbation of the electromagnetic field from the crack. On the other hand, integral methods are very fast and can be used for inversion purposes. A well established scheme for eddy current interactions with cracks is based on an electric field integral equation solved numerically via the moment method using discrete elements in the crack region [1]. A significant drawback of this approach is the requirement for a Green's function which forms the kernel of the integral equation. The Green's function describes the electric field produced by a current dipole embedded in the given structure. Analytical expressions are available for canonical geometries like infinite plates which means that eddy current interactions can be modeled only for cracks located in the middle of plates [2]. In this work, we derive a Green's function expression for the edge of a plate and efficiently model a crack at the plate edge. In doing so, we use the domain truncation approach, that allows the expression of the electromagnetic field in the form of series expansions rather than integral forms and the solution is found by manipulating matrix relationships between expansion coefficients [3]. The theoretical results are verified by both finite elements as well as by experimental ones. The experimental setup involves an impedance analyzer, a precision scanning system, characterized coils and through the thickness EDM notches at the edge of thin Aluminum plates. Excellent agreement is observed between semi-analytical (BEM), numerical (FEM) and experimental results.

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[3] T.Theodoulidis, J.R.Bowler, IEEE Transactions on Magnetics, Vol.46, pp.1034-1042, 2010.

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Detection of radial cracks at fastener holes by either eddy current or line heating stimulated thermography

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During the last years many researchers focused on the detection of fatigue cracks at fastener holes, especially in ageing aircraft structural components. Toward this aim various techniques have been used, mainly ultrasonic and eddy current testing, requiring however a point-by-point scanning over the area under inspection. The present work investigates numerically the detection of radial cracks at fastener holes by transient infrared thermography. For the numerical experiments, rectangular aluminium plates are considered, with length 15 cm, width 5 cm and thickness 1 mm. Two symmetrical cracks emanate from a central circular hole of 10 mm diameter. The direction of crack is perpendicular to the direction of loading, which is assumed to be parallel to the longer side of the

plate. In order to investigate whether it is possible to detect cracks during their growth, cracks with length 1 mm and 2 mm are considered. Two different modes of excitation are studied: (a) Excitation by a coil, inducing eddy currents within the inspected work-piece, and, (b) excitation by a line heat source, creating a heat flux inside the work-piece, which, in both cases, is inspected by infrared thermography. The diameter of the exciting coil is slightly larger than the diameter of the hole and the coil axis passes through the centre of the hole. This way, the induced eddy currents circulate around the hole. Hence, the current flow is perpendicular to the crack. In case of excitation by a line heat source, which is perpendicular to the longer side of the plate, the heat flux created is parallel to the longer side of the plate, i.e. parallel to the direction of loading. As a consequence, the heat flow is perpendicular to the crack. For the depiction of the isotherms and in order to simulate numerically the sensitivity of an infrared camera, the values of temperature resulting from the computations were rounded off to only one or two decimal digits, accordingly to the assumed sensitivity. For eddy current excitation, the isotherms indicate the position of the crack but its exact length is not quite clear. In case of excitation by the line heat source, the isotherms give only a vague indication that a defect exists. In order to improve the sharpness of the cracks, the numerical experiment results are processed by the following techniques: (i) Image subtraction, (ii) depiction of the spatial derivatives of temperature, and (iii) Discrete Fourier Transform. The improvements achieved by data processing depend on the excitation mode. So, for eddy current excitation, the numerical results are improved by image subtraction and by phase images resulting from Fourier analysis. In case of excitation by a line heat source, all three techniques improve considerably the numerical results. As far as the detection period is concerned, in case of eddy current excitation, the shorter crack is detected over a very short time interval, at the beginning of the excitation, while the longer crack is detected over a wider time interval. In case of excitation by a line heat source, the detection periods are longer and extend beyond the excitation period.

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Apparatus for measuring of liquid conductivity

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Moisture in building structures influences physical properties of materials and can cause their degradation. Apart from several exceptions, building materials are hardly ever dry. To express an anticipated negative effect of moisture on building materials related to building structures it is necessary to achieve as accurate way of determining their moisture characteristics as possible. Therefore it is necessary know information on her diffusion in porous environment. Liquid dampness in capillary porous material building construction occurs in the event of contact for instance by devaporation vapour or owing to steam condensation of waters etc. The publication presents information about experimental measurements that were carried out on porous material. The result of measurements is obtaining data for the formulation of humidity parameters and moisture profiles by help an experimentally assembled measuring apparatus, by a non-destructive method using electromagnetic microwave radiation. For monitoring of distribution and transport of weight moisture in porous material was used experimental non destructive method. This method is based on interaction principle between weight moisture and microwave radiation intensity changes. By this method we can find coordinates of moisture profile points. It makes possible subsequently coefficient of capillary conductivity of humidity κ give practical expression. The aim is to verify the above mentioned method of measurement for the description of moisture parameters of building materials in practice. At present time, no computational theory for standard use exists for the description of moisture transport in building materials. Moisture is transported by capillary forces and in porous environment by diffusion. However, disparate porous texture causes complications. The methodology of data scanning by using microwave radiation and data processing is assessed by numerical computation based on the well-known physical laws without the influence of the human factor. Moisture gradient in a porous material indicates moisture transport and capillarity. This parameter is called capillary conductivity coefficient of moisture and its dependence on moisture can be used e.g. for the specification of thermal conductivity of building materials. To record input data necessary for calculation of capillary conductivity coefficient, researchers at the Department of Building Constructions, Brno University of Technology, developed a measuring apparatus. Metering results offer enough exact terms information for others mathematical processing to formulation dependencies coefficient capillary conductivity on specific dampness.

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Automated System for Non-destructive Testing of Complex Structure and Mechanical Properties of Metallic Materials

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Presented are two modern modular unit for automated non-destructive testing of the structure, composition and physico-mechanical properties of metallic materials in laboratory and production conditions. Appliances can be used alone or integrated automated NDT. There are also devices - test pliers and an ultraviolet lamp. There are studies and assessing the feasibility of the presented tools for integrated nondestructive testing of mechanical properties of samples and products of steel and iron.

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The Necessity of Lift Inspections in Greece

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Elevators are devices that demand a high safety requirement. The elevator faults affect not only the operations of other assets but may also result in serious injuries or even death. Consequently, an elevator frequently requires the effective inspection in order to draw the appropriate maintenance strategy and to sustain its functional operations. In this paper the results from the inspections during Hellenic's Accreditation System evaluation procedure of third party organizations are presenting. The main conclusion is that the inspections are necessary for the improvement of safety. On the other hand the national bodies must improve their performance in order to improve the meaning and the result of the inspection. The results reveal this necessity.

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8:50-9:30 Plenary Session 3

Structural Health Monitoring for Aircraft, Ground Transportation Vehicles, Wind Turbines and Pipes – Prognosis

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New materials and light-weight structures call for new concepts of reliability assurance and maintenance. The progress in micro-electronics and micro-electromechanical systems (MEMS) allows development of highly integrated smart systems in large quantities at low costs that combine signal generation, data pre-processing and wireless communication accompanied by energy harvesting mechanisms, thus forming self-sufficient equipment and systems. Such sensor systems and networks are integrated into industrial components and vehicles, driving the development of smart structures. Two main concepts of global monitoring will be discussed: vibration analysis and propagation of elastic waves, and measurements of stress, strain and load conditions. Structural Health Monitoring activities at Fraunhofer IZFP Dresden are focused on Acousto-Ultrasonics and Acoustic Emission in combination with Vibration Analysis. Sensor systems and networks based on acoustic and optical principles are already in use for full scale fatigue tests and on operating windmills. The focus of aviation and aerospace activities is directed towards monitoring of fiber composite structures. Express and cargo trains are monitored by acoustic measurement equipment evaluating the noise from the rail-wheel contact. Finally, guided wave techniques are applied for corrosion and crack monitoring of pipes and piping systems. This paper provides an overview of the Structural Health Monitoring activities at Fraunhofer IZFP Dresden, and discusses future concepts.

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Session 9A: Ultrasonics II

Depth-profiling of elastic and optical properties of submicrometer thick optically transparent films by picosecond ultrasonics inteferometry

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Picosecond ultrasonic interferometry [1] is a technique for the opto-acousto-optic diagnostics of elastic and optical properties of transparent materials in the GHz range of acoustic frequencies. The technique involves the measurement of the thermoelastic excitation of a picosecond acoustic pulse by a femtosecond laser pulse. The propagation of this acoustic pulse in the bulk of the transparent material is monitored from the reflectivity changes of the time-delayed probe laser pulses, which are due to the photoelastic scattering of the probe light by the moving acoustic strain. The transient reflectivity signal at a particular instant of time contains information on the velocity of the acoustic wave and the optical reflective index in the material region where the acoustic pulse is located.

The technique is traditionally applied for the non-destructive testing of the homogeneous thin films [1-4]. We have recently demonstrated that this method can be applied for evaluation of one of the most difficult challenges of modern ultra-large scale integration (ULSI) technology in microelectronics: the depth profile in the elastic properties of submicrometers films. Such measurements were performed with a spatial resolution of 40 nm [5]. A more than 40 % variation in the longitudinal elastic modulus has been found between the front and back surfaces of a 800 nm thick low-*k* nanoporous film due to the spatially inhomogeneous UV curing of the film during the fabrication. The in-depth distribution of the acoustic velocity has been extracted from the variations in time of the characteristic frequency (the so-called Brillouin frequency) of the oscillating transient reflectivity signal. In the present communication we present new experimental results demonstrating for the first time that by performing picosecond interferometry measurements at different incidence angles of the probe laser it is possible to achieve a depth profile for both elastic (acoustic velocity) and optical (refractive index) properties of spatially inhomogeneous transparent films.

Moreover the extension of the theoretical backgrounds [1, 3] of this technique for the case of spatially inhomogeneous materials, developed by us recently, demonstrates that the slow variation of the amplitude of the oscillating transient reflectivity signal contains information on the variations of the density and photoelastic modulus in the material. The first results on the depth-profiling based on the measurements of the slow variation in time of the amplitude of the transient reflectivity oscillations will be presented. Our research results demonstrate that picosecond acoustic interferometry, also called time-resolved Brillouin scattering, is a unique tool to perform the depth profiling of the elastic and optical properties of dielectric films for microelectronic applications.

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Damage Monitoring of composite laminates using Ultrasonics

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Damage characterization of composites is usually conducted through their acoustic behavior. As damage is being accumulated, this behavior is anticipated to change. Different damage mechanisms are active during loading. These mechanisms are acting in different time scales of the service life and are interdependent. Loading of cross-ply laminates leads to the accumulation of matrix cracking, delamination between successive plies and fiber rupture at the final stage of loading. The acoustic activity of damage may be correlated to the source damage mechanisms. Additionally, damage accumulation has been reported to strongly affect the wave propagation characteristics of the material. In the case of cross ply laminates, an increase of pulse velocity and transmission occurs as the top stiff layer becomes progressively isolated from the rest of the material due to matrix cracking and delaminations. As loading continues, the accumulation of longitudinal fibre breaks becomes dominant causing an eventual decrease of transmission before the failure of the specimens. The present work aims to evaluate the efficiency of ultrasonics as a methodology for structural health monitoring.

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Ultrasonic characterization of materials using Laser Doppler Vibrometer measurements: a multi-input approach

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The analysis of material properties by means of ultrasonic waves is of great importance. Many research groups, working in engineering fields as signal processing, system identification, acoustic and vibrations measurements, collaborate in order to offer new methods based on ultrasonic characterization of materials. These studies aim to derive elasticity properties by means of density and acoustic velocity estimations and/or to determine position and size of structural defects, to evaluate the safety of materials. The use of ultrasonic waves is justified by their non invasive behavior; moreover they are cheap, easy to generate and to detect. Pulse signals are widely used for these kinds of tests. Under the assumption of plane wave propagation, acoustic velocities have been obtained performing pulse-echo or transmission experiments. Such a technique presents several limits. First of all the high crest factor (ratio between the peak and the RMS value of the signal, typically 10 in pulses) of pulses makes the signal-to-noise ratio (S/N) decrease. Secondly, high peaks may provoke non-linear behavior in the structure, as well as in the transmitter. Hence, different signals could be implemented to avoid the disadvantages of pulses, and employed especially to test highly attenuating materials (such as porous materials). Moreover, a new technique able to provide the information concerning the density of the material would be also necessary to map the elasticity properties of the samples under test. In this paper the use of interleaved compressed multisines waves for ultrasonic characterization of homogeneous and porous materials is presented. The interleaved frequencies composing the excitation signals allowed the use of two transducers at the same time. The employment of the Laser Doppler Vibrometer to capture the ultrasonic waves gave the possibility to combine transmission and reflection measurements in only one experiment. A modeling technique, able to determine simultaneously acoustic velocity, density, thickness and damping of the material under test is also proposed, at the end of the article.

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Ultrasound NDT signal analysis and material microstructure information finding

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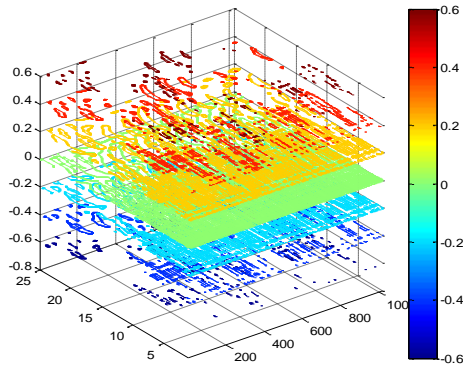


Fig 1: Structure noise energy content

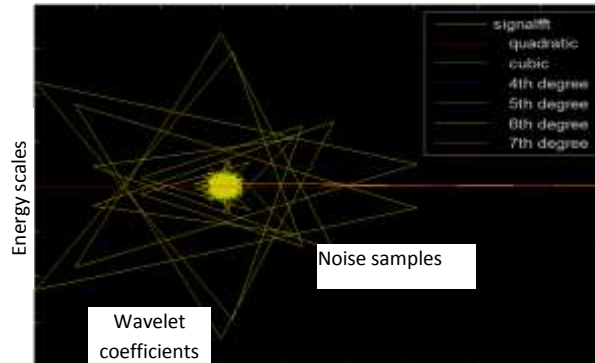


Fig 2: Attractor shape after interpolations

Ultrasonic NDT data are time series data decomposed in signal plus noise obtained from traveling ultrasonic waves inside a material and captured by piezoelectric sensors. The natural inhomogeneous and anisotropy character of steel made material causes high acoustic attenuation and scattering effect. This makes data interpretation highly complex for most of qualified Ndt operators. In this paper we address the non linear features of back scattered ultrasonic waves from steel plates. The structural noise data captured from the specimens, and processed by an algorithm based on wavelet energy approach, show significant insights into the relationship between backscattered noise and material microstructures. This algorithm along with correlation coefficients, residuals and interpolations calculations of processed ultrasonic data seems to be a well-adapted signal analysis tool for viewing material micro structural dimension scales. Experiments show interesting 3D interface and indicate a quasi linear signal energy distribution at micro structural level. It suggests incidence of microstructure acoustic signatures at different energy scales of the material phases. Finally multi polynomial interpolations of the processed noise data exhibit an attractor shape which involves chaos theory noise data modeling.

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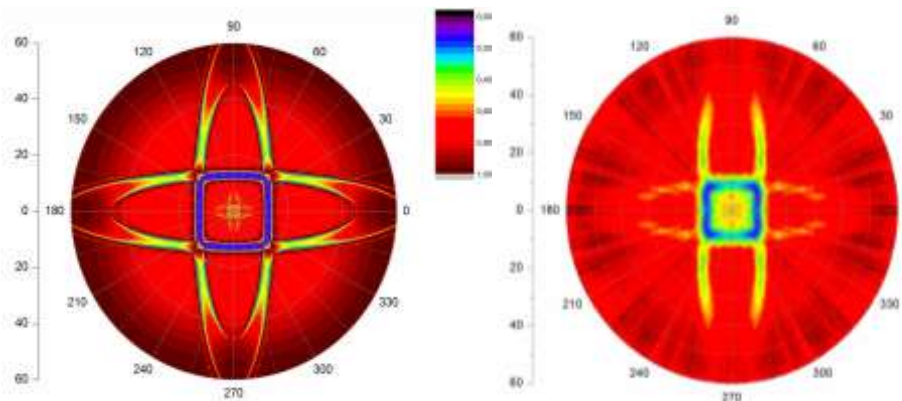
Experimental and numerical polar scans of several anisotropic materials using pulsed and harmonic ultrasonic beams

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Due to the increasing use of composite materials in critical applications demanding light weight to high strength ratio, reliable evaluation tools are necessary. Within these tools, the classical ultrasonic C-scan has already proven its usefulness in qualitatively visualizing defects, delaminations, etc. Though, because of the inherent limitations of this method for characterizing a degraded material, the quest for more sophisticated methods is a big challenge in current research. A polar scan, which makes use of ultrasound from all possible angles of oblique incidence, can serve as a prominent successor of more classical methods. By gathering the reflected (or transmitted) amplitude of the ultrasonic beam, one is able to built a polar plot which covers a certain solid angle. This paper reports on experimental polar scans using an in house developed ultrasonic test setup, which has 5 axes of freedom. The setup allows to perform the experiments in an automated way. The experimental results are compared with numerically computed polar scans for a variety of composite materials, using both pulsed as harmonic ultrasonic beams. Typically, dark rings are observed in a polar plot, which are linked to the generation of critical bulk waves (pulsed regime) or to the generation of guided waves (harmonic regime). Both types of waves are vigorous entangled with the elastic constants of the material. This implicates that a polar scan is a great candidate tool to investigate fatigue of anisotropic materials non-destructively, where the mapped amplitudes are a local fingerprint of the investigated material. Indeed, many show a gradual degradation of their elastic properties, when subjected to fatigue loading.



Numerical (a) and experimental (b) polar scan in transmission for a PPS fabric composite material (thickness $d = 2$ mm) using a harmonic bounded ultrasonic beam (frequency $f = 1$ MHz).

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Session 9B: Signal & Data Processing II

Damage Identification in Beam Structures using Modal Parameters and Artificial Neural Networks

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Structures are exposed to damage during their service life which can severely affect their safety and functionality. Thus it is important to monitor structures for the occurrence, location and extent of damage. Artificial Neural Networks (ANNs) as a numerical technique have been applied increasingly for damage identification with varied success. ANNs are inspired by human biological neurons and have been used to model some specific problems in many areas of engineering and science to achieve reasonable results. ANNs have ability to learn from examples and then adapt to changing situations when sufficient input-output data are available. It can be retrained continuously with new data, so that it can conveniently adapt to new data. This paper presents the application of ANNs for detection of damage in beam structures using dynamic parameters. Modal data are more suitable for detecting large faults and are easy to implement for damage assessment and can directly linked to the topology of structure. In this study, the required data for the ANNs, such as frequency response functions and modal data in form of natural frequencies and mode shapes will be obtained from experimental modal analysis. Also analytical modeling of beam structures will be carried out in this paper.

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Signal Feature Extraction Approach for Automatic Defect Detection using Active Thermography

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Active thermography is a highly suitable method for nondestructive material evaluation because of its wide area inspection and short measurement times. However, current inspection methods require expensive human intervention, which have to be minimized by automated evaluation procedures. Aiming for inspection automation is, nevertheless, a difficult task. This is due to the fact that several measurement disturbances complicate proper signal feature extraction, essential for automated defect detection. These disturbances include noise, variable material characteristics and, above all, inhomogeneous thermal excitation. In this paper, a novel technique for active inhomogeneous excitation correction by means of two-dimensional space filtering is proposed. Pulse-phase and pulse-compression approaches are used to process the filtered thermographic signals. Several features are extracted from this signals and ranked using the Pearson correlation criteria. Single-Variable classification for defect detection is then performed, using support vector machines with the highest ranked feature as input. Results for defect detection rate on carbon fiber reinforced plastic (CFRP) samples are presented.

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Data fusion for Lockin-thermography

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Lockin thermography being applied since two decades is a technique where the thermal response to a modulated heat input is analysed with respect both to phase and amplitude. As this analysis is performed at each surface

spot of the inspected object, phase angle images are obtained that reveal hidden features where depth range depends on modulation frequency. If two such images taken at two different frequencies on the same object are merged in such a way that the two phase angles obtained at each pixel are plotted versus each other (data fusion), the resulting scatter plot contains non-local information that can be used for filtering so that certain features are sorted out. This way effects of lateral heat flow or thickness can be extracted and visualized. Examples will be presented for various kinds of samples where the information gain for non-destructive testing becomes obvious. The technique is applicable also to other kinds of modulated imaging.

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Method of digital processing of images metallographic microstructures in MATLAB environment

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The quantitative description of structural changes and establishment of their connection with physicomachanical properties steel and alloys is an actual problem of not destroying control of technical devices. Images of microstructures represent set of not ordered geometrical objects from which it is possible to allocate the certain groups of formations reflecting deformative-structural changes of a condition of a material. The combination of such formations carries out function of the structural interface. In polycrystalline and heterogeneous materials such role is played with borders of grains and separate phases, their form, and also character of distribution of dot objects. Development of structure is define by aspiration of its free energy to a minimum. On the basis of the structural - power analysis by authors has been offered the quantity indicator of the organization of a microstructure (QC), corresponding to a minimum of free energy

$$Q_C = \sum_{i=N} \frac{D_{0i}}{2} \cdot \frac{P_i}{S_i},$$

Where D_{0i} – fractal dimension of border of the unit; P_i и S_i - perimeter and the area of microobject.

For increase of reliability of a quantitative estimation of images of microstructures it is necessary to remove influence of the human factor as much as possible. However, received digital images of microstructures possess a number of the features dependent on quality of etching, intensity of illumination and other factors. For elimination of these lacks by authors the technique of improvement of digital images of microstructures and allocation of borders of grains in various images on quality is developed and experimentally approved. Modern computer means of processing of images allow to define on photos meso- and microstructures all necessary quantitative characteristics for calculation of parameter Q_C . The image which can be considered as a bidimensional signal, is considerably more capacious data carrier, than a usual one-dimensional (time) signal. At the same time the decision of scientific and engineering problems at work with the visual data demands the special efforts leaning on knowledge of specific methods as the traditional ideology of one-dimensional signals and systems is poorly suitable in these cases. Digital processing of images means performance above them of various operations with the purpose of visual improvement of the image. The primary goal of digital processing of the image metallographic microstructures is background correction and allocation of geometrical objects for the further calculation and research. Not less important problems of processing of images are increase of their quality and elimination various noise factors. System MATLAB is offered as the programming language of a high level for the technical problems, expanded by the big number of packages of applied programs - expansions. Package Image Processing Toolbox is intended for approbation and perfection already known.

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Session 10A: Ultrasonics III

Ultrasonic Guided Waves Propagation in Complex Structures

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Multi-wire steel cables are used in many engineering infrastructures such as; bridges, ski-lifts, power, marine, civil and many other applications. They are considered to be safety critical components. The design life of these structures can be for many decades; therefore the problem of service life of the cables is very important. The location and operation of the multi-wire steel cable ensures they can be subject to variations in; temperature, pressure, pre-/post- stress and humidity. These conditions can potentially induce cracks, corrosion, delimitations and brittleness within the multi-wire steel cables. This could results in a potential source of unreliability, which could lead to failure. Therefore, there is a need for an effective examination technique that can assess the condition of the multi-wire steel cables before any malfunction takes place. In this investigation, Long Range Ultrasonic Testing (LRUT) has been selected as Non-Destructive Testing (NDT) technique to inspect multi-wire steel cables used in the marine application for defects or discontinuities. LRUT uses Ultrasonic Guided Waves (UGW) in the kilohertz range (typically between 16-300 kHz) to inspect for defects from single point of access for many meters (up to 100m) with full volumetric coverage. The aim of this work is to demonstrate the ability of LRUT to propagate ultrasonic guided waves within the multi-wire steel cables. The work was conducted using FEA analysis along with experimental validations. The findings show that the fundamental axi-symmetric wave mode, $L(0,1)$, can propagate within the multi-wire steel cable (up to 8m) at an optimum frequency of 18kHz.

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Periodic nondestructive inspection for flaws in steel plates and weldments using ultrasonic testing method in combination with fracture mechanics

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The purpose for this paper is to present the ability and necessity of ultrasonic testing method for studying fracture mechanics problems taking into account the flaws in steel plates and weldments. Periodic nondestructive ultrasonic testing in combination with fracture mechanics analysis forms the concept of damage tolerance. Some flaws are introduced to the component in service because of the load fluctuation, material performance degradation and stress corrosion. Following the ultrasonic tests and their evaluation, the resulting flaw has to be evaluated by fracture mechanics methods. Ultrasonic testing has the ability to perform testing with one-sided access to the component. It has superior penetration depth compared to other nondestructive testing methods and a good accuracy of detection and characterization of flaws. The major problem of structures containing flaws is knowledge of the flaw parameters, which include determining size, shape and orientation. The initial flaw size can be determined by using ultrasonic testing method which results in the application of fracture mechanics. Fracture mechanics principles can be used to predict the number of cycles devoted to growing a crack to some specified length or to final failure. With regular ultrasonic inspections and knowing the component crack growth rate characteristics, a cracked component may be kept in service for an extended life time. For the purpose of this paper, the computational simulation of flaw propagation for the flaws is based on a numerical integration of Paris equation. The theoretical and experimental results for both fracture mechanics and ultrasonic testing disciplines are presented. Using ultrasonic testing method with fracture mechanics, it is concluded that both disciplines are complementary and influence each other to a large extent.

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Defect detection and sizing for steel plates: an approach using long range ultrasonic tomography

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Guided Ultrasonic Waves (GUW) have been a dominant tool for application in Non-Destructive Testing. Their ability to propagate within the structure for large distances is a key feature for performing Long Range Ultrasonic Tests. Their application in defect detection for tubular structures has already been established and applied successfully on the field using various transducer types. In this paper, a technique based on Full-Matrix Capture is utilized to produce tomographic images of thin steel plates. The images representing the plate structure are input to the developed image processing algorithm, which isolates defective areas of the structure and estimates their size. The proposed technique is validated through Finite Element Modeling by simulating the guided wave propagation in large 2D plain strain models. The simulated data are used to generate the tomography image of the modeled plate on which defects and their approximate size are detected. The results presented constitute the first step towards establishing an automated tomography technique utilizing long range GUW.

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NDT and Safety of Crude Oil Storage Tanks

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JANAF Plc is a joint stock company, headquartered in Zagreb, Croatia, which is managing an oil pipeline system. Along with crude oil transportation, other major activities of JANAF Plc. include also storage of crude oil and oil products. JANAF Plc has started with its greatest investment project involving the construction at the Omišalj Terminal of 8 crude oil storage tanks of 75 m in diameter and 24 m high with capacity of 80.000 m³ each, as well as the storage tanks having the total capacity of up to 100.000 m³. The entire investment to be undertaken at the Omišalj Terminal values a EUR 150 million in total. This paper presents the results of various NDT techniques taken for the tanks foundation. It highlights the importance of NDT techniques in controlling the success of the ground improvement design solution for the tank foundation in order to ensure safety of tank structure. Ground investigation works consisted of seismological, geological, engineering-geological, geophysical and geomechanical site investigations and laboratory tests. The NDT techniques, carried out to ensure the safety of the tank and the base ground, include geoelectrical sounding, shallow seismic refraction and ground penetration radar. The results obtained have defined the position, sequence, and the quality of lithological units and contact between the weathered rock mass zone and the solid rock. The discontinuity level of the rock on the founding position of the future tank has been proved as well as the underground water condition. It has been noted that the tanks should be founded on the superficial deposit underneath which there are weathered rock mass zone and the solid rock. The thickness varies and according to the investigations it amounts up to 7.5 m. Since the deposit was created by uncontrolled heaping up with the material dug out during the construction of the existing tanks, it is considered to be heterogeneous. It has been concluded that the given location is not suitable for the tank foundation without the additional work on the superficial deposit and the weathered rock mass zone. By taking into consideration the quality and content of ground, heterogeneity and soil stratification, technical and economic analysis made, foundation's shape and dimensions, loading ability and the acceptable deformations, it has been proved that the optimal technical solution is homogenization and improvement of superficial deposit by jet grouting technics and the consolidation grouting between the deposit and solid rock including the weathered rock with poor physical-mechanical characteristics. The satisfying stability and safety of the tank's construction was ensured by using the NDT methods within ground investigation works and during the phase of ground improvement quality control.

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Session 10B: Acoustic Emission II

AE monitoring at laser cutting

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The capturing and evaluating of acoustic emission (AE) signals reveals a great potential for the laser cut quality estimation. Laser-cutting conditions affect measured AE signals, which are a result of an interaction among laser light, a cutting gas, and a plate material, which produces different physical and chemical phenomena during the laser-cutting process. During the laser-cutting process continuous AE signals, produced predominantly by the action of a cutting gas, can be captured. After laser cutting AE bursts, produced by various phenomena during material cooling, can be captured. This paper presents the results of the AE bursts measurement after the laser cutting of steel sheets of various thicknesses using oxygen or nitrogen as cutting gas. Described method of the laser cut quality estimation was applied to the austenitic stainless steel, mild steel, and structural steel. The laser cut quality which is related to the size of the dross and the waviness of the cut surface can be successfully forecast based on the captured AE signals.

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In-situ Observation and Acoustic Emission Analysis for Corrosion Pitting of MgCl_2 Droplet in SUS304 Stainless Steel

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Acoustic emission (AE) with a near-field detection and an optical video microscope (VMS) monitoring were proposed to investigate the corrosion source caused by the small chloride droplet. For the corrosion testing of work-hardened SUS304 stainless steel, four types of the detected waveform were characterized by the wavelet analysis. After a high activity of AE signals, the corrosion product sheet was extended with nothing or a low activity of AE signals. On the cross-section observation, the detected AE signals were mainly attributed to the following three sources, 1) the longitudinal and transverse cracking in the covered pitting, 2) an electrochemical pulse signal and 3) a coalescence with the covered pitting as transverse cracking.

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Fracture Properties Of Nanosilica-Based Cement Mortars Monitored By Acoustic Emission

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Use of nanoparticles in developing materials has gained recently recognition and is being applied in many fields. Specifically, such particles can lead to improving performance of building materials such as cement and concrete. This work focuses on reinforcing Portland cement type II with nanosilica. Physical and mechanical tests were conducted to assess the effect of the reinforcing nanoparticles and that of the mixture procedure on the performance. A marginal deterioration in material properties compared to plain cement mortar, while, the acoustic emission monitoring revealed differences in fracture behavior due to the addition of the nanoparticles. Specimens with well-dispersed nanosilica exhibited stronger shear fracture characteristics than those with inadequately dispersed nanosilica. The results are interpreted and discussed taking into account the properties and the dispersion of nanosilica in the cement mortar.

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Method of Acoustic Emission testing at crystallization of Sn-Pb Alloys

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In the given work make an attempt of use of modern achievements of AE method for regular researches of crystallization's process of Sn-Pb alloys (pure metals, alloys hypoeutectic, eutectic and hypereutectic structure) from the point of formation's view and buildup of dislocation structures of received ingots in concrete conditions of crystallization. As AE accompanies not only dislocation processes, but also processes of formation and development of cracks, the technique allowing to divide AE signals from each process has been used in the given researches. It is experimentally established and theoretically proved, that lattice dislocations (unlike vacancies or the introduced atoms) can arise exclusively at crystallization of metal from fusion or in the course of plastic deformation. During crystallization all kinds of dislocations are forming. As is known, all processes connected with occurrence, annihilation, movement and reproduction of dislocations it is accompanied by emission of acoustic energy of different intensity. In a number of fusible metals and alloys has been registered AE in the course of fusion and crystallization. It has been shown, that the critical temperatures of alloys registered by AE method, are well coordinate with structural diagrams of a different systems. In the majority of metals and alloys radiation of AE signals begins in the middle of crystallization's period and comes to end at the moment of the crystallization termination. It, obviously, speaks that germs of crystallization arising in metal grow some time freely and greatest AE activity starts to be registered only after their interaction with each other. AE character of pure metals is defined by a crystal lattice type. Any eutectic is characterized by small plasticity, therefore in material the increase of AE activity is observed. The greatest activity is registered in hypereutectic alloys. Crystallization of hypereutectic alloys begins with allocation of β -solid solution's crystals, deformation in which is carried out by twinning. AE in this case it is maximal. Change of speed of cooling influences on kinetics of crystallization process. The character of AE signals did not change, but AE signals continued to be registered after the termination of materials crystallization at increase of cooling speed. It is obvious that the reason of that is at larger speeds of cooling component diffusion in an alloy has not time to be carried out. The composition of a solid phase at the end of crystallization temperature does not reach average composition of an alloy and there is some part of a liquid. The further hardening also causes additional AE signals. The experimental results received by authors give the bases to believe, that AE method can serve as the sensitive tool for the control of crystallization's process of different alloys, for the purpose of management of this process and reception of ingots with initial dislocation structure.

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Acoustic emission of marble measured in the laboratory

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Acoustic emission (AE) has been extensively utilized over the past decades to quantify microstructural damage of rock both in laboratory and field studies. Modern AE acquisition and processing equipment and the increased power of microprocessors allow for real time advanced AE signal analysis and the application of advanced statistical interpretation techniques. In this paper the results from acoustic emission and deformation monitoring of Dionyssos marble specimens under laboratory testing are reported and discussed.

Prismatic and cubic marble specimens were tested under uniaxial compression up to macroscopic failure. During uniaxial compression testing of rock the load is usually increased monotonically until the specimen fails. The axial and lateral strains are measured, allowing for the construction of the stress-strain curves, from which the discrete stages of rock behavior may be deduced. Knowledge of the stress levels associated with these stages is important for the rock engineering design. Further, microcrack development is accompanied by acoustic emission of the rock and thus the acoustic emission activity may be correlated with the stages of rock damage during loading. Marble beam specimens were subjected to three point flexural loading. With the three point bending test a single fracture is developed in the specimen, where damage localization occurs very close to the peak load and growth of the intrinsic process zone is usually observed before failure. AE activity was monitored throughout the loading tests using piezoelectric acoustic emission sensors and a multichannel acoustic emission recording system. The

relation of rock damage to the acoustic emission parameters and the AE activity with the applied load is investigated. The results indicate a rapid increase of the AE activity near the failure load. The energy release is also rapidly increased at this stage, while the b-values of the frequency-magnitude relation of AE signals show an apparent decrease just before failure. These parameters appear to be suitable to characterize the fracture process and they are precursors of the brittle rock failure.

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Special session

Funding opportunities for NDT Technologies & future prospects

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PRAXI/HELP-FORWARD, Member of the Enterprise Europe Network – Hellas National Contact Point for the 7th Framework Programme

The 6th annual call for year 2012 of theme 4 – NMP - Nanosciences, Nanotechnologies, Materials and new Production Technologies will be presented with a special focus on topics related directly or indirectly to Non destructive testing technologies. NMP research aims to strengthen the competitiveness of European industry by generating 'step changes' in a wide range of sectors and implementing decisive knowledge for new applications between different technologies and disciplines, with non destructive testing technologies being one of them. Funding the NMP research theme will benefit new, high tech industries and higher-value, knowledge-based traditional industries, with a special focus to the appropriate dissemination of research results to SMEs.

Session 11A: Ultrasonics IV

The technique for estimation of the dispersion of phase velocity of ultrasonic guided waves

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Ultrasonic guided waves are already successfully used for inspection of pipes. There are also many attempts to apply them to other objects. The main advantages of guided waves used for inspection are their ability to propagate long distances with a relatively low attenuation, strong dependency of their parameters on the geometry and the elastic properties of the object and presence of multiple modes, what make these waves very informative. On the other hand all listed features of guided waves makes more complicated their application and signal analysis.

The measured guided wave signals are quite different comparing to the signals acquired using conventional ultrasonic bulk waves. The waveforms of such signals usually contain segments corresponding to different modes, many times reflected or mode converted waves. Identification of these segments is critical for measurement of the parameters of propagating guided waves. The objective of the work presented was to develop such signal processing techniques which enable to identify the segment of the waveforms corresponding to different guided waves modes even in the case of a single signal and to measure main parameters of the guided waves under analysis.

As the result of investigation the phase velocity measurement technique based on the accurate estimation of the multiple zero-crossing instants in the waveform of the signal was developed. The zero-crossing instances enable to measure the variation of the duration of half periods in the burst of propagating waves. This information gives distribution of the frequency in the burst of the signal. In the case of several signals measured at short distances between them the same measured time instants are used for estimation of the phase velocity. It was proposed to relate the phase velocities measured using different zero-crossing instants to the frequency distribution within waveform of the signal what gives estimation of the segment of the dispersion curve.

As the phase velocity dispersion curves are unique for propagating guided wave modes, the proposed analysis enables identification of different modes. As the distribution of the frequency components in the burst depends on the shape of a dispersion curve, the proposed technique enables identification of different modes even in the case of a single signal. However the dispersion curves of propagating guided waves should be used as a priori information. The frequency distribution in the burst of the signal also depends on a propagation distance, so it can give a rough estimation of the distance which mode under analysis propagated also. The limitation of the proposed technique is in the fact that it will not work perfectly in the case of interfering signals of different modes or overlapping reflections.

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Visualization of ultrasound waves in non-destructive material characterization

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In ultrasound material characterization and non-destructive testing the propagating waves are usually measured using piezoelectric transducers. The use of these sensors has several important disadvantages: firstly, the presence of the transducer perturbs the sound field. Secondly, it is very time consuming to obtain a spatially dense measurement. In this paper we will compare to alternative measurement methods that allow the visualization of ultrasound waves in water and the interaction of the waves with a material: laser Doppler vibrometry and Schlieren visualization. Both techniques measure changes in refraction index that are caused by the ultrasound waves, but the instrumentation to perform this task is completely different. In literature several

authors have used Schlieren photography to visualize ultrasound waves and their interaction with materials [1][2].

At lower frequencies the Schlieren method has also been used in a more quantitative way to measure the acoustic absorption of sound waves in materials [3]. However, to the authors' knowledge no quantitative use of ultrasound Schlieren measurements has been reported in literature. The use of the scanning laser Doppler vibrometer (LDV) on the other hand was proposed recently as an alternative method to visualize (ultra)sound waves [4]. The method allows the full-field 3D reconstruction of the sound field [5]. The LDV visualization technique has also been used with success to identify acoustic absorption materials at audible frequencies and ultrasound. In this paper a comparison of both measurement techniques (Schlieren and LDV) will be performed on an ultrasound 1MHz burst wave impinging on an aluminum plate. The potential of both measurement techniques to identify the material properties of the aluminum is investigated.

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Non-destructive testing of elastic properties of nanostructured anodized alumina film by picosecond acoustics methods

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The understanding of elasticity and phonon transport in nanosized and nanostructured materials is of prime importance for their integration as smart nanodevices. The integration of such systems requires indeed basic knowledge on their elastic properties in order to know and eventually to control the possible mechanical mismatch appearing with the surroundings materials with whom they are connected (host substrate, inserted nanoparticles, fluids). Furthermore, the design of new opto-nano-mechanical devices requires a deep understanding of the optical control on the coherent nano-motion. In the present communication, we describe the elastic properties of the very popular anodized tubular nanoporous alumina film.

This is accomplished through a complete description of the dynamics of GHz acoustic waves based on the non-destructive picosecond laser ultrasonics methods. The transparent thin film with a thickness of $H=360\text{nm}$, is made of laterally disordered cylindrical pores with a diameter of 20nm that are etched perpendicularly to the surface of an aluminium substrate forming a system of air-filled tubes with interconnected alumina walls. These vertical tubes are separated from an aluminium substrate by a transparent alumina layer of a $\sim 30\text{nm}$ thickness. The tubes are opened like organ pipes only at the free surface. The hypersound is photogenerated by the femtosecond pump in the opaque aluminum substrate and penetrates in the nanoporous layer. Time-resolved Brillouin oscillations within the transparent nanoporous film as well as acoustic echoes returning to the substrate are then detected by the time-delayed probe beam. This allows the determination of the longitudinal sound speed V_L and the optical refractive index of the nanoporous film. Additionally up to seven standing acoustic waves (eigenmodes) associated to the vibrations of the entire nanoporous film were detected. Most of the frequencies f_n of these eigenmodes exhibit just a little departure from the closed organ pipe $f_n=(2n-1)V_L/4H$ ($n=1, 2, \dots$) sequence. The knowledge of these eigenmode frequencies improves the precision in the determination of V_L . Furthermore, these GHz eigenmodes exhibit unusual long lifetimes greater than 1ns . Their strong confinement has been explained by the presence of the thin alumina layer playing the role of an acoustic mirror. The reflection of the acoustic waves incident on the layer/substrate structure increases with increasing frequency up to $\sim 80\text{GHz}$. Finally, we

demonstrate that our failure to detect some particular eigenmodes through the photoelastic effect is due to the orthogonality of the acoustic standing-wave function and the probe beam electric field wave function.

The selection rules for the detection of the coherent confined phonons derived by us have been never reported before. Earlier the failure to detect through the classical Brillouin scattering of light by thermal phonons the acoustic resonances of thin films deposited on the substrates had been attributed either to compensation of the photoelastic scattering from the film by that from the substrate [1] or to the compensation of the photoelastic effect by the so-called “ripple” effect [2].

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Preliminary results on non-contact characterisation of weathered mineral materials by surface acoustic waves

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Due to deterioration and weathering, mineral materials found in cultural heritage objects show a depth dependent change of properties. Mineral cultural heritage objects within the scope of the project could be stone objects like facades or sculptures, as well as brick walls, mortars, plasters, and mural paintings. By using of non-contact surface acoustic waves (SAWs) of different wavelengths depth profiles of acoustically sensitive properties could be measured. The results on weathered sandstone samples, mortars of different porosities, and consolidated samples showed that the method is well suited to assess the weathering state. The results correlate with validation measurements using minimal invasive destructive methods. Future research will focus on the development of a non-destructive scanning method for weathered mineral materials to evaluate the actual state of objects and to monitor changes due to the application of conservation methods.

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New opportunities for ultrasonic characterization of stiffness anisotropy in composite materials

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Stiffness anisotropy is a natural consequence of a fibrous structure of composite materials. The effect of the anisotropy is two-fold: it is highly desirable in some cases to assure a proper response to mechanical loading, while it might be even harmful for the applications based on “isotropic” composite materials. To provide a controllable flexibility in material architecture by corresponding fibre alignment, the methodologies for precise nondestructive monitoring of the fibre orientation are required. The in-plane stiffness anisotropy causes ultrasonic shear waves to be birefringent: their propagation velocity depends on the wave polarization direction. In this paper, the polarization effects in ultrasonic birefringence are applied for monitoring fibre orientation and evaluation of in-plane stiffness anisotropy in various composite materials. The birefringence approach is shown to suggest a simple way to rapid mapping of fibre orientation in short- and long-fibre reinforced materials. Precise measurements (units of degrees) of the in-plane fibre undulation are demonstrated in carbon fibre-reinforced composite. In cross-plyed composite laminates, the birefringence probes the difference in the in-plane stiffness between successive plies and, therefore, is similar to a differential circuit in electrical engineering. That provides an extraordinary high sensitivity of the technique to any deviation from the symmetry caused either by extra plies or by the variation in their alignment. The technique is shown to be sensitive to alteration of stiffness anisotropy induced by impact damage in multi-axial non-crimped fabric composite materials.

The anisotropy of stiffness also affects strongly the propagation of plate waves in composites. In the paper, the effect of the plate wave structure on the velocity anisotropy is analysed. It is shown that measurements of Young's modulus anisotropy by means of flexural waves are based on the wave structure with axial strain domination that requires different frequencies in various azimuthal directions. The relation between axial and shear strains in different propagation directions is found to vary with frequency thus causing dispersion of velocity anisotropy. Inhomogeneous depth distribution of axial strain in flexural waves enables depth-resolved NDT of stiffness anisotropy in "isotropic" composite laminates. The velocity anisotropy and its frequency dependence provide frequency variation of the beam steering angle for plate waves (dispersion of beam steering). This effect is important to be accounted for in various NDT applications of plate waves, e.g. it might affect the configuration of ultrasonic sensors in SHM-applications. The results obtained show that the effect of anisotropy and its implications can be enhanced or reduced by matching the operation frequency.

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Session 11B: In service/strain/damage monitoring

Damage detection of frame structures based on dynamically measured flexibility matrix

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Damage in the structure causes change in the stiffness of the damaged member, which consequently changes the flexibility matrix. Flexibility matrix can be dynamically measured by measuring modal. The use of dynamically measured flexibility matrix to indicate and locate damage is reported in many studies. However their focus is mostly on structures with single-dimensional motion e.g. beams or slabs. It means each node has one degree of freedom and all DOF's are in the same direction. This makes the damage detection easy in many ways. Firstly it is more likely that the damage section affects the lower modes. Secondly, because all mode shapes are in one direction, damage affects more of the detected modes. It is much easier to relate the damaged section to the affected DOF's. For a 3-D structure with degrees of freedoms in three directions e.g. frame structures, both modal testing and damage detection become more complicated. In a frame structure, members are connected to two joints. Considering each joint as a node, each member is correlated to six DOF's. Each member has axial and shear stiffness. So considering the structure's geometry, the contribution of members to the stiffness matrix is more complicated than a beam or slab. Diagonal members add to this complexity since the local axes of axial and shear stiffness are not parallel to the global axes. In this system, each DOF of the stiffness matrix is influenced by all the members connected to that node but in different ways, depending on the geometry of that member. When one member is damaged, it certainly affects the related degrees of freedom in the stiffness matrix. A change in a degree of freedom could be caused by the damage of any of the correlated members. Since flexibility matrix is global, damage does not only affect the related DOF's, but others too. So a change in a degree of freedom of flexibility matrix is not necessarily because of its related members, but could be due to the change in other DOF's. This article aims to develop a reliable damage detection method for frame structures. The modal parameters of a three story frame are calculated numerically for intact and damage cases. Changes in the flexibility matrix were analysed for scenarios when the damage member is known. There are few patterns that relate DOF's and members which can be used to locate the damage member.

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Methods for detection and cleaning of fouling in pipelines

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The detection and cleaning of fouling in pipes is currently a highly important problem in several industry sectors such as petrochemical and food. The event of fouling is associated with a substantial increase in the plant operation costs. Furthermore, fouling not only promotes corrosion susceptibility but also allows the growth of micro-organisms thereby reducing the pitch area and pipe efficiency. This in turn increases the cost of pumping and therefore the energy required in production. As a result a replacement of the pipes is often needed. A number of methods and patents have been developed to address these problems and various mechanical, chemical, or combined tools have been employed to date. Most of these procedures require halting production and consequently there is a considerable cost associated with such practice and the current cleaning processes involved. In addition, these processes bring about significant environmental and safety implications. A critical review of new state of the art cheaper, safer and more environmentally friendly methods is presented in this study, including ultrasonics based approaches. This paper also seeks to analyse limitations in terms of detection, cleaning and attendant materials issues that are pertinent to prevention of fouling in pipes. Finally, an overview of recent developments in this area with an emphasis on potential market opportunities is captured.

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Concrete compressive strength estimation in situ using direct and indirect testing methods according to EN 13791.

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Fig. 1: Pullout testing (left) and Schmidt Rebound Hammer testing (right)

The aim of the present study is the testing procedure and the results from the lab and in situ testing of precast bridge beams that took place in order to: (i) Determine the correlation between direct and indirect compressive strength testing methods (ii) Estimate the compressive strength of all the precast beams of the bridge under discussion using indirect compressive strength testing methods (iii) In order to estimate the compressive strength with a combination of direct and indirect methods testing with both methods, was carried out, in

situ, at the same positions. Tests included: (i) Concrete cores cutting and test of the cores in compression at the laboratory (EN 12504-1) (ii) Schmidt Rebound Hammer testing (EN 12504-2) (iii) Pull-out testing (EN 12504-3). A new correlation curve was calculated for the calibration of the indirect testing methods. Using this new correlation curve, the estimation of the compressive strength of all the bridge's beams was made possible.

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An Experimental study on the strain contribution of horizontal and vertical web reinforced bar of High Strength Concrete Deep Beams

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Reinforced concrete deep beams have many useful applications particularly in foundations, tall buildings, nuclear power plants and offshore structures. The design of these structural elements is not covered adequately by national codes of practice: for example the current British Code BS 8110, explicitly states that 'for design of deep beams, reference should be made to specialist literature. Deep beams are structural elements loaded as beams in which a significant amount of the load is transferred to the supports by a compression strut trajectory joining the load and the reaction. In this regard the presence of the web reinforcement is mostly to limit the crack widths which may be caused by the principal tensile stresses which lead to failure load. A comparative study is performed to predict the strain contribution of horizontal and vertical web bar located at compression strut trajectory from support point to load points. For this purpose three high strength concrete (HSC) rectangular-section deep beams with the length to depth ratio less than three, were designed based on American Concrete Institute (ACI) code with variation of tensile bar percentage and casted and loaded in laboratory. The longitudinal, web steel strains and concrete strains were measured for every incremental load. Based on the strain analysis at the web bar located in compression strut trajectories before of first crack occurrences, the vertical bar strain is more than horizontal bar strain and by first crack happening this ratio is same and increasing toward horizontal bars while it becomes more than two times in horizontal bars when tensile bar yields. At ultimate load the strain contribution of horizontal bar is more than four times in comparison by vertical bars.

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A Soft and Hardware Complex for Recording and Processing of Acoustic Emission Signals and for Location and Identification of Their Sources

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Acoustic emission (AE) is one of the methods for nondestructive testing of materials and structures, which consists in recording ultrasonic waves emitted in the process of local structural rearrangement of the material. The complexity of decoding the AE signals and determining dependencies between the AE parameters and the mechanical and operational characteristics imposes limitations on the active introduction of this method in various spheres of research studies and diagnostics of states of materials and structures. On the other hand, the high efficiency and reliability of the AE method shows the urgency of its evolution and application in development of equipment and software for recording, processing, analyzing, and identifying the AE signals. The amplitude of AE signals decreases as they propagate in the material, thus creating certain difficulties in their recording. The program uses the simplifying assumption that the calculated time delay is equal to the difference between recording times of corresponding peak values of amplitudes for each signal. This leads to small errors, but allows one to substantially decrease the amount of calculations. The excess of the discrimination threshold voltage is traced by the program in the channel selected as a trigger source, and, in a certain moment, the event occurs, triggering the data reading procedure in all channels. Further, in accordance with the simplifying assumption, the time delays in the arrival of signals at the RCs are determined from the total data array obtained from all channels. The peak amplitude values are selected for each signal, and the differences of corresponding time values are determined. The use of the wavelet analysis technology makes it possible to identify AE sources by types of defects and mechanisms of their development, namely, plastic deformation and ductile failure (generation and movement of dislocations, twinning), and brittle failure (formation of microdiscontinuity flaws and cracks). This procedure was approved on a number of materials. It is based on an evaluation of specific features of AE signals by digital signal processing. The energy and time localized wavelet spectrum of AE signals are selected as informative AE parameters. The analysis and further identification of types of AE signals were performed on testing of a wide circle of structural materials, namely, carbon and alloy steels and titanic and aluminum alloys under conditions of various loading schemes. The execution of this procedure in real time is confronted with certain difficulties due to a need of using sufficiently large processor resources of the computer. Therefore, the problem of optimizing realtime identification of the AE source is not currently carried out as a part of the described software product.

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