Proceedings of the 6th International Conference on INTEGRITY-RELIABILITY-FAILURE
(Lisbon/Portugal, 22-26 July 2018)
Proceedings of the 6\textsuperscript{th} International Conference on INTEGRITY-RELIABILITY-FAILURE
(Lisbon/Portugal, 22-26 July 2018)

Editors

\textit{J.F. Silva Gomes and Shaker A. Meguid}

FEUP-INEGI
(2018)
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Preface</th>
<th>xxiii</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Scientific Committee</td>
<td>xxiv</td>
</tr>
<tr>
<td>Organizing Committee and Secretariat</td>
<td>xxv</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>xxvi</td>
</tr>
<tr>
<td>List of Tracks and Symposia</td>
<td>xxvii</td>
</tr>
</tbody>
</table>

## INVITED KEYNOTE PAPERS

1

7001 STRATEGIES FOR IMPROVED VEHICLE SAFETY: SURVIVABILITY OF OCCUPANTS. Shaker A. Meguid, Mohamed T.Z. Hassan.

3

7002 ENHANCEMENT OF FATIGUE LIFE AND ELONGATION OF METALLIC MATERIALS BY HIGH-DENSITY PULSED ELECTRIC-CURRENT. Yang Ju.

5

7003 SAFETY IN SPORTS: CHALLENGES AND OPPORTUNITIES. Veit Senner.

## CONFERENCE MAIN TOPICS

### TOPIC-A: COMPOSITE AND ADVANCED MATERIALS

11


13

7097 INVESTIGATION INTO THE THERMAL RESISTANCE OF A POLYMER COMPOSITE WITH AEROGEL. Robert Szczepaniak, Pawel Przybylek, Arkadiusz Bartuzi.

23

7110 MECHANICAL PROPERTIES OF NiAl-TiB2 COMPOSITE MATERIALS. Masashi Yoshida.

31

7123 EFFECTS OF ACCELERATED AGEING ON THE TENSILE PERFORMANCE OF GFRP/EPOXY COMPOSITE AND THERMOSET EPOXY. Silviu Ivan, Matteo Cavasin, Stefanos Giannis, Ivo Dlouhy, Barry Thomson.

41

7129 SOME QUASI-ISOTROPIC LAMINATES ARE MORE ISOTROPIC THAN OTHERS. Mazen A. Albazzan, Ramy Harik, Zafer Gürdal, Jesse Hartzell.

43

7135 THERMO-PROTECTIVE PROPERTIES OF POLYMER COMPOSITES WITH NANOTITANIUM DIOXIDE. Sylwester Stawarz, Natalia Bryła, Wojciech Kucharczyk, Mohamed Bakar, Magdalena Stawarz.

57

7137 THE MECHANICAL AND THERMAL BEHAVIOR OF EXPONENTIALLY GRADED SANDWICH PLATES IN BENDING TEST. Dongdong Li, Zongbai Deng, Shang-Chao Hung, Nai-Jen Cheng.

75


77
MATERIAL CHARACTERISTICS OF GEOPOLYMERS BASED ON AN INDUSTRIAL WASTE PRODUCT. Jan Fořt, Eva Vejmelková, Zdeněk Soukup, Pavla Rovnaníková, Robert Černý. 85

SURFACE MODIFICATION OF POLYSTYRENE BEADS WITH SULFONAMIDE DERIVATIVES AND APPLICATION TO WATER SOFTENING SYSTEM. Seong Ik Jeon, Cheol-Hee Ahn. 93

MECHANICAL PROPERTIES AND MICROSTRUCTURE OF CARBON-FIBRE/ALUMINIUM-MATRIX AND CARBON-FIBRE/TITANIUM-MATRIX COMPOSITES. Alexander Rudnev, Rida Gallyamova, Andrew Gomzin, Andrew Kolchin, Sergei Galyshev, Fanil Musin, Sergei Mileiko. 95

APPLICATION OF ZEOLITE IN CONCRETE MIXTURES FOR RADIONUCLIDE BARRIERS. Eva Vejmelková, Martin Keppert, Petr Bezdíčka, Robert Černý. 97

DAMPING PROPERTIES OF CORK/FIBRE REINFORCED POLYMER COMPOSITES. Ali Daliri, Tahsin Anowar, José Silva. 101

SILICATE-BASED FIBRES TO REINFORCE HIGH TEMPERATURE COMPOSITES. Sergei Mileiko, Andrew Kolchin, Natalia Novokhatskaya, Nelly Prokopenko, Olga Shakhlevich, Vladimir Chumichev, Sergei Abashkin. (Invited Paper). 103

EFFECT OF HOSTILE SOLUTIONS ON THE VISCOELASTIC BEHAVIOUR OF CARBON/EPOXY LAMINATES. M. Kamocka, Ana M. Amaro, Paulo N.B. Reis, Maria A. Neto, José Maria Cirne. 105

THERMAL AND MECHANICAL ANALYSIS OF AN EPOXY FOAM SYNTHESIZED BY MEANS OF A CHEMICAL FOAMING AGENT. Matteo Cavasin, Marco Sangermanno, Milena Salvo, Stefanos Giannis. 107

ISOLATING VIBRATION BY PERIODIC COMPOSITE STRUCTURES. Hongping Hu, Yuantai Hu. 109

SELF-ACTUATED MORPHING COMPOSITE WITH TUNABLE FREQUENCY AND DAMPING. Arnaldo Casalotti, Giulia Lanzara. 111

CLUSTERING OF TRIBOLOGICAL FAULTS USING THE WARD METHOD. Antonio P.V. Pinto, Carlos E.F. Bezerra, Andreyvis S. Souza, Marco A.L. Cabral, Efrain P. Matamoros. 125

MATHEMATICAL MODELING OF THE BLENDED WING BODY AIRCRAFT FLOW-OVER IN CRUISE MODE. Franceska Slobodkina. 135

TIME-HARMONIC ANALYSIS OF LINEAR ANISOTROPIC ELASTIC SOLIDS WITH A BOUNDARY ELEMENT METHOD. Leonid Igumnov, Ivan Markov, Igor Vorobtsov, Mikhail Grigoryev. 139

THREE-DIMENSIONAL DYNAMIC ANALYSIS OF A THREE-PHASE POROELASTIC MEDIUM USING THE TIME-DOMAIN BOUNDARY ELEMENT METHOD. Andrey Petrov, Leonid Igumnov, Igor Vorobtsov, Aleksandr Belov. 141

NUMERICAL SOLUTION FOR A TRANSIENT PROBLEM OF A SANDSTONE LAYER ON A SOIL FOUNDATION UNDER VERTICAL LOAD USING BEM. Svetlana Litvinchuk, Akeksandr Ipatov, Aleksandr Boev. 143
7207  STRUCTURAL INTEGRITY ASSESSMENT OF CRACKED COMPOSITE PLATE UNDER AEROELASTIC LOADING BY MEANS OF XFEM. Nur Azam Abdullah, Jose L. Curiel Sosa, Nanda Wirawan, Mahesa Akbar.

7208  AEROFRACTURELASTIC ON WING BOX OF MULTI-PURPOSE COMMUTER AIRCRAFT UNDER GUST LOAD BY MEANS OF XFEM. Nur Azam Abdullah, Nanda Wirawan, Jose L. Curiel Sosa, Mahesa Akbar.

7215  ASYMPTOTIC STOKES FLOWS USING AXIAL GREEN FUNCTION METHOD WITH REFINEMENT. Junhong Jo, Hong-Kyu Kim, Do Wan Kim.

7219  ANALYSIS OF THE COLD FORMING PROCESS. Sigita Kilikevičiutė, Ramūnas Česnavičius, Povilas Krašauskas, Andrius Juodsnukis.

7223  NUMERICAL AND EXPERIMENTAL ANALYSIS OF AERONAUTICAL CFRP COMPONENTS SUBJECTED TO STRUCTURAL LOADS. Alessandro Castriota, Vito Dattoma, Riccardo Nobile, Francesco Panella, Alessandra Pirinu, Andrea Saponaro.

7232  NEW APPROACH TO SOLVING MATHEMATICAL EQUATION FOR DAMPED OSCILLATIONS BY SLIDING (COULOMB) FRICTION AT THE KARAKURI MECHANISM. Tomas Riegr, Ivan Masin.

7246  SIMULATION OF A VIBRATORY SYSTEM WITH SHAPE MEMORY ALLOY UNDER ROTATING UNBALANCE EXCITATION. Michel A. Silva, Vinicius Piccirillo, Carlos A. Andrade.

7307  FROM PERCOLATION OF FRACTURED MEDIA TO SEISMIC ATTENUATION: A NUMERICAL STUDY. Mikhail Novikov, Vadim Lisitsa.

TOPIC-C: EXPERIMENTAL MECHANICS AND INSTRUMENTATION

7052  DETERMINATION OF BURST PRESSURE FOR DEFECTED PIPES. Abdullah M. Al Shabibi, Majid Al Moharbi, Sultan Al Owaisi.

7060  MECHANICAL BEHAVIOR OF NEW POLYUREA ELASTOMERS: CONSTITUTIVE MODELLING. Nahuela Rull, Antoni Sanchez-Ferrer, M. Patricia Frontini.

7101  FATIGUE STRENGTH OF CARBON STEEL COVERED WITH PROTECTIVE LAYERS FOR CO2 ASSISTED SHALE GAS MINING. Marta Baran, Tomasz Brynk, Z. Pakiela.

7111  RESIDUAL STRESSES - NEUTRON DIFRACTOMETER STRESS-SPEC @ FRM II. Joana Rebelo Kormmeier, Michael Hofmann, Weimin M. Gan, Jens Gibmeier, Jan Saroun.

7152  COMPARATIVE STUDY ON ACCELERATED FLUID DIFFUSION IN THERMOSET EPOXY AND GFRP FOR MARINE APPLICATIONS. Matteo Cavasin, Silviu Ivan, Stefanos Giannis, Marco Sangermano, Milena Salvo, Barry Thomson.

7156  CONDITION MONITORING OF AN INDUSTRIAL BUCKET ELEVATOR FOR BULK MATERIALS. Piotr Sokolski, Marek Sokolski.

7163  DIAGNOSIS OF BEARING FAULTS IN COMPLEX MACHINERY USING SPATIAL DISTRIBUTION OF SENSORS AND FOURIER TRANSFORMS. Aouni Lakis, Ali Mahvash, Mohammad Toorani.

7182 EDDY CURRENT APPROACH FOR METALLURGICALLY CLAD PIPE INSPECTION. Cesar G. Camerini, João M.A. Rebello, Rafael W. Santos, João M. Santos, Gabriela R. Pereira.

7197 ADVANCED NDT PROCEDURES AND THERMAL DATA PROCESSING ON CFRP AERONAUTICAL COMPONENTS. Vito Dattoma, Riccardo Nobile, Francesco Panella, Alessandra Pirinu, Andrea Saponaro.

7220 STRENGTH AND MICROSTRUCTURE ANALYSIS OF SPOT WELDED JOINTS. Ramūnas Česnavičius, Sigitas Kilikeyčius, Povilas Krūskauskas, Vytautas Jurgaitis.


7266 ANALYSIS OF HIGH TEMPERATURE PIPE INTEGRITY USING CUSTOMIZED EDDY-CURRENT SYSTEM. Fernando S. Crivellaro, Ana Peixoto, Miguel A. Machado, José P. Sousa, António Custódio, J. Pamies Teixeira, Telmo G. Santos.

TOPIC-D: FATIGUE AND FRACTURE MECHANICS

7074 FRACTURE MECHANICS ANALYSIS OF POROSITY EFFECT ON STRENGTH CHARACTERISTICS OF POROUS ALUMINA. Natsumi Miyazaki, Toshihiko Hoshide.

7080 CREEP FRACTURE OF PLATES IN UNSTEADY COMPLEX STRESS STATE IN THE PRESENCE OF AMBIENT MEDIUM. Alexander Lokoshchenko, Leonid Fomin.

7089 INVESTIGATION OF FATIGUE PROPERTIES OF SOME STEAM TURBINE BLADE MATERIALS. Jan Chvojan, Jaroslav Václavek.

7092 NEW CORROSION MODEL TO PREDICT STEEL STRENGTH. Rachid Dami.

7102 STUDY OF THE EFFECT OF STRESS CONCENTRATORS IN FATIGUE FAILURE ANALYSIS OF A CRANKSHAFT. José R.G. Carneiro, Leonardo C. Aguiar, Gilmar C. Silva, João P.S. Carneiro.

7166 THE EFFECT OF FRESH WATER CORROSIVE SOLUTION ON FATIGUE STRENGTH OF LOW CARBON STEEL. Marta Morgantini, Volodymyr Okorokov, Yevgen Gorash, Donald MacKenzie, Ralph van Rijswick.

7172 APPROACH TO FULL-SCALE FATIGUE TEST OF THE MIG-29 VERTICAL STABILIZER WITH REPAIR OF COMPOSITE STRUCTURES. Piotr Synaszko, Michał Salaciński, Michał Dziendzikowski, Krzysztof Dragan, Andrzej Leski.

7230 PERIDYNAMIC MECHANOCHEMICAL MODELING OF STRESS CORROSION CRACKING. Ziguang Chen, Siavash Jafarzadeh, Shumin Li, Florin Bobaru, Qin Qian.

7233 STRENGTH AND LIFE ANALYSIS IN THE PLASTIC STRAIN RANGE. NEUBER VERSUS STRAIN ENERGY CONSERVATION PRINCIPLE. Luciano Brambilla.
ADVANCED NUMERICAL TECHNIQUES APPLIED TO THE STRENGTH PREDICTION OF STEPPED-LAP ADHESIVE JOINTS. Rui Machado, Raúl Campilho. 311

MIXED-MODE FRACTURE OF BONDED JOINTS USING THE ASYMMETRIC TAPERED DOUBLE-CANTILEVER BEAM TEST. Filipe Nunes, Raúl Campilho. 313

REAR SUSPENSION DEVELOPMENT: DURABILITY STUDY ON THE EFFECTS OF VARIATION OF VEHICLE AND SUSPENSION CHARACTERISTICS IN A TWIST BEAM REAR SUSPENSION. Guilherme Carneiro, Marco Anjos, Ernani S. Palma. 315

COUPLED METHOD TO INVESTIGATE PLASTIFICATION OF HEAVY HAUL RAILWAY WHEELS. Pedro Picanço, Felipe Bertelli, Eduardo A. Lima, Thailon R. Costa, Auteliano A. Santos. 317

TOPIC-E: NANOTECHNOLOGIES AND NANOMATERIALS 325

EFFICIENT FABRICATION METHOD OF METALLIC NANO/MICRO STRUCTURES FOR NANO DEVICES. Masahiko Yoshiino, P. Potejanasak, Duc P. Truong, Motoki Terano. 327

NANOINDENTATION INDUCED PLASTIC DEFORMATION IN NANOCRYSTALLINE ZrN COATING. Zhoucheng Wang. 329

ALUMINA DOPING FOR IMPROVING PROPERTIES OF ZIRCONIA CERAMICS. Danil Belichko, Larysa Loladze, Tetyana Konstantinova, Alexandr Myloslavskyy. 331

NEW CHALLENGES IN THE CREATION OF RELIABLE CERAMIC NANOCOMPOSITES. Igor A. Danilenko, Tetyana E. Konstantinova, Oxana A. Gorban, Irina I. Brukhanova, Larysa V. Loladze, Danil R. Belichko, Artyom V. Shylo. 333

ZINC OXIDE MATERIAL FOR OPTOELECTRONIC APPLICATIONS. Irinela Chilibon. 335

CARBON NANOTUBES BASED SENSORS FOR DAMAGE DETECTION. Erika Magnafico, Arnaldo Casalotti, Maryam Karimzadeh, Krishna C. Chinnan, Giulia Lanzara. 337

IMPROVEMENT OF ADHESION STRENGTH OF THE COPPER NANOWIRE SURFACE FASTENER BY INVESTIGATING THE DIAMETER RATIO OF NANOWIRES. Motohiro Kato, Yuhki Toku, Yasuyuki Morita, Yang Ju. 345

ELECTROMAGNETIC PERFORMANCE OF SPIRALLY DEFORMED COATED NANOWIRES. Yuhki Toku, Yuji Ueda, Yasuyuki Morita, Yang Ju. 347

TOPIC-F: TRIBOLOGY AND SURFACE ENGINEERING 349

STRUCTURAL DEGRADATION OF LUBRICATING GREASES. AN ENERGY DRIVEN PROCESS. Erik Kuhn. 351

CROSS-SECTIONAL MICROSTRUCTURE AND STRESS DISTRIBUTIONS IN THIN FILMS DURING INDENTATION REVEALED BY X-RAY NANODIFFRACTION. Josef Keckes, Rostislav Daniel, Juraj Todt, C. Krywka, M. Burghammer. 353

EVALUATION OF RESEARCH OPPORTUNITIES OF A TRIBOLOGICAL TESTING TAPE MACHINE. Wojciech Żurowski, Wojciech Kucharczyk, Jarosław Zepchlo. 355

FAULT DETECTION IN DIESEL ENGINE INJECTORS USING A VIBRATION AND SOUND PRESSURE LEVEL TECHNIQUE. Jarbas S. Medeiros, Daniel M. Lago, Antônio C. Moreira Filho, Efrain P. Matamoros, João T.N. Medeiros. 357
<table>
<thead>
<tr>
<th>Paper ID</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7304</td>
<td>MICROSTRUCTURE ANALYSIS OF RARE EARTH-MAGNESIUM ALLOY REPAIRED USING HIGH POWER SURFACE LASER CLADDING.</td>
<td>Rongjuan Yang, Dongyun Ge, Xuan Zhao.</td>
</tr>
<tr>
<td>7059</td>
<td>USING DESIGN S-N CURVES AND DESIGN STRESS SPECTRA FOR PROBABILISTIC FATIGUE LIFE ASSESSMENT OF VEHICLE COMPONENTS.</td>
<td>Miloslav Kepka, Miloslav Kepka Jr.</td>
</tr>
<tr>
<td>7077</td>
<td>QUANTITATIVE ANALYSIS OF RELATIONSHIP BETWEEN EXTRUSION BLOW MOLDING PROCESS PARAMETERS AND DEFORMATION PROPERTIES.</td>
<td>Esther R. Dorp, Berenika Hausnerova, Bernhard Möginger.</td>
</tr>
<tr>
<td>7082</td>
<td>MAIN EXPECTED PROBLEMS DURING THE IMPLEMENTATION OF &quot;INDUSTRY-4.0&quot; REFORMS AND THEIR PRACTICAL SOLUTIONS BASED ON IMPROVING THE EFFICIENCY OF USED MECATRONIC SYSTEMS.</td>
<td>Raul Turmanidze, Vasili Bachanadze, Giorgi Popkhadze.</td>
</tr>
<tr>
<td>7189</td>
<td>A NUMERICAL AND EXPERIMENTAL STUDY OF THE ENERGY ABSORPTION CAPACITY OF AUXETIC STRUCTURES MANUFACTURED WITH ADDITIVE TECHNOLOGY.</td>
<td>Filip Sarbinowski, Remigiusz Labudzki, Rafał Talar, Adam Patalas.</td>
</tr>
<tr>
<td>7270</td>
<td>DESIGN METHODOLOGY OF AN ALUMINIUM CHASSIS.</td>
<td>Ana L. Ramos, Oscar Zapata, Tania Berber, Natalia Navarrete.</td>
</tr>
<tr>
<td>7301</td>
<td>COMPARISON OF UNIBODY AND FRAME BODY VERSIONS OF ULTRA EFFICIENT ELECTRIC VEHICLE.</td>
<td>Wojciech Skarka, Tomasz Pabian, Michał Sosnowski.</td>
</tr>
<tr>
<td>7305</td>
<td>METHODOLOGY FOR THE OPTIMIZATION OF AN ENERGY EFFICIENT ELECTRIC VEHICLE.</td>
<td>Wojciech Skarka.</td>
</tr>
<tr>
<td>7050</td>
<td>KINEMATICS ANALYSIS OF MOZAMBIKAN ATHLETES IN THE 100 METERS RACE.</td>
<td>Ercilio Machanguan, Anicêncio Macitela, Alberto Graziano.</td>
</tr>
<tr>
<td>7051</td>
<td>ANALYSIS OF THE PERFORMANCE OF LOWER MEMBERS IN SUSPENSION SERVICE IN VOLLEYBALL.</td>
<td>Anicêncio Macitela, Alberto Graziano.</td>
</tr>
<tr>
<td>7063</td>
<td>THE EFFECT OF MULTIPLE NEUROTRANSMISSION ON THE BIOMECHANICS OF THE HUMAN STOMACH.</td>
<td>Saleh Alrowaili, Roustem Miftahof.</td>
</tr>
<tr>
<td>7066</td>
<td>BIOMECHANICS OF THE BOLUS PROPULSION IN THE COLON.</td>
<td>Omar Al Qatrawi, Roustem Miftahof.</td>
</tr>
<tr>
<td>7067</td>
<td>BIOMECHANICS OF THE HUMAN STOMACH AFTER DIABETIC VAGOTOMY.</td>
<td>Dareen Bash, Roustem Miftahof.</td>
</tr>
<tr>
<td>7075</td>
<td>CONTRACTILE ACTIVITY OF THE HUMAN STOMACH UNDER COMPLEX STIMULATION.</td>
<td>AlDana M. Zaid, Roustem Miftahof.</td>
</tr>
</tbody>
</table>
MODELING OF LARGE GAUGE ARTERIES WITH A SOFT ELASTIC MEMBRANE PIPE FINITE ELEMENT. Francisco Q. Melo, António G. Completo, José L.S. Esteves.

A MECHANICAL ANALYSIS OF CANCELLOUS BONE IN FEA SIMULATION RESEARCH AND EXPERIMENTAL TESTING WITH THE µCT CONTROL. Adam Patalas, Remigiusz Labudzki, Filip Sarbinowski, Bartosz Gapiński, Rafal Talar.

INFLUENCE OF BONE QUALITY IN THE BEHAVIOUR OF GRAFT FIXATION IN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION. Covadonga Quintana, Cristina Rodriguez, Ines Peñuelas, Antonio Maestro.

BIOMECHANICAL BEHAVIOUR CHARACTERIZATION OF THE MATERIALS INVOLVED IN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION. Covadonga Quintana, Cristina Rodriguez, Ines Peñuelas, Antonio Maestro.

IN VIVO CHARACTERIZATION OF MICRO ARCHITECTURE OF A HUMAN VERTEBRA BY MICRO-IMAGING. Hacene Ameddah, Hammoudi Mazouz.

TOPIC-I: CIVIL AND STRUCTURAL ENGINEERING APPLICATIONS

AGGREGATE SIZE AND LATERAL DIMENSION EFFECTS ON CORE COMPRESSIVE STRENGTH OF CONCRETE. Adel Benidir, M'Hamed Mahdad, Ahmed Brara.


SUBSTITUTION OF THE TRANSVERSE REINFORCEMENT WITH ENGINEERED CEMENTITIOUS COMPOSITE IN RC EXTERIOR BEAM-COLUMN JOINTS SUBJECTED TO CYCLIC LOADING. Shwan H. Said.

THE EFFECTS OF SOIL CATEGORY ON THE SEISMIC RESPONSE OF CIRCULAR STEEL WATER TANKS WITH MEDIUM H/D RATIO USING LAGRANGIAN APPROACH. Armen Assatourians, Sohrab Fallahi.

IDENTIFICATION OF HYSTERICALLY DEGRADING STRUCTURES USING THE BOUC-WEN-BABER-NOORI (BWBN) MODEL. Ying Zhao, M. Noori, Wael Altabay.

PERFORMANCE OF AIR CURED CONCRETE TREATED WITH WATERPROOFING ADMIXTURES OR SURFACE TREATMENTS. Sirwan Kamal, Hsein Kew, Hamid Jahromi.

NON-DESTRUCTIVE EVALUATION OF DETERIORATED REINFORCED CONCRETE SLAB USING EXPERIMENTAL AND NUMERICAL METHODOLOGIES. Norbert Renault, Jean-Louis Gallias, Christophe Barnes.

STRAIN-RATE INFLUENCE ON A SHAPE MEMORY ALLOY BASED DAMPER. João Morais, Carlos Santos, Paulo Morais.

PROBABILISTIC TRAFFIC LOAD IDENTIFICATION FOR CONCRETE BRIDGES. Sebastian Zorn, Jörg F. Unger.

COST CONSEQUENCE-BASED RELIABILITY ANALYSIS OF BURSTING FAILURE IN SUBSEA PIPELINES. Bahram Mehrafrooz, Pedram Edalat, Mojtaba Dyanati.

DAMDAMAGE1.0: A MATLAB 3DFE PROGRAM FOR NON LINEAR ANALYSIS OF ARCH DAMS. André Alegre, Sérgio Oliveira.
<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7165</td>
<td>RESILIENCY OF SLAB TRACK SYSTEMS SUBJECTED TO LONG-TERM DETERIORATION: NUMERICAL MODELLING WITH SUBSTRUCTURING TECHNIQUES.</td>
<td>Samuel Matias, Patrícia Ferreira.</td>
</tr>
<tr>
<td>7167</td>
<td>INFLUENCE OF 4 BOLTS-PER-ROW CONNECTION ON A STEEL FRAME BUILDING SUBJECTED TO COLUMN LOSS.</td>
<td>Daniel Nunes, I. Marginean, Adrian Ciutina, Florea Dinu.</td>
</tr>
<tr>
<td>7168</td>
<td>MODAL IDENTIFICATION METHODS IN TIME DOMAIN NUMERICAL TESTS AND APPLICATIONS IN CIVIL ENGINEERING.</td>
<td>Ana Prior, Sérgio Oliveira, Matilde Freitas.</td>
</tr>
<tr>
<td>7170</td>
<td>MONITORING AND ANALYSIS OF CONCRETE DAMS BEHAVIOR OVER TIME CONSIDERING SWELLING EFFECTS. INTEGRATED USE OF FINITE ELEMENT MODELS AND MODELS FOR EFFECTS SEPARATION.</td>
<td>Miguel Rodrigues, Sérgio Oliveira.</td>
</tr>
<tr>
<td>7171</td>
<td>OPTIMIZATION OF WEB STIFFENER IN COLD-FORMED STEEL CHANNEL BEAMS SUBJECTED TO PURE BENDING.</td>
<td>Ayman R. Ahmed, Ahmad M. Abdullah, Sedky A. Tohamy, Amr Bakr Saddek.</td>
</tr>
<tr>
<td>7188</td>
<td>EVALUATION OF HYGRIC PROPERTIES OF CONTEMPORARY PLASTERS.</td>
<td>Jan Fořt, Zbyšek Pavlík, Lukáš Balík, Robert Černý.</td>
</tr>
<tr>
<td>7191</td>
<td>ULTIMATE CAPACITY OF STEEL FRAMES WITH BOLTED CONNECTIONS UNDER COLUMN LOSS SCENARIOS.</td>
<td>Ioan Marginean, Florea Dinu, Robert Kulcsár, Simina Sabău, Dan Dubina.</td>
</tr>
<tr>
<td>7192</td>
<td>APPLICATION OF A COMPLETE STRUCTURAL HEALTH MONITORING CHAIN ON THE CANADIAN RIVIÈRE-AUX-MULETS BRIDGE NUMERICAL MODEL SUBJECTED TO A SEISMIC LOAD.</td>
<td>Farouk Frigui, Jean-Pierre Faye, Carmen Martin, Olivier Dalverny, François Pérès, Sébastien Judenherc.</td>
</tr>
<tr>
<td>7195</td>
<td>NUMERICAL STUDY OF THE ROBUSTNESS OF STEEL STRUCTURES WITH FRICTION JOINTS.</td>
<td>Francisca Santos, Aldina Santiago, Gianvittorio Rizzano, Luís S. Silva, Massimo Latour.</td>
</tr>
<tr>
<td>7201</td>
<td>STATIC AND DYNAMIC ELASTICITY MODULE ANALYSIS OF CEMENT COATING MORTARS.</td>
<td>Ana Isabel Marques, João Morais, Carlos Santos, Paulo Morais, Maria do Rosário Veiga.</td>
</tr>
<tr>
<td>7202</td>
<td>DEVELOPMENT OF ALTERNATE LOAD PATHS IN STEEL FRAMES WITH COMPOSITE BEAMS SUBJECT TO ACCIDENTAL EXPLOSIONS.</td>
<td>Florea Dinu, Ioan Marginean, Ioan Petran, Mihai Senila, Calin Neagu, Dan Dubina.</td>
</tr>
<tr>
<td>7205</td>
<td>NUMERICAL STUDIES ON SEISMIC RESPONSE OF STEEL AND COMPOSITE ECCENTRICALLY BRACED FRAMES.</td>
<td>Mihai Senila, Ioan Petran, Calin Neagu, Florea Dinu.</td>
</tr>
<tr>
<td>7212</td>
<td>FRAGILITY CURVES FOR RC BRIDGES USING GENERALIZED PUSHOVER ANALYSIS.</td>
<td>Camilo Perdomo, Ricardo Monteiro.</td>
</tr>
<tr>
<td>Page</td>
<td>Title</td>
<td>Authors</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>7216</td>
<td>STUDY OF THE PERFORMANCE OF R.C. WALLS WITH OPENINGS USING AN</td>
<td>Alaa Morsy, Youssef Ibrahim.</td>
</tr>
<tr>
<td></td>
<td>ANALYTICAL FINITE ELEMENT MODEL.</td>
<td></td>
</tr>
<tr>
<td>7217</td>
<td>INTEGRATING THREE INSPECTION/MONITORING METHODS FOR CIVIL ENGINEERING</td>
<td>Amir Nasrollahi, Piervincenzo Rizzo.</td>
</tr>
<tr>
<td></td>
<td>APPLICATIONS.</td>
<td></td>
</tr>
<tr>
<td>7227</td>
<td>ECODESIGN FOR DECONSTRUCTION IN THE LIFE CYCLE POST-OPERATIONAL</td>
<td>Silvia Leticia Vacelkoski, George Stanescu.</td>
</tr>
<tr>
<td></td>
<td>STAGE TO IMPROVE CONCRETE RECYCLING IN BRAZIL.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RESISTANCE TO progressive COLLAPSE.</td>
<td></td>
</tr>
<tr>
<td>7248</td>
<td>IMPACT OF PREVENTIVE MAINTENANCE ON FLEXIBLE PAVEMENT SERVICE LIFE.</td>
<td>Manuel Ruiz, Luis Ramirez, Fermín Navarrina, J.R. Fernández Mesa, David López-Navarrete, Mario Aymerich.</td>
</tr>
<tr>
<td>7250</td>
<td>USE OF STRUCTURAL MASONRY OF CONCRETE BLOCKS AND PROTECTED LABS</td>
<td>Harlen Nunes, Roberto Carvalho.</td>
</tr>
<tr>
<td></td>
<td>WITH FENCED CORDOBA IN RESIDENTIAL BUILDINGS.</td>
<td></td>
</tr>
<tr>
<td>7255</td>
<td>STRUCTURAL RECOVERY AND PROJECT MANAGEMENT: THE DESIGN DRAWS</td>
<td>Giorgio Garzino.</td>
</tr>
<tr>
<td></td>
<td>CONTRIBUTION.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DAMPING.</td>
<td></td>
</tr>
<tr>
<td>7260</td>
<td>THERMAL EFFECT OF A LOCALIZED FIRE IN THE STEEL STRUCTURE OF AN</td>
<td>Paulo Piloto, Edson M.S. Júnior, Francisco A.A. Gomes.</td>
</tr>
<tr>
<td></td>
<td>OPEN CAR PARK.</td>
<td></td>
</tr>
<tr>
<td>7261</td>
<td>FIRE DYNAMICS IN OPEN COMPARTMENTS.</td>
<td>Paulo Piloto, Ketlen Possoli, Luiz C.M. Júnior, Khadouma Nechab, Benarous Abdallah.</td>
</tr>
<tr>
<td></td>
<td>IN STRUCTURES.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SIGN STRUCTURES IN WEST VIRGINIA.</td>
<td></td>
</tr>
<tr>
<td>7276</td>
<td>DEVELOPMENT OF A STRUCTURE VIBRATIONS MONITORING INSTRUMENT USING</td>
<td>J.G.S. Jesus, Matheus S. Vieira, Thalyta L. Santos, R.S. Gonçalves.</td>
</tr>
<tr>
<td></td>
<td>TRIAXIAL ACCELEROMETER.</td>
<td></td>
</tr>
<tr>
<td>7286</td>
<td>STABILITY EVALUATION OF MARBLE STONE CLADDING AFFECTED BY BOWING AND</td>
<td>Rui Sousa, Hipólito Sousa.</td>
</tr>
<tr>
<td></td>
<td>WIND PRESSURE - A CASE STUDY.</td>
<td></td>
</tr>
</tbody>
</table>

**TOPIC-J: IMPACT AND CRASHWORTHINESS**

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7131</td>
<td>A FINITE ELEMENT MODEL TO STUDY WELD AND GEOMETRIC IMPERFECTIONS IN</td>
<td>Jose A. López-Campos, Abraham Segade, E. Casarejos, Jose R. Fernandez, J.A. Vilán.</td>
</tr>
<tr>
<td></td>
<td>AN IMPACT ATTENUATOR DEVICE.</td>
<td></td>
</tr>
<tr>
<td>7132</td>
<td>STUDY OF A CRASH BOX DESIGN OPTIMIZED FOR A UNIFORM LOAD PROFILE.</td>
<td>Abraham Segade, Alejandro Bolaño, Jose A. López-Campos, E. Casarejos, Jose R. Fernandez, J.A. Vilán.</td>
</tr>
</tbody>
</table>

-iii-
<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7144</td>
<td>RESEARCH ON THE ANISOTROPIC PROPERTIES OF WOOD AT HIGH-RATE LOADING.</td>
<td>Anatoly Bragov, Alexander Konstantinov, Andrey Lomunov.</td>
</tr>
<tr>
<td>7160</td>
<td>ESTIMATION OF DEFORMATION ENERGY DURING IMPACT DESTRUCTION OF ADHESIVE JOINT SAMPLES.</td>
<td>Jan Godzimirski, Andrzej Komorek, Robert Szczepaniak.</td>
</tr>
<tr>
<td>7198</td>
<td>OPTIMIZATION STRATEGIES FOR CRASH RELEVANT VEHICLE STRUCTURES.</td>
<td>Ralf Sturm, Michael Schäffer, Marco Münster.</td>
</tr>
<tr>
<td>7256</td>
<td>MECHANICAL STUDY OF ADDITIVE MANUFACTURED HONEYCOMB STRUCTURES.</td>
<td>Piotr Dziewit, Paweł Platek, Jacek Janiszewski.</td>
</tr>
<tr>
<td>7321</td>
<td>MULTIBODY DYNAMIC ANALYSIS OF WHIPLASH.</td>
<td>Mohamed T. Z. Hassan, Mo Gabriel Shi, S. A. Meguid.</td>
</tr>
<tr>
<td>7322</td>
<td>EFFECT OF IMPACT SEVERITY ON OCCUPANT’S RESPONSE DURING REAR-END COLLISIONS.</td>
<td>Mohamed T. Z. Hassan, S. A. Meguid.</td>
</tr>
</tbody>
</table>

**TOPIC-L: INDUSTRIAL ENGINEERING AND MANAGEMENT**

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7055</td>
<td>CUTTING AND PASSIVE TIMES CALCULATION FOR TURNING PROCESS.</td>
<td>Nivaldo L. Coppini, Gabriel N. Oliveira, Danilo E. Braga.</td>
</tr>
<tr>
<td>7070</td>
<td>CONDITION MONITORING WITH PREDICTION BASED ON OIL ENGINES OF URBAN BUSES - A CASE STUDY.</td>
<td>Hugo Raposo, José T. Farinha, Inácio Fonseca, Luís A. Ferreira.</td>
</tr>
<tr>
<td>7087</td>
<td>BUSINESS SUSTAINABILITY THROUGH THE PRACTICE OF CSR: THE A. PETTI SPA EXPERIENCE.</td>
<td>Maria R. Sessa, Ornella Malandrino, Daniela Sica, Stefania Supino.</td>
</tr>
<tr>
<td>7133</td>
<td>DEVELOPING THE BEST PREVENTIVE MAINTENANCE POLICY FOR FULLY AUTOMATED SHIP-TO-SHORE CRANE.</td>
<td>Yassine Achhal, Hassan Samadi.</td>
</tr>
<tr>
<td>7148</td>
<td>COMMON CAUSE ANALYSIS OF CIRCULAR VARIABLE NACELLE INLET CONCEPTS FOR AERO ENGINES IN CIVIL AVIATION.</td>
<td>Stefan Kazula, David Grasselt, Klaus Höschler.</td>
</tr>
<tr>
<td>7153</td>
<td>NEW APPROACH FOR THE JOINT OPTIMIZATION OF THE DESIGN AND MAINTENANCE OF MULTI-COMPONENT SYSTEMS BY INTEGRATION OF LIFE CYCLE COSTS.</td>
<td>Oussama Adjoul, Khaled Benfriha, Améziane Aoussat, Yacine Benabid.</td>
</tr>
<tr>
<td>7155</td>
<td>METHODOLOGICAL FRAMEWORK FOR IMPLEMENTATION OF A PREDICTION RELIABILITY MODEL FOR IGBT POWER MODULES USED IN RAILWAY APPLICATIONS.</td>
<td>Essi Dabla, François Pérès, Carmen Martin, Claire Fournier, Michel Piton, Floran Andrianoeilon.</td>
</tr>
<tr>
<td>7157</td>
<td>DEFINITION AND IMPLEMENTATION OF AN INTEGRATED MANAGEMENT PLAN (IMP) APPLIED TO THE EQUIPMENT AT PERIODICAL TECHNICAL INSPECTION (PTI) STATIONS.</td>
<td>Julio Julio Garcia-Cordonié, Pablo Izquierdo, José A. Vilán, Abraham Segade, E. Casarejos, M.L. Lago.</td>
</tr>
</tbody>
</table>
7159 PRELIMINARY SYSTEM-SAFETY-ANALYSIS AND COMPARISON BETWEEN TWO NEW BROADBAND NOISE ABSORBING ACOUSTIC-LINER CONCEPTS FOR CIVIL AVIATION. Marcel Mischke, Stefan Kazula, David Grasselt, Klaus Höschler.

7169 A MECHANICAL AND STATE ANALYSIS OF A GAS TURBINE. Suzana Lampreia, Vitor Lobo, José Requeijo.

7180 INTEGRATION OF MAINTENANCE SYSTEMS. Sarje Suhas.

SPECIAL SESSIONS

SYMPOSIUM-1: EXPERIMENTAL MECHANICS FOR RELIABILITY

7058 DRAG REDUCTION OF A SWEPT WING BY MEANS OF PLASMA ACTUATORS. Sergey Chernyshev, Marat Gamirullin, Andrey Kiselev, Aleksandr Kuryachii, Sergey Manuilovich, Dmitry Sboev.

7127 DUCTILITY OF TITANIUM ALLOYS IN A WIDE RANGE OF STRAIN RATES. Vladimir V. Skripnyak, Vladimir A. Skripnyak, Evgeniya G. Skripnyak.

7141 AN IN-SITU EVALUATION OF STRUCTURAL DAMAGE IN A HIGH POWER SPALLATION NEUTRON SOURCE. Masatoshi Futakawa, Tao Wan, Hiroyuki Kogawa, Takashi Naoe.


7274 APPLICATION OF THREE-AXIS ACCELEROMETER ON VIBRATION ANALYSIS IN MACHINING PROCESSES. R.S. Gonçalves, Thalyta L. Santos, J.G.S. Jesus, Matheus S. Vieira.

7323 TRACKING OF DISPLACEMENT FIELD USING STEREO-CORRELATION IMAGES. A. May, A. Mokdad, H. Habouche, T. Rehamnia.

SYMPOSIUM-2: MODELING OF FRACTURE AND FRAGMENTATION OF SOLIDS UNDER STATIC AND DYNAMIC LOADING. DETERMINISTIC AND PROBABILISTIC APPROACHES

7078 PERIDYNAMICS ANALYSIS OF GLASS FRACTURE UNDER EXPLOSION LOAD. Jian Tu, Li-jun Zhao, Shan Yu, Chun-liang Xin.

7079 PROTECTION OF STRUCTURES AGAINST LONG PROJECTILES. Alexander Gerasimov, Sergey Pashkov, Roman O. Cherepanov.

7099 MODELLING POROUS STRUCTURES AND MECHANICAL BEHAVIOUR OF CERAMICS USING PROBABALISTIC APPROACH. Igor Yu. Smolin, Valentina A. Mikushina, Pavel V. Makarov, Mikhail O. Eremin.


7128 MODELLING OF THE MECHANICAL RESPONSE OF Zr-Nb AND Ti-Nb ALLOYS IN A WIDE TEMPERATURE RANGE. Vladimir A. Skripnyak, Vladimir V. Skripnyak, Evgeniya G. Skripnyak, Nataliya V. Skripnyak.

7145 PROBABILISTIC FAILURE OF CERAMICS UNDER HIGH-VELOCITY IMPACT. Sergey A. Zelepugin, Vladimir F. Tolkachev, Alexey S. Zelepugin.

7147 NUMERICAL SIMULATION OF THE EXPLOSIVE COMPACTION OF MULTI-COMPONENT MIXTURES. Sergey A. Zelepugin, Oksana Ivanova.

7185 DISCRETE ELEMENTS SIMULATION OF GEOLOGICAL FAULT FORMATION. Vadim Lisitsa, Vladimir Tcheverda, Victoria Valyanskaya.


7234 ANALYSIS OF THE PENETRATION OF BARRIERS BY IMPACTORS WITH AN EXPLOSIVE SUBSTANCE. Viktor P. Glazyrin, Maxim Yu. Orlov, Yuri N. Orlov.

7263 A METHOD FOR DETERMINING RELIABILITY OF A SELECTED STRUCTURAL COMPONENT OF AN AIRCRAFT FROM THE POINT OF VIEW OF FATIGUE PROCESSES. Mariusz Zieja, Mirosław Zieja, Mariusz Ważny.

SYMPOSIUM-3: FRACTURE BEHAVIOUR AND FATIGUE DAMAGE OF STRUCTURES: THEORY AND EXPERIMENTS

7095 FRACTURE FRAMEWORK OF PLASTIC PIPES: EXPERIMENTAL WORK AND FINITE ELEMENT ANALYSIS OF DOUBLE POLYETHYLENE CANTILEVER BEAM SPECIMENS. Federico Rueda, César Hernández, Patricia Frontini.

7142 INFLUENCE OF MICROSTRUCTURE ON THE MECHANICAL BEHAVIOUR OF STEEL IN EXTREME ENVIRONMENT. Valeriy Lepov, Albert Grigoriev, Afanasiy Ivanov, V. Achikasova, Anastassia Ivanova, Nikolay Balakleiskii, Boris Loginov, Artem Loginov.

7146 EFFECT OF GRAPHITE MORPHOLOGY ON COMPACTED GRAPHITE IRON THERMOMECHANICAL FATIGUE PROPERTIES. Edwin A. Lopez, S. Ghodrat, Leo Kestens.

7206 FATIGUE IMPROVEMENT OF WELDED ELEMENTS BY ULTRASONIC IMPACT TREATMENT. Yuri Kudryavtsev.

7210 ULTRASONIC MEASUREMENT OF RESIDUAL STRESSES IN WELDED JOINTS. Yuri Kudryavtsev, Jacob Kleiman.

SYMPOSIUM-4: RELIABILITY OF TRIBOLOGICAL SYSTEMS AT VARIED LENGTH SCALES

7091 EFFECT OF SURFACE ENERGY ON FRICTION COEFFICIENT OF CARBONACEOUS HARD COATINGS BY IN-SITU MEASUREMENT IN ESEM. Taichi Nakao, Makoto Terada, Noritsugu Umehara, Motoyuki Murashim.

7154 THE INFLUENCE OF MOLECULAR CLUSTERS ON LUBRICATING FILM FORMATION. Antoni Jankowski, Mirosław Kowalski, Andrzej Kulczycki, Wojciech Dziegielewski, Jarosław Kaluzny, Jerzy Merkisz.
7247 A NEW STOCHASTIC MODEL FOR PARTICULATE MATTER AND DEBRIS EMITTED BY DIESEL ENGINES. Fábio Oliveira, Daniel Lago, Manoel Oliveira Filho, João Medeiros.

7302 PROPOSAL OF DEVELOPMENT GUIDELINE FOR LOW FRICTIONAL MATERIAL IN OIL LUBRICATION WITH HIGH PERMITTIVITY MATERIAL. Motoyuki Murashima, See-Jun Oh, Takaaki Miyachi, Noritsugu Umehara, Takayuki Tokoroyama, Kota Konishi, Tatsuya Okamoto.

7306 THE WEAR OF DIAMOND-LIKE CARBON BY MOLYBDENUM BASED PARTICLES UNDER BOUNDARY LUBRICATION. Takayuki Tokoroyama, Takahiro Nishino, Makoto Yamaguchi, Khairul Kassim, Noritsugu Umehara.

SYMPOSIUM-5: ADDITIVE MANUFACTURING AND RAPID PROTOTYPING

7064 3D PRINTING TECHNIQUES OF CERAMIC CORES USED FOR TURBINE BLADES MANUFACTURING. Rafal Cygan.

7124 RESISTANCE OF 3D PRINTED POLYMER STRUCTURES AGAINST FATIGUE CRACK GROWTH. Johannes Knöchel, Michael Kropka, Thomas Neumeyer, Volker Altstädt.

7125 FATIGUE RESPONSE OF AS BUILT DMLS PROCESSED MARAGING STEEL AND EFFECTS OF MACHINING, HEAT AND SURFACE TREATMENTS. Dario Croccolo, Massimiliano De Agostinis, Stefano Fini, Giorgio Olmi, Francesco Robusto, Snezana Ciric-Kostic, Aleksandar Vranic, Nusret Muharemovic, Nebojsa Bogojevic.

7126 EXPERIMENTAL STUDY ON THE SENSITIVITY OF DMLS MANUFACTURED MARAGING STEEL FATIGUE STRENGTH TO THE BUILD ORIENTATION AND ALLOWANCE FOR MACHINING. Dario Croccolo, Massimiliano De Agostinis, Stefano Fini, Giorgio Olmi, Francesco Robusto, Nusret Muharemovic, Nebojsa Bogojevic, Aleksandar Vranic, Snezana Ciric-Kostic.

7214 HOW BUILD ORIENTATION AND THICKNESS OF ALLOWANCE MAY AFFECT THE FATIGUE RESPONSE OF DMLS PRODUCED 15-5 PH STAINLESS STEEL. Dario Croccolo, Massimiliano De Agostinis, Stefano Fini, Giorgio Olmi, Nebojsa Bogojevic, Snezana Ciric-Kostic.

7262 EVALUATION OF DIFFERENT NDT TECHNIQUES FOR THE PRODUCTION OF COMPOSITE MATERIALS FABRICATED BY ADDITIVE MANUFACTURING. J.P. Oliveira, Patrick L. Inácio, Fernando Crivellaro, Carlos P. Simão, E. Camacho, Rosa M. Miranda, A. Velhinho, F.M. Braz Fernandes, Telmo G. Santos.

SYMPOSIUM-6: FASTENING AND JOINING TECHNOLOGY

7122 A NOVEL FINITE ELEMENT MODEL METHODOLOGY FOR THE GENERIC MODELLING OF ADHESIVE AGEING. Mathias Creyf, Pol Coudeville, Wim Desmet, David Seveno, Stijn Debruyn.

7136 INFLUENCE OF THE STIFFNESS AND FRICTIONAL CHARACTERISTICS ON THE SHANK TORQUE OF SCREWS IN BOLTED JOINTS. Dario Croccolo, Massimiliano De Agostinis, Stefano Fini, Giorgio Olmi, Francesco Robusto, Omar Cavalli, Nicolò Vincenzi.

7235 MECHANICAL PERFORMANCE AND FRACTURE BEHAVIOR OF ADHESIVE-MULTI PIN JOINTS BETWEEN COMPOSITE AND METALLIC MATERIALS. Longquan Liu.
7237 STRUCTURAL VALIDATION OF INTRAMEDULLARY NAILS: FROM EXPERIMENTATION TO VIRTUAL TESTING. Dario Croccolo, Massimiliano De Agostinis, Stefano Fini, Silvia Funaioli, Giorgio Olmi, Francesco Robusto.

7242 DESIGN INFLUENCES OF PRELOAD RELAXATION BEHAVIOUR IN BOLTED JOINTS USING ALUMINIUM PARTS. Jens Peth, Christoph Friedrich.

SYMPOSIUM-7: INFLUENCE OF MANUFACTURING PROCESSES IN INTEGRITY OF MECHANICAL OR STRUCTURAL COMPONENTS


7054 VALUE STREAM MAPPING IN OPTIMIZING TERRESTRIAL PIPELINES ASSEMBLY. Nivaldo L. Coppini, Luiz F.C. Cunha.


7073 STUDY OF WEAR BEHAVIOR OF A HELICAL GEAR. Miguel Mousinho, Teresa Morgado, David Braga, Alexandre Velhinho, Carla Machado, J. Pamies Teixeira.

7239 EXPERIMENTAL STUDY OF LASER BEAM MACHINING IN Ti6Al4V ALLOY. Gabriela Belinato, Danielle M.D. Costa, Pedro P. Balestrassi, Pedro A.R.C. Rosa.

7314 INTERACTION BETWEEN LEAN PHILOSOPHY AND INDUSTRY 4.0: EXPLORATORY STUDY. Beatrice P. Santos, Fernando C. Santos, Tânia M. Lima.

SYMPOSIUM-8: SUSTAINABLE ENERGY SYSTEMS

7056 DATA CENTERS AND THEIR ENERGY CONSUMPTION FOR CLIMATIZATION. Clito F. Afonso, João Moreira.

7088 NUMERICAL INVESTIGATION OF FILM COOLING EFFECTIVENESS USING THE ANTI-VORTEX CONCEPTION. Fadéla Nemdili, Saliha Nemdili, Abbé Azzi.

7115 A METHOD FOR HEAT TRANSFER CALCULATION IN FOUR-STROKE SPARK IGNITION INTERNAL COMBUSTION ENGINES. Pedro Carvalheira.

7116 A METHOD FOR MASS BURNING RATE CALCULATION IN FOUR-STROKE SPARK IGNITION INTERNAL COMBUSTION ENGINES. Pedro Carvalheira.


SYMPOSIUM-9: OPTIMIZATION AND UNCERTAINTY QUANTIFICATION

7069 UNCERTAINTY QUANTIFICATION USING A NEW NON INTRUSIVE STOCHASTIC APPROACH: APPLICATION TO THE ESTABLISHMENT OF INUNDATION MAPS DUE TO DAM BREAK FLOWS. Azzedine Abedou, Azzeddine Soulaimani.

7093 EFFECTIVE ESTIMATION OF CONFIDENCE IN THE VULNERABILITY ASSESSMENT OF UNCERTAIN STRUCTURAL SYSTEMS. Marco Vailati, Giorgio Monti.
<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7104</td>
<td>THE RELIABILITY INDEX APPROACH WITH EVOLUTIONARY ALGORITHMS:</td>
<td>Gonçalo N. Carneiro, Carlos C. António.</td>
</tr>
<tr>
<td></td>
<td>APPLICATION TO THE RBRDO PROBLEM OF COMPOSITE STRUCTURES.</td>
<td></td>
</tr>
<tr>
<td>7106</td>
<td>MULTI-OBJECTIVE OPTIMIZATION AIMING THE SUSTAINABLE DESIGN OF FRP</td>
<td>Carlos C. António. (Invited Paper)</td>
</tr>
<tr>
<td></td>
<td>COMPOSITE STRUCTURES.</td>
<td></td>
</tr>
<tr>
<td>7107</td>
<td>RESEARCH AND VALIDATION OF GLOBAL MPP IN THE RELIABILITY ANALYSIS</td>
<td>Luisa N. Hoffbauer, Carlos C. António.</td>
</tr>
<tr>
<td></td>
<td>OF COMPOSITE STRUCTURES.</td>
<td></td>
</tr>
<tr>
<td>7280</td>
<td>THE USE OF RESPONSE SURFACE OPTIMIZATION METHOD TO MINIMIZE THE</td>
<td>João E. Ribeiro, Manuel B. César, Ana I. Pereira.</td>
</tr>
<tr>
<td></td>
<td>VIBRATIONS IN THE MILLING PROCESS.</td>
<td></td>
</tr>
<tr>
<td>7313</td>
<td>RELIABILITY SYSTEM ANALYSIS FOR AIRCRAFT COMPOSITE STRUCTURES.</td>
<td>Paola Caracciolo.</td>
</tr>
</tbody>
</table>

**SYMPOSIUM-10: BIOMECHANICS OF CARDIOVASCULAR AND ORTHOPAEDIC DISEASE**

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARTERIES - VALIDATION.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLAQUE DEPOSITION IN LEFT ANTERIOR DESCENDING ARTERY.</td>
<td></td>
</tr>
<tr>
<td>7178</td>
<td>HEMODYNAMICS IN PATIENT-SPECIFIC CORONARY ARTERIES CONSIDERING BLOOD</td>
<td>Sónia I.S. Pinto, João B. Campos.</td>
</tr>
<tr>
<td></td>
<td>ELASTIC BEHAVIOR: NUMERICAL STUDY.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LUMBAR INTERBODY FUSION.</td>
<td></td>
</tr>
<tr>
<td>7293</td>
<td>VESSEL DETECTION IN CAROTID ULTRASOUND IMAGES USING ARTIFICIAL</td>
<td>Catarina F. Castro, Carlos C. António, Luisa C. Sousa.</td>
</tr>
<tr>
<td></td>
<td>NEURAL NETWORKS.</td>
<td></td>
</tr>
</tbody>
</table>

**SYMPOSIUM-12: MECHATRONICS DESIGN: APPLICATIONS AND CASE STUDIES**

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>7183</td>
<td>DESIGN OF A CONTROL SYSTEM FOR A MEDICAL WRIST REHABILITATION DEVICE.</td>
<td>Eurico Seabra, Luis F. Silva, Valdemar Leiras, Ricardo Ferreira.</td>
</tr>
<tr>
<td>7184</td>
<td>DESIGN, DEVELOPMENT AND CONSTRUCTION OF A MEDICAL WRIST REHABILITATION</td>
<td>Eurico Seabra, Luis Silva, Ricardo Ferreira, Valdemar Leiras.</td>
</tr>
<tr>
<td></td>
<td>DEVICE.</td>
<td></td>
</tr>
<tr>
<td>7249</td>
<td>HAND TENSOR: A FULL MOTION HAND PROSTHESIS WITH MECHANISMS BY ONE</td>
<td>João E. Polis, Cecilia Amélia Zavaglia, Carlos A. Cimini Jr.</td>
</tr>
<tr>
<td></td>
<td>SINGLE TRACTION ENGINE.</td>
<td></td>
</tr>
<tr>
<td>7252</td>
<td>ASBGO*: A MECHATRONIC IMPROVED SMART WALKER.</td>
<td>Joana Alves, Cristina P. Santos, Eurico Seabra, Luis F. Silva.</td>
</tr>
<tr>
<td>7278</td>
<td>TGK DYNAMIC ANALYSIS OF A HUMANOID RESCUE ROBOT.</td>
<td>Gerardo García, Enrique Vazquez, Pedro de J. García, Jonathan A. Soto, Isidro Sanchez, Juan G. Sandoval.</td>
</tr>
</tbody>
</table>
### SYMPOSIUM-13: STRUCTURAL DYNAMICS AND CONTROL SYSTEMS: THEORY, EXPERIMENTS AND APPLICATIONS

**7114**  
THE EFFICIENCY OF USING ADDITIONAL ISOLATED UPPER FLOOR (AIUF) IN SEISMIC UPGRADEING OF RESIDENTIAL R.C. FRAME BUILDINGS IN ARMENIA. Armen Assatourians, Mohammad Reza Mehrdoust, Sohrab Fallahi.

**7143**  
DETECTION OF DEFECTS IN COMPOSITE HELMETS USING ULTRASONIC IR THERMOGRAPHY. Monika Pracht, Waldemar Swiderski.

**7187**  
MODAL DECOMPOSITION PROCEDURES FOR FE-BASED STRUCTURAL MODELS WITH NON-PROPORTIONAL DAMPING. Evgueni Stanoev.

**7218**  
EVALUATION OF DYNAMIC WHEEL LOAD CONSIDERING BALLAST FOULING DURING TRAIN PASSAGE. Chayut Ngamkhanong, Keiichi Goto, Sakdirat Kaewunruen.

**7282**  
DYNAMIC CHARACTERIZATION OF MAGNETORHEOLOGICAL DAMPER AND EXPERIMENTAL ADJUSTMENT OF MODIFIED BOUC-WEN NUMERICAL MODEL. Said Boukerroum, Nadjira Kheznadji, Nacer Hamzaoui.

**7284**  

**7285**  

**7287**  
NUMERICAL STUDY OF VIBRATIONS IN THE MILLING PROCESS. Ana Isabel Pereira, Manuel Braz-César, João E. Ribeiro.

**7288**  
THERMAL-BRIDGE ASSESSMENT IN GLAZING AND ALUMINIUM FRAMES BY THERMO-IMAGES: A CASE STUDY. Thiago Laignier, Manuel Braz-César, João Ribeiro.

**7308**  

**7309**  
ON THE USE OF RADAR INTERFEROMETRY FOR THE STRUCTURAL MONITORING OF BRIDGES. Rui C. Barros, Fábio M. Paiva.

**7310**  
DYNAMIC STRUCTURAL HEALTH MONITORING OF A TRANSMISSION TOWER USING INTERFEROMETRIC RADAR. Fábio M. Paiva, Rui C. Barros, Luís Guerreiro.

### SYMPOSIUM-14: NEW PRODUCT DEVELOPMENT - DESIGN RESEARCH, MATERIALS SELECTION, INNOVATION SYSTEMS

**7065**  
RELIABILITY AND FAILURE OF POLICY IMPLEMENTATION OF INCLUSIVE DESIGN: CASE STUDIES OF OPEN SPACE IN BEIJING, TAIPEI, AND HONG KONG. Kin W.M. Siu, Yi Lin Wong, Jia Xin Xiao.

**7173**  
FAILURE OF SOCIAL INCLUSION IN PUBLIC SPACE: A CASE STUDY OF CHILDREN’S INCLUSIVE PLAYGROUND AND THEIR ENGINEERING STANDARDS IN HONG KONG. Yi Lin Wong, Mei Seung Lam, Kin W.M. Siu.

**7231**  
TECHNICAL CONTRADITIONS SOLVING TECHNIQUE IN PLANT MAINTENANCE. Ivan Masin.
GUIDELINES FOR THE ALIGNMENT OF THE INTEGRATED MANAGEMENT SYSTEM WITH THE BUSINESS STRATEGY IN INDUSTRIAL COMPANIES. Luis C. Barbosa, Gilberto Santos, Otávio J. Oliveira.

THE CONTRIBUTION OF DESIGN TO THE SUSTAINABLE DEVELOPMENT BY THE TRANSFORMATION OF “NON-PLACES” IN URBAN GARDENS FOR PRACTICING URBAN AGRICULTURE. António Barroso, Maria João Félix, Gilberto Santos.

MATERIALS SELECTION AND INNOVATION SYSTEMS IN PACKING DESIGN FOR HEALTHY FOOD. Verónica Duarte, Maria João Félix.

LINKING MOULD FILLING AND STRUCTURAL SIMULATIONS. Carlos N. Barbosa, Julio C. Viana, Markus Franzen, Thomas Baranowski, Ricardo Simões.

FABRICATION LABORATORIES: WHERE NEW DIGITAL TECHNOLOGIES COME TO LIFE. Laura Bravi, Gilberto Santos, Federica Murmura.


USING DMAIC FOR AUTOMATED IDENTIFICATION OF CAUSES AND MEASURES. Patrick Drange, Klaus Seiffert, Roland Jochem.

MAINTENANCE PLANS FOR KNOWN FAULTS EVENTS ADJUSTED WITH FUZZY LOGIC SUPPORT. Joaquin S. Herrera, Jhonny Rodrigues, Miguel Strefezza.

STATISTICAL ANALYSIS OF MAJOR ACCIDENT HAZARDS DATA: LEARNING FROM THE PAST TO DEVELOP A SAFETY CASE. Nasser M. Blahareth, Soliman A. Mahmoud.

ADAPTING KANO’S THEORY FOR WEIGHTING AND IMPLEMENTING CUSTOMER REQUIREMENTS ON A SOFTWARE TOOL FOR ASSESSING HUMAN RELIABILITY IN MANUAL ASSEMBLY. Christian Kern, Robert Refflinghaus.

DEVELOPING AND VALIDATING A MODEL OF ISO 9001 EFFECTIVENESS GAP: EMPIRICAL EVIDENCE FROM CHINA. Xiaojing Sun, Decheng Wen, Dongwei Yan.

THE ANALYSIS OF THE HELICOPTER TECHNICAL READINESS BY MEANS OF THE MARKOV PROCESSES. Józef Żurek, Mariusz Zieja, Jarosław Ziolkowski.

HUMAN FACTOR INFLUENCE ON EDDY CURRENT NON-DESTRUCTIVE TESTINGS. Carlos E. Silva, Rita C. Ferreira, Yasmin S. Martins, Dalton G. Souza, Ana C. Santos.

R&R STUDY FOR VALIDATION OF THE MEASUREMENT SYSTEM OF A PROCESS FOR THE MANUFACTURE OF WIRE COILS IN A TEXTILE INDUSTRY. Fabricio A. Almeida, Vinicius R. Paula, Rachel C. Sabioni, Daniel S. Cortez, José H. Gomes, Pedro P. Balestrassi.
R&R STUDY FOR ANALYSIS OF THE MEASUREMENT SYSTEM OF A PUMP LABELING PROCESS. Vinicius R. Paula, Rachel C. Sabioni, Fabricio A. Almeida, Petra N. Leite, José H. Gomes, Pedro P. Balestrassi.

THE JOURNEY OF MULTI NATIONAL ENTERPRISES INTO BUSINESS AND HUMAN RIGHTS. Pasquale Vetta.

CLUSTER ANALYSIS FOR ENHANCING PROCESS QUALITY IN JOB SHOP PRODUCTION. Antonia Fels, Max Ellerich, Robert Schmitt.

AN ANALYSIS OF QUALITY CONTROL GAME BETWEEN ONLINE SHOPPING PLATFORMS AND SELLERS UNDER COMPLETE INFORMATION. Yaping Li, Decheng Wen, Dongwei Yan.

MATHEMATICAL MODELING OF TECHNOLOGIES FOR THE DESIGN OF INNOVATIVE FUNCTIONAL BIO-COATINGS FOR DENTAL IMPLANTS. Alla V. Balueva, Ilia N. Dashevskiy.

SURFACE CHANGES (SCANNING ELECTRON MICROSCOPE) INDUCED BY ARTIFICIAL SALIVA IN TITANIUM-MOLYBDENUM ORTHODONTIC LOOPS. Saul Castro, Maria Ponces, J.C. Reis Campos, Jorge Lopes, Maria Pollmann.

COMPARATIVE STUDY OF FLEXURAL STRENGTH IN THERMOFORMABLE DENTURE BASE RESINS. Tomás Pacheco, José M. Rocha, Nuno V. Ramos, J.C. Reis Campos, Maria H. Figueiral.

MAXILLARY AND MANDIBULAR SUPERIMPOSITIONS IN THE ASSESSMENT OF ORTHODONTIC TREATMENT OUTCOMES. Berta Meireles, Ana C. Braga, Lucinda G. Faria, Saul Castro, Maria João Ponces.


BIS-ACRYL RESIN COLOR EVALUATION BEFORE AND AFTER SURFACE TREATMENTS AND IMMERSION IN COLORING BEVERAGES. Susane L. Gras, Joseane Silva, Paula Vaz, César Silva, J.C. Sampaio Fernandes, Claudia Volpato.

BIOMEDICAL RAPID PROTOTYPING OF FREE-FORM SURFACES BY PLANAR CONTOURS METHOD. Hacene Ameddah, Hammoudi Mazouz.

FORENSIC IDENTIFICATION TOOL IN DENTAL REMOVABLE PROSTHODONTICS. Adélia Fernandes, André Correia, Ana Margarida Silva, Cristina Figueiredo.

AUTHOR INDEX
HOW BUILD ORIENTATION AND THICKNESS OF ALLOWANCE MAY AFFECT THE FATIGUE RESPONSE OF DMLS PRODUCED 15-5 PH STAINLESS STEEL

Dario Croccolo\textsuperscript{1}, Massimiliano De Agostinis\textsuperscript{1}, Stefano Fini\textsuperscript{1}, Giorgio Olmi\textsuperscript{(o)}, Nebojsa Bogojevic\textsuperscript{2}, Snezana Ciric-Kostic\textsuperscript{2}

\textsuperscript{1}Department of Industrial Engineering (DIN), University of Bologna, Bologna, Italy
\textsuperscript{2}Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Serbia

\textsuperscript{(o)}Email: giorgio.olmi@unibo.it

ABSTRACT

The present study is focused on the fatigue strength of 15-5 PH Stainless Steel, built by Direct Metal Laser Sintering. Six-specimen sets were manufactured, mechanically and thermally treated and tested under rotating bending fatigue. The study investigates the effects of the build orientation (parallel, perpendicular, or 45° inclined with respect to the vertical stacking direction) and of allowance for machining (1mm or 3mm at gage). The results, processed by an ANOVA methodology, indicate that allowance for machining has a beneficial effect on the fatigue response. Removing the surface irregularities, averagely leads to a 19% enhancement of the fatigue limit. The build orientation also becomes beneficial, when the slanted samples are included in the experiment. In this case, a fatigue strength increase up to 20% can be achieved. Further developments will include the investigation of the effects of heat and surface treatments, involving also further materials in the study.

Keywords: rotational bending, fatigue strength, stainless steel, direct metal laser sintering, build orientation, allowance for machining.

INTRODUCTION

Nowadays, there is an increasing interest towards Additive Manufacturing (AM) techniques, as this technological process is potentially capable of producing even complexly shaped parts in a relatively short time (Scott-Emuakpor, 2015; Abe, 2001). In addition, the parts can be easily built, with a high level of flexibility, starting from a CAD model (Rafi, 2013; Santos, 2006; Herderick, 2011). AM offers further advantages arising from a faster time-to-market, a high efficiency in material utilization with a particularly reduced powder waste (Razavi, in press). A possible drawback of AM techniques consists in the residual stresses that may be generated during part building. Therefore, suitably shaped supports are usually applied to safely attach the built part to a rigid base-plate, thus preventing its movements through the powder bed or distortions induced by the residual stress field (Rafi, 2013). Moreover, AM produced parts are likely to be affected by defects, being often due unmolten particles, entrapped gas bubbles, or missing fusion (Razavi, In Press; Vilaro, 2011). Direct Metal Laser Sintering (DMLS) by EOS and Selective Laser Melting (SLM) by MTT Technologies Group can be mentioned among the most important AM processes for metals (Herderick, 2011). Nowadays they can be regarded as basically the same technique, being grouped under the powder bed fusion technologies. They both have wide applications to metals, as pointed out in recent review studies (Herderick, 2011; Lewandowski, 2016).
The aforementioned base-plate is usually placed on a horizontal plane, and the parts are generated along a vertical stacking direction. A number of studies, involving different materials and AM processes, have been focused on the possible effect of the build direction on the mechanical static and fatigue responses of the manufactured parts. Some researchers investigated a possible influence of the angle between the main axis of inertia (namely, the longitudinal axis of the specimen) and the stacking direction on the part strength (Edwards, 2014; Edwards, 2015). The possible effect of the build direction on the fatigue response, considering both the fatigue limit and the fatigue strength in the finite life domain, was also the topic of a previous study by the same authors. This research involved MS1 Maraging steel parts, built, considering three different orientations, with post-manufacture mechanical and heat treatments. An experimental campaign led to the result that the fatigue response is not significantly affected by the build direction, since, for Maraging steels, post-manufacture treatments have a great role at removing sources of anisotropy (Croccolo, 2016).

Further research in the literature was focused on the mechanical behaviour of 15-5 PH stainless steel parts. This type of steel is commonly used in applications such as aircraft components, or for parts under high pressure or working in harsh corrosive environments, including valves, shafts, fasteners, fittings and gears (Rafi, 2013; Abdelshehid, 2007). A lack of studies on the effect of the build direction on the fatigue properties of this steel can be pointed out. In particular, the research (Rafi, 2013) was focused on the build orientation effect on the static response only. Additional studies (Ozbaysal, 1994; Palanisamy, 2016; Wu, 2002) deal with the static properties of 17-4 PH stainless steel, focusing on the effects of build direction and microstructure, whereas very few deal with the fatigue response of this steel. Moreover, just two build orientations are considered in the aforementioned studies, except for one, mainly dealing with low cycle fatigue (Brandl, 2012).

The subject of this paper consists in an experimental study on the fatigue response of 15-5 PH stainless steel parts fabricated by the DMLS process. Two factors were considered: the build direction and the post-processing procedure. In particular, three different build orientations were considered, with different inclinations of the main axis of inertia of the parts with respect to the base plate. Regarding the post-processing procedure, the effect of allowance and subsequent machining, with different thicknesses of material to be removed was studied. This experimental plan derives its motivations from the previous study dealing with Maraging steel (Croccolo, 2016), which was focused on the effect of the build orientation, and from some recent studies, e.g. (Edwards, 2015; Zhang, 2017; Zhang, 2016; Van Hooreweder, 2012), which are starting to investigate the effects of the amount of material to be removed after sintering on mechanical properties. However, in these papers, the size effect of the block, from which the part is machined, is studied from the point of view of fracture mechanics. In particular the properties related to crack growth seem to be improved, when machining components from oversized blocks. Similar investigations dealing with high cycle fatigue properties are still missing. Issues of novelty also arise from considering three orientations with respect to the vertical stacking direction: horizontal, vertical and slanted.

EXPERIMENTAL

The experimental campaign was performed under rotating bending, following the ISO 1143 (ISO 1143, 2010) Standard. Specimens were designed accordingly, with reference to the cylindrical smooth geometry (with uniform cross section at gage). A drawing of the specimen is shown in Figure 1, with indication of all its dimensions and tolerances. The chemical composition of 15-5 PH stainless steel (PH1 stainless steel by EOSGmbH-Electro Optical Systems, Krailling/Munich, Germany) is provided in Table 1 (http://www.eos.info/material-m).
Fig. 1 - Technical drawing of the sample for fatigue tests under rotating bending (all dimensions in mm)

<table>
<thead>
<tr>
<th>Chemical composition of 15-5 PH1 Stainless Steel by EOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr [%]</td>
</tr>
<tr>
<td>14-15.5</td>
</tr>
</tbody>
</table>

The specimens were manufactured by EOSINT M280 system (EOS GmbH - Electro Optical Systems, Krailling/Munich, Germany), equipped with Ytterbium fibre laser with 200W power and emitting 0.2032mm thickness and 1064nm wavelength infrared light beam. The process takes place in an inert environment and the scanning speed may range up to 7000 mm/s. The machine features a working space with 250 × 250 mm dimensions on the horizontal plane and a maximum height of 325 mm. The applied process parameters were defined according to the EOS Part Property Profile named “Surface”. In particular, the layer thickness was set to 20 µm and a parallel scan strategy with alternating scan direction was adopted. For the subsequent layers the scanning direction was rotated by approximately 70°, in order to prevent or reduce in-plane property variations.

All the specimens underwent surface cleaning by micro-shot-peening, in order to close the pores that may be induced by laser sintering. Afterwards, the H900 heat treatment was performed (Rafi, 2013; http://www.eos.info/material-m), thus following the recommendations by EOS. For this purpose, the samples were kept at the temperature of 482°C for 2 hours after a ramp increase (from the room temperature) in 1 hour time. Finally, the specimens underwent machining and refining by grinding with the aim of accomplishing the roughness and dimensional specifications and of improving the fatigue performance.

Six specimen sets were manufactured: those of types #1 and #4 were built while lying horizontally on the base plate, therefore the angle between their longitudinal axis and the vertical stacking direction was 90°. Whereas, those of types #2 and #5 were built while standing vertically: in this case, the angle between their main axis of inertia and the stacking direction was 0°. Finally, the samples of sets #3 and #6 were built along a 45° inclined direction with respect to the base plate, so that the angle between their longitudinal axis and the vertical stacking direction was 45°. The difference between the samples of sets #1 and #4 is that the first ones were produced with the same shape as shown in Figure 1, with a 1mm uniform allowance both at the gage (diameter increased from 6 to 8 mm) and at the heads (diameter increased from 10 to 12 mm). The samples were then machined to meet the drawing specifications, regarding both dimensions and roughness. Conversely, the samples of set #4 were built with a cylindrical shape with 12 mm diameter over their entire length. It implies
that the allowance was 1mm at the heads and 3mm at the specimen gage. These samples also went through machining to meet the same specifications as in Figure 1: therefore, a higher thickness of material was removed at the gage with respect to the samples of type #1. The same difference applies also to sets #2-#3 (built with uniform allowance and reduced section at gage) and #5-#6 (built with cylindrical layout).

The described experimental plan can be regarded as a 2-factor experiment: the first factor, build orientation, was investigated over three levels (horizontal, vertical and slanted), whereas the second one, allowance (material thickness to be removed by machining) was considered at two levels (1 mm and 3mm at gage). This experimental plan is summarized in Table 2, with indication of sample set numbers and of short names to be used in the following. Each set was composed by 7 to 10 samples (the number of samples for each set is also reported in Table 2), considering that some samples were unfortunately damaged during manufacturing.

<table>
<thead>
<tr>
<th>Orientation of the longitudinal axis of the sample (during the building process)</th>
<th>Thickness of allowance for machining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>1 mm</td>
</tr>
<tr>
<td>Set #1 (H,1): 7 samples</td>
<td>Set #4 (H,3): 9 samples</td>
</tr>
<tr>
<td>Vertical</td>
<td>Set #2 (V,1): 10 samples</td>
</tr>
<tr>
<td>Slanted</td>
<td>Set #3 (S,1): 10 samples</td>
</tr>
</tbody>
</table>

The fatigue campaign made it possible to obtain the S-N curves and the fatigue limits (FLs). A staircase method was applied to determine the FL: for this purpose, the series of failure and not-failure events was processed by the Dixon method (Olmi, 2013; Dixon, 1983; Olmi, 2010; Van Hooreweder, 2012). A life duration of $10^7$ cycles was set as run-out, based on the few available data on the fatigue response of sintered 15-5 PH stainless steel (Rafi, 2013). The Dixon method is an abbreviated staircase method that makes it possible to estimate FL even from a short series of nominal trials at staircase (four to six in this work). A confidence analysis (90% confidence level) was also performed based on the standard deviation of FL (scattering of the experimental results) and on the size of the sequence that led to its computation. The data in the finite life domain were processed according to the Standard ISO 12107 (ISO 12107, 2012): the stress and life were linearly interpolated in logarithmic coordinates. The lower and upper limits of the S-N curve have been determined, based on the standard deviation of the logarithm of the fatigue life. Respective failure probabilities of 10% and 90% were considered together with a 90% confidence level.

The specimens were tested under rotating bending fatigue by a rotary bending testing machine, where the specimen is loaded in the four-point bending configuration, so that bending moment $M_b$ keeps constant over the entire sample length, and in particular at its gage (Olmi, 2013). The sample was clamped at its ends by a pressure of approximately 70 MPa (Croccolo, 2013; Croccolo, 2014). All the tests were conducted under fully reversed bending load (stress ratio $R = -1$) at the frequency $f$ of 60 Hz.

Fractographic and micrographic analyses were then performed with the aim of investigating the possible presence of porosities, inclusions, spots of oxides and micro-cracks. For this
purpose, a Stemi 305 stereo-microscope (by ZEISS, Oberkochen, Germany) has been utilized for fractographies, whereas an Optiphot-100 optical microscope (by Nikon, Melville, NY, United States) has been applied for both micrographic and (more zoomed) fractographic analyses. In the case of micrographies, chemical etchings were performed by the following solution for a duration of 30s after heating in oven up to 90°C. 20 ml of Glycerol (C₃H₈O₃) were mixed with 10 cc of Nitric Acid (HNO₃), then 20 cc of Chloridric Acid (HCl) were mixed with 10 cc of Hydrogen peroxide (H₂O₂).

![Fig. 2](image)

**RESUME OF THE RESULTS AND CONCLUSIONS**

The following points are worth mentioning, concerning the performed experimentation and the achieved results.

Six sample sets have been manufactured: horizontally, vertically and 45° inclined with respect to the base plate, built with uniform 1mm allowance and with an incremented one, 3mm, at specimen gage (manufactured as cylindrical parts). This experiment can therefore be regarded as a 3-by-2 plan, involving two factors, build orientation and material thickness to be removed, respectively with three and two levels. The fatigue tests led to the determination of both the sloping parts of S-N curves and of the fatigue limits. The fatigue curves in the finite life domain for the three sample sets with 1 mm allowance are shown in Figure 2, whereas the...
S-N curves for those with incremented thickness to be removed by machining are plotted in Figure 3. The fatigue limits, considering the aforementioned run-out of $10^7$ cycles, are finally collected in the bar graph in Figure 4.

Fig. 3 - S-N curves for sample Sets #4 (H,3), #5 (V,3) and #6 (S,3) (arrows indicate run-outs): effect of the build orientation compared for incremented (3 mm) allowance for machining

Fig. 4 - Fatigue limits for $10^7$ cycles run-out plotted together with their confidence bands (95% confidence level)
The results have been processed by statistical methods (Olmi, 2012): the outcomes of the conducted analyses indicate that allowance has a significant effect at enhancing the fatigue response. Conversely, the build orientation does not have an effect, when just horizontal and vertical orientations are considered. However, this factor turns to be significant, as slanted samples are included in the experiment: this orientation proved to be able to improve the fatigue strength.

These results have been carefully discussed, to get a better awareness of the impact of the studied factors and of the stacking process on the fatigue properties. The retrieved outcomes indicate that machining makes it possible to remove the irregularities and residual stresses induced by the additive process, which are mainly concentrated at the surface layers (between the external contour lines and the inner solid portion). Moreover, the slanted orientation has the effect of reducing the notch effect due to defects arising from unmelted spots, powder residuals or scan errors due to lack of perpendicularity between the surface and the laser path. The overall amount of defects per layer is reduced and the resistance against crack propagation is also improved due to the layered structure. This issue has a noticeable impact on the mechanical response, considering that, taking advantage of build orientation, or removing the surface irregularities may lead to increments of the fatigue strength in the order of 20%. Moreover, it is worth noticing that the optimization of these factors leads to a fatigue performance that is well comparable to that of wrought material (ratio between the fatigue limit and the ultimate tensile strength around 50%). This is a very important point, especially with regard to the applications that combine the great advantages of additively produced parts (in particular, the remarkable drop of the time to market) and the need for a satisfactory structural strength.

Finally, fractography and micrography have shown that, despite heat treatments, the layered structure induced by the process is still well visible, which can explain the observed moderate effect of build orientation on fatigue. Micrographies depicting the microstructures on the build plane and along the stacking direction are shown in Figure 5.

Fig. 5 - Micrographic analyses on horizontally built samples: (a) laser scans on the build plane (contiguous planes are visible, relative angle highlighted), (b) layers along the stacking direction

Further developments will include the investigation of the effects of heat and surface treatments, including also further materials in the study. Possible effects, in terms of the generation of oxidation spots and of voids, arising from the actual position of the parts in the build chamber will also be investigated.

Further details on the applied methodology, on the results and on the novel approach to data analysis are available in (Croccolo, 2018).
ACKNOWLEDGMENTS

The research presented in this paper has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 734455.

REFERENCES


