University of Zagreb
Faculty of Mechanical Engineering
and Naval Architecture

SVEUČILIŠTE U ZAGREBU
METALURŠKI FAKULTET

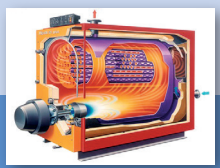
UNIVERSITY OF ZAGREB
FACULTY OF METALLURGY

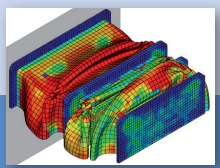
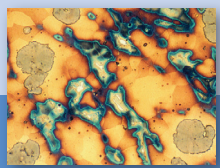
# Eighth Annual PhD Workshop

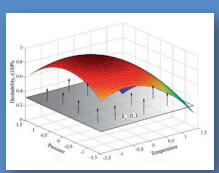
PhD Study of Mechanical Engineering, Naval Architecture,
Aeronautical Engineering and Metallurgical Engineering

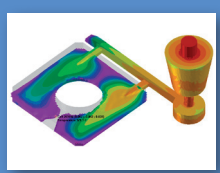
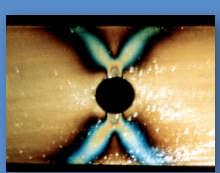
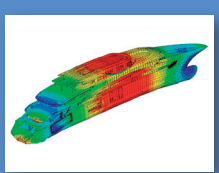
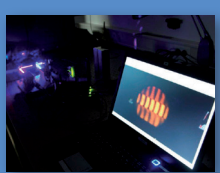
# Book of Abstracts

July 4, 2022



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# Preface

This booklet contains abstracts presented at the 8th Annual PhD Workshop, which took place on July 4, 2022. The annual PhD workshop is the integral part of PhD program of Mechanical Engineering, Naval Architecture, Aeronautical Engineering and Metallurgical Engineering, launched in academic year 2014/15. The PhD program is jointly developed by two faculties of University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture and Faculty of Metallurgy. The PhD Workshop is aimed to provide forum for exchange of ideas among PhD students, to help students to strengthen their presentation skills and to provide a platform to initiate new scientific collaborations. Additionally, the workshop should unify quality and transparency of PhD theses produced at different modules of the PhD program.

Contributions in this booklet are divided in two broad groups, abstracts of preliminary PhD topics and abstracts of final PhD topics. Former are mostly presented by the first year PhD candidates, while latter are presented by PhD students of second and higher years. Abstract are structured in a way to encourage students to write clearly and concisely purposes of their PhD theses in order to bring their research closer to the wide community and even to those who are not specialists in the field. This booklet could be a valuable and relevant reference for PhD students and their mentors as it represents kind of a milestone in the progress of their PhDs. It will also be useful for all stakeholders of PhD education to evaluate quality and progress of PhD theses. Finally, it can be useful for the industry in Croatia as it contains in one place most of the research efforts at two faculties.

54 participants on the PhD workshop presented preliminary topics of their theses, while 22 participants presented final PhD topics. 74 workshop participants are from Croatia, while 2 are from foreign countries (1 from Bosnia and Herzegovina and 1 from Kosovo). Contributions collected in the booklet of abstracts are from different modules of the PhD study: Process and Energy Engineering (22 contributions), Computational Mechanics (9), Theory of Structures (13), Mechatronics and Robotics (5), Industrial Engineering and Management (4), Scientific Metrology in Mechanical Engineering (2), Aeronautical Engineering (1), Materials Engineering (5), Advanced Production Technologies (8), Naval Architecture and Ocean Engineering (6) and Metallurgical Engineering (1). Diversity of these topics clearly indicates broad and rich research interests and activities at the Faculty of Mechanical Engineering and Naval Architecture and Faculty of Metallurgy.

*Editors*

# Contents

**TOPIC NOT APPROVED**

# Optimization of Data Centre Waste Heat Integration into Existing District Heating Networks

**PhD candidate:** Josip Miškić
**Mentor/s:** Tomislav Pukšec
**Affiliation:** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

## Introduction

The number of data centres (DC) in recent years is growing rapidly, with that, share in total consumption of electricity is growing too. A significant amount of electricity is transformed into heat energy which increases the optimal temperature in data centres for component operation. This heat needs to be removed and usually, it doesn't have any further application. Today it is recognized that waste heat can be integrated into district heating (DH) and by using it reduce the usage of conventional heat fuels. Utilization of waste heat is possible in three ways: with a heat exchanger (HE), with a heat pump (HP), or with the combination of the heat exchanger and heat pump. In this paper, a combination of the HP and HE was used. Although those utilizations are examined and implemented, there is a lack of research on the optimization of integration of waste heat in district heating networks. To perform optimization, a thermodynamic model of the data centre and a linear programming optimization model were developed, whose objective function is to maximize the amount of waste heat exploitation considering the pinch temperature gap, and temperature regimes of streams by minimizing the cost of the HE. The created model consists of the data centre, vapor compressor chiller, HE, HP, and cooling tower. As a case study, the City of Zagreb was chosen, together with its existing data centres and district heating network. Optimization was conducted considering the possibility to use different refrigerants in HP, and various temperature regimes in the DH network. This article will give insight into the results such as the Coefficient of Performance (COP) of HP, the percentage of used waste heat, energy savings due to waste heat integration in the DH network, and cost-benefit parameters. The main outcome from the paper is to analyse how the optimization of waste heat integration impacts the levelized cost of heat (LCOH), cooling tower capacity, and heat energy savings in DH.

## Keywords

district heating, waste heat, data centre, optimization, heat exchanger, heat pump

# Selection of the City District of the City of Zagreb for the Implementation of the Analysis of the Potential for Demand Response Using Multi-Criteria Analysis

**PhD candidate:** Ružica Budim
**Mentor/s:** Tea Žakula
**Affiliation:** Energy Institute Hrvoje Požar, Croatia

## Introduction

The area of research of the doctoral thesis includes the analysis and quantification of the demand response potential in the building sector on the example of the city district of Zagreb. The first part of the research is the selection of the city district of the city of Zagreb, where all further analyzes will be conducted. For this purpose, a multi-criteria analysis was performed. More precisely, the method of goal programming was implemented which purpose is to find a solution as close as possible to the given goal - district whose criteria deviate the least from the criteria of the city of Zagreb, taking into account the following criteria:

- population,
- mix predominate types of building use (multi-apartment buildigns, family houses, office buildings, education, hospitals, hotels and restaurants, sport halls, shops and other), and
- energy mixes for heating and domestic hot water preparation by all types of buildings.

By performing the described method of multicriteria analysis, deviations were obtained for all city districts (17 in total) and grades were obtained in such a way that the smallest deviations for each criterion were awarded the highest score. In addition, when summing up the scores by criteria, each criterion was assigned equal weighting factors. By summing the assigned grades, it was obtained that Novi Zagreb - West best shows the overall picture of the city of Zagreb according to defined criteria. Conducting this analysis can serve as a basis for other purposes when it is necessary to select a sample from a large data set that best describes the whole data set. After selecting such a sample, in this case the city district, it is possible to collect all further data for it, conduct different analyzes (in this case perform an analysis of demand response potential), where the analyzes conclusions can be replicated in a large data set, in this case the city of Zagreb.

## Keywords

multi-criteria analysis, goal programming

# Non-Reciprocal Vibration Transmission Through Absolute Position and Velocity Feedback

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**Mentor/s:** Neven Alujević
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## Introduction

Active metamaterials have received increased attention in the last 20 years. By integrating active elements in the structure of the material, it is shown that completely new dynamical characteristics, uncommon even for classical (passive) metamaterials arise. Although the cancellation of reciprocity was easily achieved in the electromagnetism, vibro-acoustic systems are show not to be prone to reciprocity interruptions.

## Aims

In this study, the effect of reciprocity loss in vibration transmission of active structures is studied. This effect can be achieved by using a non-collocated absolute velocity feedback to drive a reactive force actuator. However, such reciprocity cancellation is effective only at medium (close to resonance) and high frequencies, while low frequencies were not altered with respect to direction of propagation. This is not ideal as low frequency sound is extremely hard to suppress with conventional (passive) techniques. On the other hand, at low frequencies, position, rather than velocity feedback should be more effective at sound transmission reduction, and so it is emphasized that such PI effect may indeed encourage more significant absence of reciprocity.

## Methods

The first step of the methodology is to derive a mathematical model of the plant. The paper will assume a 2 degree of freedom vibratory system with concentrated parameters. The 2-input system can be divided to 2 transfer functions that should behave differently under same input signals. The derivation of the model enables the analysis of stability conditions using Routh-Hurwitz criteria. As well, MATLAB shall be used to simulate the system response. Secondly, experimental analysis on the 3D printed test rig will be used to validate the results.

## Expected scientific contribution

The paper will conclude an addition to development of acoustic metamaterial cell for reciprocity cancellation. The improved cell would be efficient at wider range of frequencies than previously achieved. It is theorized that such cell would enable efficient selective reinforced transmission in one direction, while absorbing the sound propagation in the opposite direction - a significant step for acoustic metamaterials.

## Acknowledgments

The Croatian Science Foundation HRZZ- IP-2019-04-5402 (DARS) support is gratefully acknowledged.

## Keywords

Active metamaterials, reciprocity cancellation, vibro-acoustics, position and velocity feedback

# Investigation of Photosensitive Electrodes for Direct Production of Renewable Hydrogen Using Solar Energy

**PhD candidate:** Dinko Brezak
**Mentor/s:** Ankica Kovač
**Affiliation:** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

## Introduction

Finding a method that could make hydrogen production more attractive and competitive is crucial for achieving hydrogen economy goals and carbon-free society until 2050. The most used renewable production method of producing hydrogen is via water electrolysis using electricity, but another method with direct separation of water molecules into hydrogen and oxygen using solar energy could reduce system complexity and increase efficiency by omitting the part of the process in which electricity must firstly be produced and then used for electrolysis. This method, firstly discovered 40 years ago, has awoken significant scientific interest in the last decade. Due to many challenges that need to be overcome, this method has not yet been successfully commercialized, which paves the way for new development and innovative solutions while solving the burning problems of society.

## Aims

The main goal of this research is to make and test a certain number of photo-electrodes. Variety of materials with different chemical and physical properties would be stacked in layers and that would enable the production of photo electrodes with diverse properties that are essential for an efficient photo electrochemical reaction. Some of the important properties are good adsorption of the solar spectrum, adequate band gap, low electron-hole recombination, corrosion stability, and good electrical conductivity. Also, in addition to meeting the desired electrode properties using a variety of materials, it is in our best interest to use cheap and widely available materials

## Methods

The research will include design and construction of photo-electrochemical cell, preparation of different types of multilayer photo-sensitive electrodes with different chemical synthesis methods such as hydrothermal method, sol-gel processes, and electrochemical anodizing. Each of the prepared photo-electrodes will be tested experimentally within the constructed photo-electrochemical cell. Results will be mutually compared to achieve optimal materials ratio and distribution for building the photo electrodes and to investigate their newly obtained characteristics. Devices, materials, measuring equipment, system for analyzing measured parameters, chemical accessories and protective equipment needed to carry out the research will be defined. Experimental results will be followed by theoretical considerations and mathematical modeling.

## Expected scientific contribution

The main expectations of this paper are changing and improving the characteristics of photo-electrochemical conversion by testing various materials, increasing their photosensitive band gap, accelerating the electrochemical reaction, reducing electron-hole recombination, and increasing stability in aggressive media. These changes will be experimentally verified and described.

## Acknowledgments

The authors thank the Croatian Science Foundation, which finances the project UIP-2020-02-7332 Advanced methods of green hydrogen production and its transportation, within which research was conducted, and the results of which are presented in this work.

## Keywords

hydrogen, photo-electrochemical water splitting, photo-sensitive electrodes

# Green Inventory Management in Modern Supply Chains

**PhD candidate:** Jasmina Žic
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## Introduction

Modern supply chains typically operate as a part of global market, in a complex environment where continuous business improvement is necessary. Such conditions imply flexibility in business operations, permanent cost reduction and the ability to quickly adapt to market demands. The European Union's environmental policies prescribe the obligation of a long-term reduction of greenhouse gas emissions, so determination of sustainable business strategies that contribute to the achievement of this strategic goal is of practical importance. Doctoral research aims to investigate the possibility of green inventory management according to the (R, s, S) model in modern supply chains using the standard EN 16258 through numerical simulations and scenario analysis. To this end, relations, influencing factors and interdependencies of variables of the (R, s, S) inventory management model will be additionally examined in order to gain insight on how to optimally manage it, depending on the business goal.

## Aims

The main objective of the research is to develop method of optimal green inventory management for (R, s, S) inventory management model.

## Methods

The methods which are planned to be used for this doctoral research are: analysis, numerical simulation and modelling, statistical data processing and analysis and multicriteria optimisation.

## Expected scientific contribution

The scientific contribution of the proposed research is manifested in:

1) quantification of the relationship between the parameters of (R, s, S) inventory management model and environmental performance indicators, measured through GHG emissions according to EN 16258 standard.
2) developed method of optimal green inventory management in (R, s, S) inventory management model.

## Keywords

Green supply chain management, inventory management, greenhouse gas emission, numerical simulation

# Experimental and Numerical Analysis of Surface Heat Transfer Systems

**PhD candidate:** Darko Zajec
**Mentor/s:** Vladimir Soldo
**Affiliation:** Variotherm d.o.o. Zagreb, Croatia

## Introduction

Due to the fact that modern systems for surface heat transfer in buildings, so-called low-temperature surface heating and so-called high-temperature surface cooling, combine two seemingly difficult to connect concepts, such as very high degree of thermal comfort in environment and significant energy savings, the implementation of these systems expands to growing range of design heating and cooling solutions, regardles concerning new buildings or more or less adapted buildings.

The proposed research will primarily include issues of discontinuous heat flow distribution in rooms with large glass surfaces, containing openings (sliding walls, doors, etc.), which are often encountered in practice. Given that modern architecture, especially in the part related to residential buildings of higher value, nurtures the approach of connecting the interior with the exterior, while applying large glass surfaces, requiring the highest possible degree of thermal comfort in room at the same time.

## Aims

1. Heat losses
2. Exploring the possibility of so-called passive space cooling, without the use of a compression device
3. Increasing the energy efficiency of heat sources of low-temperature heating systems such as heat pumps
4. Verification of the temperature field in the heated / cooled space and the influence of the temperature of the wall, floor and ceiling on its profile and comfort in the space

## Methods

1. Measurements in the experimental room
2. Development of a computer simulation

## Expected scientific contribution

Analyze the interaction of surface heat transfer systems of known geometry, composition and operating parameters of a thermally activated plate with a light permeable wall, through which the differentials of radiant thermal energy are irradiated.

## Keywords

radiant heat, heat loses, thermal comfort, surface heating

# Ventilation Impact on Aerosol Dispersion in a Closed Environment

**PhD candidate:** Borut Omerzo
**Mentor/s:** Tea Žakula
**Affiliation:** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

## Introduction

The coronavirus disease pandemic caused huge harm to almost every aspect of our lives, drastically impacting public health, societies, and economies around the world, causing one of the biggest health crises since the 20th century. Although the World Health Organization emphasized the importance of handwashing, social distancing, and wearing masks at the beginning of the pandemic, recent evidence suggests that the airborne route could be a significant source of infection, for which the mentioned disease control methods may not be applicable. Current guidelines regarding control measures for the coronavirus spread show no consensus regarding ventilation impact on virus dispersion in closed environments. Even though it is well established that ventilation impacts aerosol dilution in the room and consequently airborne transmission, which ventilation type and what air flow rate is most appropriate in certain applications remains unclear.

## Aims

In this study, both experimental and numerical research will be conducted with the objective to further clarify this impact and help define safer and more efficient guidelines for current and future pandemics. In the proposed research, suitable and efficient experimental and numerical methods that can be used to study the impact of ventilation on aerosol dispersion in a closed environment will be defined. Also, detailed and systematic experimental and numerical analyses will be conducted in the RCK building in Zagreb. Finally, better and safer guidelines for virus infection risk mitigation strategies using building HVAC systems will be established.

## Methods

Preliminary numerical simulations will be conducted prior to the experiment with the aim of efficiently designing the experiment. Different research methods such as tracer gas and aerosol techniques will be considered for the experimental part of the research. Experimental measurements will be used to validate numerical models and also to provide invaluable information regarding system performance, airflow patterns, and concentration patterns in a realistic environment. Finally, extensive numerical simulations will be carried out using the models that are validated by the measurements. The purpose of those simulations is to improve and extend the findings of experiments by running additional tests with modified parameters, for example, different room configurations, ventilation parameters, and occupancy patterns.

## Expected scientific contribution

With this research, experimental methods for studying the effect of ventilation systems on aerosol dispersion and the overall efficiency of ventilation systems will be improved. Key ventilation parameters that affect the airborne transmission will be defined and quantified by using both experimental and numerical tests, which will result in high reliability.

## Keywords

airborne transmission, numerical analysis, experimental analysis, ventilation

# Offshore Floating Charging Platform for All-Electric Vessels Powered with Renewable Energy Sources: Techno-Economic Feasibility and Emission Reduction Potential

**PhD candidate:** Lovro Frković
**Mentor/s:** Tomislav Pukšec
**Affiliation:** Center of Technology Transfer LLC, Croatia

## Introduction

Maritime transport carries over 80% of the global trade and it is the most energy-efficient mode of transport. This mode of transport depends on fossil fuels, and it is a major generator of greenhouse gas (GHG) emissions. As emission standards push forward the energy transition of the maritime transport, the battery-powered electric ships are becoming the environmentally friendly, low-cost alternative solution that could decarbonize short-sea shipping. However, available batteries on the market and their characteristics make the electrification of the relatively long-distance international ferry routes more complex.

## Aims

This study is proposing a concept of mobile offshore charging platform for all-electric vessels to enhance electrification of long-distance maritime routes such as international ferry routes. A model considers the replacement of a conventional diesel-powered ferry with a battery powered one and the implementation of a renewable-based floating charging station (FSC).

## Methods

The floating charging station can be used to decrease the required battery capacity of the battery-powered ships, due to the possibility of recharging batteries along the course of voyage. The floating charging station should act as self-sufficient facility entirely relied on the electricity generated from Renewable Energy Sources (RESs) and hybrid energy storage technologies. The proposed model is designed and verified using EnergyPLAN program.

## Expected scientific contribution

The study results shows that implementation of the renewable-based offshore FCS for charging battery-powered electric ferries (BEFs) along the relatively longer sea routes is inevitable.

## Acknowledgments

The research was supported under the project Strengthening Transnational Co-operation, Knowledge and Technology Transfer in Development of Electric Vessels and Fostering Innovations in SME's (ZEVinnovation), (Project Index No. 2018-1-1185) funded by Iceland, Liechtenstein and Norway through the EEA and Norway Grants Fund for Regional Cooperation and conducted by the Center of Technology Transfer LLC (Croatia) together with the University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture (Croatia).

## Keywords

Floating charging station (FSC), All-electric vessels, battery-powered electric ships, Renewable energy sources (RES), Maritime electrification

# Numerical Modelling of E-Fuel Combustion Process for a Future Passenger Car Compression Ignition Engine

**PhD candidate:** Marijan Marković

**Mentor/s:** Milan Vujanović

**Affiliation:** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

## Introduction

Given the recent energy trends in the transport sector to pursue carbon-neutral fuels, e-fuels are arising as a suitable replacement for conventional fuels in the transportation sector.

## Aims

In this paper, a research of applying polyoxymethylene dimethyl ether 3 (OME3) as a prominent e-fuel to substitute the conventional diesel fuel is given. The scope of this analysis includes examinations of single injection and multi-injection operating conditions inside an industrial compression ignition engine for OME-3 fuel, each examined for different regimes with different injection rates.

## Methods

To adequately simulate the combustion process, two approaches are employed: General Gas Phase Reactions (GGPR) with detailed chemical kinetics and combustion model three-dimensional Extended Coherent Flame Model (ECFM-3Z). The ECFM-3Z model is employed as an adequate solution that describes autoignition, premixed, and diffusion flames, calculating transport equations only for certain chemical species, thus saving computing power and time compared to the detailed chemical kinetics. The validation of the GGPR approach is performed in computational fluid dynamics software AVL FIRE™ on the existing experimental results for diesel fuel and compared with the mean temperature, pressure, and rate of heat released experimental data.

## Expected scientific contribution

The simulations confirmed that due to the inferior lower heating value of OME-3 compared to the diesel fuel, OME-3 offers less energy per mass, meaning that the amount of fuel and injection rates are required to be higher to provide the same output power as conventional fuel.

## Acknowledgments

This work was funded under the auspice of the European Regional Development Fund, Operational Programme Competitiveness and Cohesion 2014–2020, KK.01.1.1.04.0070.

This work has been supported by the Croatian Science Foundation.

## Keywords

Computational Fluid Dynamics, e-fuel, OME-3, multi-injection, ECFM-3Z

# The Eigenspectrum of a Finite Volume Matrix

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**Affiliation:** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

## Introduction

The discretisation of partial differential equations using the Finite Volume Method results in linear systems with square, sparse coefficient matrices, which have symmetric addressing. The dimension of the coefficient matrix is equal to the number of finite volumes in the spatial discretisation, i.e. computational mesh. The sparseness pattern of the coefficient matrix is determined by the position of the elements inside the matrix and can affect the performance of iterative linear solvers. The convergence of these iterative methods depends greatly on the eignespectrum of the iteration matrix, which is often correlated with the eigenvalues of the coefficient matrix.

## Aims

In this paper, we shall investigate the eigenspectrum, i.e. eigenvalues and eigenvectors of coefficient matrices obtained from the Finite Volume discretization of partial differential transport equations. We shall compare the effects of mesh properties: number of cells, mesh connectivity (structured, unstructured), cell type and size, cell anisotropy and cell volume ratio. The tests will be conducted for cases with single-phase, incompressible, laminar and turbulent flows. The eigenvalues shall be calculated for velocity and pressure coefficient matrices and compared for cases with dominant convection and diffusion transport. We shall implement and employ the power method for calculating the dominant eigenvalues, as well as an external library, coupled to OpenFOAM.

## Keywords

eigenspectrum, iterative linear algorithms, finite volume discretisation

# Fluid-Structure Interaction Analysis of Thoracic Aorta Blood Flow

**PhD candidate:** Anja Horvat
**Mentor/s:** Željko Tuković
**Affiliation:** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

## Introduction

Aortic dissection is a serious cardiovascular disease, where the inner layer of the aorta is injured enabling blood flow in between layers. Complications can lead to death, however, the preferred method of treatment isn't yet defined. To assist clinical decision–making, patient-specific computational modelling has lately been used. In this study, a partitioned FSI solver based on finite volume discretisation is used to calculate the interaction between blood flow through idealised thoracic aorta and flexible vessel wall, as a first step toward the application of a solver on more complex geometries involving aortic dissection.

## Aims

The aim of this study is to perform a comparative analysis of the blood flow through the rigid and flexible vessel wall to show the importance of applying FSI analysis for realistic predict thoracic aorta hemodynamics.

## Methods

A partitioned FSI solver based on finite volume discretisation is used to calculate the interaction between blood flow through idealised thoracic aorta with a flexible vessel wall. The laminar flow of incompressible, Newtonian fluid is described by Navier Stokes equations in arbitrary Lagrangian-Eulerian form. The deformation of incompressible, neo-Hookean hyper-elastic material is described by momentum equation in total Lagrangian form. Solid properties are assumed to be homogeneous and isotropic. The second-order accurate finite volume method is used for the spatial discretisation of both fluid and solid models and the first-order accurate implicit Euler method is used for temporal discretisation. The radial slip boundary condition is imposed on outlets and inlets of the solid domain which enables radial displacements and prevents displacements in the axial direction. The outer wall is defined as traction free. Time-varying flow rate is imposed on the inlet and three-element Windkessel is imposed on outlets of the fluid domain. Coupling between fluid and solid is performed using Robin-Neumann partitioned procedure, where the fluid pressure at the interface is bounded by solid inertia which ensures stability. Simulations were performed using open-source toolbox solids-4foam.

## Expected scientific contribution

The use of a new FSI solution procedure based on Robin BC for pressure for completely incompressible solid (Poisson ratio = 0.5).

## Acknowledgments

This work was supported by grants from the Croatian Science Foundation (project IP-2020-02-4016 and DOK-2021-02-3071).

## Keywords

Fluid – structure interaction, computational fluid dynamics, finite volume method, aorta

# Optimization of Combined Plants with the Aim of Maximum Thermodynamic Efficiency

**PhD candidate:** Iva Slatina
**Mentor/s:** Mislav Čehil
**Affiliation:** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia

## Introduction

Combined-cycle power plants use fossil fuels as an energy source and account for a good share of global electricity generation. They represent the one of the most efficient energy conversion technology and the most sought-after option for meeting the world's growing electricity consumption.

The performance of combined plants has improved with increasing application over the years. With regard to directives and strategies related to climate change and the need for "cleaner" energy, various analyzes and measures to improve thermodynamic cycles are carried out, with consideration of different plant configurations, in order to increase efficiency and reduce greenhouse gas emissions.

A review of the scientific literature established that the steam turbine part of the combined plant was investigated in detail and the integration of organic working fluids in steam cycles proved to be optimal from a thermodynamic point of view. Utilization of waste heat from the gas turbine part of the combined cycle is one of the traditional ways of converting waste heat into energy, which reduces fuel consumption, electricity production costs and greenhouse gas emissions.

## Aims

The ultimate goal of this research is to achieve better overall thermodynamic efficiency, reduce emissions, greenhouse gases and identify appropriate parameters to achieve the desired and optimal results of combined plants.

## Methods

The methods to be applied for the purpose of this research are based on a number of numerical methods used so far to model similar systems. Theoretical research will be conducted first, followed by numerical research, in order to achieve the previously mentioned goals. A simulation model will be developed in the numerical tool MATLAB in which both cycles of the combined plant will be integrated, and which code will include thermodynamic and exergoeconomic analysis as well as plant optimization. The components of the combined plant will be modeled according to thermodynamic principles while the optimization of the plant will be carried out using appropriate optimization algorithms. The model will be adapted to consider different plant configurations. After optimizing each of the configurations, the optimal results for each of them will be presented and then a comparative analysis of all the obtained results will be made.

## Expected scientific contribution

The gas turbine part of combined plant cycle contains a number of potentially applicable measures that would contribute to increasing the overall efficiency in combination with the already well-researched steam turbine part of the cycle. Further research would be based on a detailed theoretical analysis of existing proposed and applied measures to improve the gas turbine part of the plant and the configuration of the plant as a whole, and consideration of potential new configurations and measures. It would include modeling the gas turbine part of the plant, considering measures to improve it, researching the scope of these measures, their integration with previous knowledge related to the steam turbine part of the plant, optimizing the operation of the entire combined plant and searching for configurations that will lead to higher thermodynamic efficiency compared to the proposed configurations of combined plants so far.

## Keywords

Combined cycle, gas turbine cycle, optimization, improvement measures, thermodynamic efficiency

# Polymer Linear Stage Efficiency Improvement Utilizing Multi Material Approach

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**Mentor/s:** Marko Katić
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## Introduction

In the most metrology applications, either measurement object or measurement system has to be accurately moved through measurement range. In addition, precise positioning is often required for alignment of measurement sample in relation to the machine. Actuators used in these applications, has to be able to provide the necessary linear motion, with high resolution and repeatability. Traditionally, a leadscrew has been used for displacement generation, but problems with backlash, creep and non-linearity limits their usage in high precision applications.

In recent years, piezoelectric actuators (PEA) have been commonly used for displacement generation. PEA have many positive characteristics such as high resolution in comparison to leadscrews, high output force and short input response time. Their main weakness is the limited range of travel (in range of several micrometres). To avoid the limitation, piezoelectric actuators are often combined with mechanical amplifiers such as lever or screw-based mechanisms and generally, the best precise positioning results can be achieved by pairing lever stroke amplifier with piezoelectric actuator. In nano positioning and metrology, stroke amplifiers are the most commonly used in the form of compliant mechanisms. Compliant mechanisms provide motion through deformation of their body elements. This is highly desirable in nanometre applications as these mechanisms can be produced in a single piece, which eliminates motion errors such as creep and backlash. Although compliant mechanisms have numerous benefits such as no need for assembly or maintenance this kind of mechanisms are more difficult to analyse, design and produce. Combination of the piezoelectric actuator with mechanical amplifier and linear stage mechanism is commonly known as piezoelectric stage.

The synthesis process of this mechanisms is often a nonintuitive and time-consuming process, so in order to simplify construction, standard types of flexure hinge shapes have been defined. To further improve efficiency of the piezoelectric stage (displacement generated at the input force) the possibility of using multi material design is presented in this research. Usage of the materials with different mechanical properties could allow production of piezoelectric stages with hinges that require less force to deform. Composite materials have great potential in providing required selective reinforcement in needed areas. Different materials will be used to selectively reinforce sections of the mechanism and increasing rigidity. For the analysis of different materials potential for this application as well as optimal reinforcement layout FEM simulations will be use. During construction process special attention will be paid to the new design possibilities that modern production technologies such as additive manufacturing provide.

## Keywords

piezo linear stage, polymer, multi-material, compliant mechanism

# Investigation of Application of Polymer Based Composite Materials in the Transmission System Structures

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## Introduction

Finding a composite material types that could improve performance and/or reduce weight and production cost has become attractive in a modern transmission system engineering. Polymer based composite materials while having a wide range of possible combinations still remains poorly researched as a material used in a transmission system structures. There exists some researches mostly in the field of polymer based composite gears but only few of those researches are regarding housings and gearboxes of the system which leaves a big research gap.

## Aims

The main goal of this research is to vary material types, configurations and levels in a polymer based composite materials from which will samples be created in order to test the mechanical and chemical properties of those samples by conducting experiments. After finding candidate materials which could possibly improve transmission system housings and gearboxes those elements will be constructed from those materials and will be tested and evaluated as possible substitution for a convectional transmission system structures materials.

## Methods

The research will include design of experiment according to which samples will be made and tested for their properties like tension, compression and flexion mechanical properties as well as vibration damping and chemical resistance. After that results will be gathered and analyzed in order to conclude which material types, configurations and levels could be used as construction material for the transmission systems housings and gearboxes. Housing will be produced and tested on a testing rig while measuring important properties like vibration damping, maximum load capacities etc. Experimental results will be followed by simulation so that simulation results can be validated by the experimental measurements.

## Expected scientific contribution

Expected contribution of this research is to find polymer based composite material which could improve performance of the transmission system housing by either improving mechanical properties like damping, stiffness or by reducing weight and cost of the production of such constructions in order to offer adequate alternative for conventional housings and gearboxes.

## Keywords

Polymer based composites, polymer concretes, mineral casts, transmissions systems, gearboxes

# The Impact of Slow Steaming on Ship Hydrodynamic Characteristics

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## Introduction

Nowadays maritime industry is focused on reduction of greenhouse gas (GHG) emissions from shipping. Although about 2.89 % of the total global anthropogenic CO2 emissions comes from shipping industry, in 2018 the International Maritime Organization (IMO) adopted the strategy to lower the total annual GHG emissions by at least 50 % by 2050, in comparison to 2008. Different measures to mitigate the emissions are proposed and used in the shipping industry, which can be classified into technological and operational measures. The use of alternative fuels and renewable energy sources could be considered as a third category of mitigation measures. One of the short-term operational measures that is being implemented in maritime transport is slow steaming. It is a low-cost measure that can greatly reduce the emissions since fuel consumption depends on the sailing speed. However, it is important to investigate whether the savings in fuel consumption due to lower sailing speed can exceed the costs of a higher number of vessels that have to be engaged to keep the yearly transport work constant. The ship operators would gladly implement this measure if the savings achieved by speed reduction would be greater than the capital and operating costs.

## Aims

By implementing the slow steaming measure, ships are sailing in conditions that can significantly differ from the design conditions leading to modification of ship hydrodynamic characteristics. The aim of this study is to determine the impact of slow steaming on the hydrodynamic characteristics of various ship types using numerical simulations.

## Methods

In this study, Computational Fluid Dynamics (CFD) based on the viscous flow theory will be employed. Reynolds Averaged Navier-Stokes (RANS) equations will be numerically solved within the commercial software package STAR-CCM+. The Finite Volume Method (FVM) will be used to transform the differential equations into a system of algebraic equations while the Volume of Fluid (VOF) method will be utilized to locate and track the free surface. The High-Resolution Interface Capturing (HRIC) scheme will be applied to maintain a sharp interface between the two phases. To model the ship motion, the Dynamic Fluid Body Interaction (DFBI) model will be used, thus enabling six degrees of freedom. The uncertainty due to time step and grid size will be calculated by the Grid Convergence Index (GCI) method. The numerically obtained results will be validated against the results of towing tank measurements.

## Expected scientific contribution

Determination of ship hydrodynamic characteristics, as well as a detailed representation of the flow around the ship hull, can be obtained with numerical simulations based on the viscous flow. A series of numerical simulations will be performed in order to determine the impact of speed on the ship hydrodynamic characteristics for different ship types. This will allow new insights into the impact of speed reduction on the ship hydrodynamic characteristics.

## Acknowledgments

This study has been fully supported by the Croatian Science Foundation under the project Sustainable slow steaming for low carbon shipping (STARSHIP), (Project No. IP-2020-02-8568).

## Keywords

Computational Fluid Dynamics, Reynolds Averaged Navier-Stokes equations, Finite Volume Method, slow steaming, greenhouse gas emissions

# Development of Non-Destructive Impedance Testing on Layers Formed by Pacvd Process

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## Introduction

Modern surface engineering methods are particularly useful to improve important properties of machine parts or tools, such as wear resistance and corrosion resistance, in order to extend their durability. Demands for lower costs, and at the same time increasing productivity and product quality, encourage the development and application of surface coating procedures. One such process is plasma-assisted chemical vapor deposition (PACVD), which is also one of the most modern surface engineering technologies. In the proposed research, it is planned to apply the procedure of PACVD coating with TiN, TiCN and TiBN coatings on tool steels and to carry out the characterization procedure which includes testing of mechanical, corrosion and tribological properties of those coatings. It is planned to apply the novel, recently developed experimental method for non-destructive impedance testing of corrosion resistance to the mentioned PACVD coatings. The specificity of the novel method is the use of quasi-solid-phase electrolyte. The method was originally developed for application on organic coatings but has recently been successfully applied to chromium and vanadium carbide coatings obtained by the TRD method. PACVD coatings generally show several orders of magnitude higher impedance values than unprotected substrate, which indicates their lower reactivity and the formation of a barrier between the environment and the substrate. To determine the reliability of the novel method for practical application and to gain new basic knowledge about the impedance behavior of coatings obtained by PACVD method, impedance measurements on PACVD coatings should be performed and linked to other coating characteristics, such as thickness and porosity.

## Aims

The aim is to determine the reliability of the novel recently developed experimental method for measuring electrochemical impedance spectroscopy for practical application in quality assurance and quality control of PACVD coatings, and to gain new fundamental knowledge about the impedance behavior of PACVD coatings.

## Methods

In the first phase of the research, coating of tool steels will be obtained by plasma-assisted chemical vapor deposition process. In order to test the achieved properties of the obtained coatings, the characterization of coatings will be performed, which will include tests of thickness, adhesion and roughness of coatings, testing of chemical composition of the coating and substrate, microstructure of the substrate, crystallographic structures by XRD measurements, abrasion and erosion resistance tests and chemical resistance of the coating. To correlate the impedance properties of the coating with the listed tested properties, the impedance spectra and impedance on new coatings will be measured before and after mechanical wear (abrasion, erosion), chemical influences, physical influences, and corrosion effects, using a recently developed experimental method for measuring electrochemical impedance spectroscopy with quasi-solid-phase electrolyte in the form of a paste.

## Expected scientific contribution

The potential practical significance of the development of a new method for assessing the quality of PACVD coatings, as well as scientific knowledge about the relationship between impedance response and coating condition determined by complementary methods, are the basis of this paper's motivation.

## Keywords

PACVD, TiN, TiCN, TiBN, non-destructive impedance testing

# Improvement of Transformer Insulation Drying Process by Employing a Simultaneous Heat and Mass Transfer Model

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## Introduction

Electrical grade paper and pressboard as well as impregnating mineral oil are widely used transformer insulating materials. Together they make up so-called transformer main insulation. The major drawback of cellulose materials is their hygroscopic nature which combined with hydrophobic nature of oil results in majority of moisture in transformer being bound to cellulose part of insulation. Moisture as such significantly reduces the dielectric strength of insulation and consequently the life expectancy of transformer. It is therefore extremely important to reduce the cellulose insulation moisture content before the oil impregnation process. This is achieved by subjecting the cellulose insulation to a thorough vacuum drying process which, depending on the size of the transformer and the drying technique, can last from days to a few weeks and is usually the component consuming the most energy and a bottleneck of the whole manufacturing process.

## Aims

This work aims to show that conventional vacuum drying of transformer cellulose insulation can be well described by simultaneous heat and mass transfer model and that this model can be further used to improve the drying process in terms of both required drying time and energy intensity.

## Methods

First step in this research is to formulate a proper simultaneous heat and mass transfer model followed by the simulation of the process results of which will be spatially and temporally discrete fields of insulation temperature and moisture content. To validate the model, experimental setup consisting of a scaled vacuum chamber equipped with infra-red electric heaters for insulation surface temperature control will be constructed. The scaled model of insulation will be subjected to specifically defined alternating cycles of heating and vacuum application. During these cycles the temperature distribution of the cellulose insulation along the thickness will be measured with fixed number of temperature sensors. Additionally, two-point moisture content will be evaluated in real-time. For this purpose, a frequency domain spectroscopy analyzer, a device typically used for on-site transformer diagnostics will be employed in a novel way. Once validated, the model will serve as a tool to find an improved way of controlling the vacuum drying process in such way to reduce the drying time with constraint on energy "consumption". This will be done by taking a several influential and controllable parameters and investigate optimization accordingly.

## Expected scientific contribution

Firstly, validation of the above-mentioned mathematical model will clarify which heat and mass diffusion-driving mechanisms are predominant within the cellulose insulation drying. Moreover, employing a frequency domain spectroscopy to obtain the transient moisture content distribution has not been come across so far among the published scientific papers. This method of moisture content measurement could be applied to other types of transient processes wherever it is impractical to use gravimetric method, for example due to the interruption of the process. Lastly, validated mathematical model provides a very useful tool for further improvements of this type of vacuum drying process, regimens of which are otherwise mostly based on trial and error. This way of improving the process was not found in the published papers.

## Keywords

transformer, vacuum drying, heat and mass transfer, frequency domain spectroscopy, moisture

# Influence of Cumulative Distribution Function Approximations on Risk Assessment

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## Introduction

The obtained measurement results of an item of interest must conform to specified requirements. The decision of whether a measured quantity is accepted as satisfactory is made based on a predetermined tolerance interval. Such a procedure is called conformity assessment decision. When assessing the conformity with specified requirements, there is a risk for both the producer and the consumer. The measured value may be within the tolerance interval, while the actual value is outside the tolerance interval. In that case, it is a mistake of false acceptance. This is an incorrect decision whose probability is called consumer's risk. The costs associated with that kind of error often are borne by the consumer. Conversely, the measured value may be outside the tolerance interval while the actual value is within the tolerance interval. In this case, a false rejection error was made. This incorrect decision is called producer's risk and associated costs are borne by a producer. To avoid such decision-making errors, the consumer and producer risks are determined. The analytical term for calculating both risks, consumer and producer, includes the cumulative distribution function (CDF) of the standard normal distribution. The CDF of the normal distribution is the integral of the normal probability density function (PDF). Such integral cannot be evaluated in closed form. For that reason, several approximations for CDF of standard normal have been developed. These approximations will be applied for risk calculation.

## Aims

Different approximations of CDF for the given range of values of the function argument have different levels of accuracy. These deviations will influence the risk. This research aims to select the approximations which are most suitable for risk assessment.

## Methods

The producer and consumer risk are calculated as the integral of the product of CDF and PDF of standard normal distribution in a given area. The area of integration is determined by the limits of the tolerance interval, the limits of the acceptance interval, and the measurement uncertainty. Integration is performed numerically, by the trapezoidal method. The calculation is performed for two examples. The first example is from the JCGM 106:2012 norm, and it is about risk assessment in the manufacture of precision resistors. The second one is from practice, about risk assessment in welding machine production. Calculations will be made for selected, historically known approximations of CDF for standard normal distribution. After estimating, a comparison of the obtained results will be performed with results from the listed examples.

## Expected scientific contribution

The expected scientific contribution is to determine the impact of approximation of cumulative distribution function for standard normal on the accuracy of producer and consumer risk assessment.

## Keywords

Approximations to CDF of normal distribution, CDF, consumer risk, producer risk

# Predictive Control of a Cleanroom Ventilation System Based on Reduced Order Models

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## Introduction

Based on the results of computational fluid simulations (CFD), it is possible to determine ventilation effectiveness and consequently reduce the energy consumption required to achieve adequate air quality in a cleanroom. However, the implementation of simulations for each individual room and ventilation mode is still expensive and time-consuming. This research aims to provide the method for the evaluation of cleanroom ventilation effectiveness in a much shorter time period. The appropriate formulation of the reduced order model will be determined and implemented to monitor temperature, humidity, and pollutants concentration as a basis for predictive control. By optimizing the airflow and temperature for each individual air diffuser in accordance with the actual needs of the cleanroom (the location and intensity of pollutants emission, and the heat load) for the observed time period, the ventilation effectiveness will be improved.

## Aims

The goal of this research is to determine the appropriate formulation of the reduced order model (ROM) that reproduces the results of numerical simulations with satisfactory accuracy in significantly smaller time for different ventilation operating modes in cleanrooms. Furthermore, an algorithm for predictive control of the ventilation system will be formulated. Its purpose is to determine the optimal ventilation operating mode in accordance with the current needs of the cleanroom, utilizing reduced number of sensors, which leads to reduced number of air changes per hour and significant energy savings.

## Methods

An incompressible, nonisothermal, multispecies flow inside the room will be modeled on polyhedral numerical mesh in order to generate the training data which includes the temperature, velocity, humidity, and pollutants distribution for different cleanroom conditions such as: location and intensity of pollutants emissions, heat load, and ventilation operating modes. Projection based and machine learning based ROMs will be compared, based on the results of CFD simulations. Finally, an algorithm for predictive control will be formulated with occupants' location and intensity of contaminant emission as input parameters and optimal flow and temperature per air diffuser as output parameters.

## Expected scientific contribution

It is expected that this research will develop the method for the selection and development of an appropriate reduced order model for pollutants concentration, air temperature, and humidity monitoring for different ventilation operating modes, which will facilitate the development of an algorithm for predictive control of the ventilation system in clean rooms based on a reduced number of simulations. The development of a demand-response algorithm for predictive control of the ventilation system based on the results of the reduced model will reduce the number of air changes in the room by optimizing the flow and temperature per diffuser, therefore reducing energy consumption required for air conditioning and transport.

## Keywords

Cleanroom, MPC, reduced order model, CFD

# Application of Deep Learning for Prediction of Pedestrian Behaviour Intended for Optimal Control of Autonomous Vehicle Speed Near Pedestrian Crossings

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## Introduction

Autonomous driving is an area that has progressed at high speed over the past few years, driven by significant breakthroughs in the fields of artificial intelligence, computer vision, high data processing power etc. It is clear that autonomous vehicles are still far from complete autonomy that does not require some form of driver intervention. Although some autonomous driving tasks are well solved, others involving some kind of autonomous vehicle interaction with other road users (e.g. pedestrians, cyclists, other vehicles) are still in their infancy. Artificial intelligence algorithms on which autonomous vehicles are based still do not have the strong ability to understand the complex social interactions between pedestrians and vehicles, which are very common in urban driving conditions, nor the cause-and-effect relationships needed to understand traffic situations.

## Aims

The main goal of this research is to propose a model for predicting pedestrian behavior near pedestrian crossings based on deep neural networks. Considerable attention will be paid to the design of the structure for model inputs for the general case of pedestrian crossing configuration, road, number of pedestrians, number of other vehicles and other road agents. For the purpose of adapting the model while driving, an appropriate data collection procedure and a computer-efficient algorithm will be proposed. The development and validation of the developed model will be carried out first on simulation data, and then on a large set of real-world data collected.

## Methods

The research is predominantly numerical and analytical in terms of conducting computer analyses, numerical optimization (i.e. learning in the context of neural networks) and simulations. Advanced deep learning methods implemented in the standard TensorFlow library in Python will be used to analyze and develop appropriate pedestrian behavior prediction algorithms. Matlab and the SUMO (Simulation of Urban Mobility) software environment will be used to simulate the vehicle-pedestrian interactions, within which the functionality of the developed algorithms listed in the research objectives will be tested.

## Expected scientific contribution

The expected scientific contribution is development of methods for: 1) design of the model structure for the general case of pedestrian crossing configuration, road, number of pedestrians, number of adjacent vehicles and 2) appropriate data collection procedure for the purpose of adapting the model in production and a computer-efficient algorithm for model adaptation.

## Acknowledgments

The research work is part of the research project “Safe Speed Anticipating for Encountering Pedestrian Crossing”, supported by Ford Motor Company through the University Research Program (URP) framework.

## Keywords

autonomous vehicles,pedestrian behavior,machine learning,deep learning,safety

# Experimental and Numerical Analysis of the Initiation Process and Crack Growth in a Pressure Veseli

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## Introduction

Complete characterization of welded joints in terms of performance properties, implies observation of their behaviour in the presence of defects, i.e. the assessment of their resistance to initiation and crack propagation as the most dangerous type of defect. Due to localized heating and subsequent rapid cooling of the welded joint and the base material, residual stresses and deformations occur. In addition to that, combined with the workload, it can accelerate the formation of fatigue cracks and fractures.

## Aims

The aim of the proposed research is to define a procedure for numerical modeling of damage accumulation process in welded joints due to cyclic loads. Based on the results for residual stresses and strains, the goal is further to develop and validate a numerical procedure for predicting the formation and growth of cracks in welded joints subjected to cyclic loading. Currently, there are a relatively small number of publications related to numerical models for predicting fatigue damage of welded joints in thick-walled structural components obtained by high-performance welding processes. The results of the research will contribute to a more accurate definition of the criteria for assessing the integrity of these welded joints.

## Methods

Quasi-static tests and cyclic fatigue testing of welded joints will be performed on a high-frequency pulsator that is currently in the process of procurement. The non-destructive energy X-ray diffraction method will measure the normal and shear components of the residual stress on the sample surface, while the semi-destructive hole drilling method will be applied to determine the amount and direction of the main stresses. Within the framework of numerical investigations, a thermo-mechanical finite element analysis is performed by using a shell/three-dimensional modeling technique toimprove both the computational efficiency and the accuracy. In thermal analysis, the temperature field is determined as a function of time for each integration point. This temperature time-history is used as an input into the thermal stress analysis. All numerical modeling and simulations of these procedures will be carried out in the commercial software package ABAQUS, which is based on the finite element method. Specialized software packages ZenCrack and FE-Safe will be used for modeling cracks and fatigue analysis.

## Expected scientific contribution

It is necessary to record the parameters of the welding process and use thermocouples and a thermal camera to record temperature changes, while the digital image correlation method will record surface displacements through which the system will calculate the deformations. In this way it will be possible to give the dependence of deformations on temperature. Metallographic analysis of the weld zone, heat impact zone and base material will be made using a light microscope. In this way, it will be possible to establish the phase changes that have occurred due to the welding process. At the end of the test, i.e. after cooling to room temperature, residual stresses must be measured. Based on quasi-static results for residual stresses and experimental research of welded joints, a numerical procedure for predicting the formation and growth of cracks in welded joints subjected to cyclic loading will be developed. Verification and validation of numerical algorithms will be attempted.

## Keywords

pressure vessels, high-efficiency welding process, residual stresses due to welding, numerical modeling, damage, fracture mechanics, cracks, fatigue

# Damage Quantification in Fiber Reinforced Polymer via Digital Volume Correlation

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## Introduction

Due to their advantageous properties, the application of fiber reinforced polymers (FRPs) is in constant growth. The heterogeneous nature of such materials induces the occurrence of various damage mechanisms on different scales. Coupling mechanical tests observed with X-ray Computed Tomography (XCT) and Digital Volume Correlation (DVC) allows for in-situ full-field displacement measurements and calculation of 3D strain maps. Furthermore, global approaches to DVC based on finite element (FE) discretizations perform registrations over the entire Region of Interest (ROI) by assuming the continuity of the displacement fields. The key advantage of such approaches is the availability of correlation residuals corresponding to the gray level difference between the reference volume and the volume of the deformed material corrected by the measured displacement fields. The quality of the measured kinematics is evaluated from the correlation residual maps, as the high values reveal local violations to the gray level conservation (being the underlying hypothesis of DVC). Thus, employing global approaches provides the opportunity to assess in-situ damage processes within the investigated materials.

## Aims

The present work aims to analyze strained band activity and damaged zones, as well as their interplay within a glass fiber mat reinforced polyester resin. FE-based DVC was employed to measure 3D bulk kinematics. As DVC assumes gray level conservation, correlation residuals serve as a correlation quality inspection tool and provide information crucial for observation, identification, and quantification of damage growth. Furthermore, such an analysis enables the changes in microstructure within the observed damage zones to be correlated with DVC results.

## Methods

In-situ cyclic tensile experiments were performed on two dogbone specimens (a rectangular notch was cut on the one side of the second specimen to induce high strain gradients). 3D scans of investigated specimens were acquired by using XCT, while the reconstructed volumes were analyzed via FE-based DVC. The calculated major eigen strain fields and correlation residual maps were analyzed to observe and quantify damage mechanisms and their interaction with the local strain fields. Damage growth was further quantified by analyzing major eigen strain and correlation residual histograms and their cumulative probabilities. Last, dominant damage mechanisms were identified by laying the correlation residuals over the corresponding mesostructure sections, as well as analyzing mesostructure sections of the deformed volumes corrected by the measured displacements.

## Expected scientific contribution

The present work brought new experimental evidence on the events leading to the final fracture of the investigated material. Volumetric correlations revealed that various damage mechanisms were induced within the material bulk. It was shown that the final failure of the investigated material was primarily driven by its heterogeneous mesostructure. The influence of the latter prevailed over the high strain gradients induced by specimen machining and/or geometric singularity (i.e., notch).

## Acknowledgments

This work was performed within the FULL-INSPECT project supported by the Croatian Science Foundation (UIP-2019-04-5460 Grant).

## Keywords

Glass fiber reinforced polymer, Damage, Digital Volume Correlation, Gray level residuals

# Improvement of Heat Conductivity of a Polyethylene with Graphite Nanoparticles

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## Introduction

Global energy demand, on one hand, and a strife of leading world economies for greenhouse gas reduction, on the other, combined are a generator of renewable energy source development. Within past thirty years energy obtained by solar panels and cells, as well as energy obtained from geothermal sources is in a constant increase. Annular installed capacities from 2015. to 2019. are growing year by year, 8,7% in average, from 70 855 MWt in 2015. to 107 727 MWt in 2019. relatively. Ground heat exchanger (GHE) is one of the most important parts of a passive house, using ground heat energy as unlimited source of heat. GHE can be implemented as a vertical (probe) system or ground borehole heat exchanger (GBHE) or as a horizontal system. Horizontal heat exchangers demand a shallow ground excavation up to 30 meters deep, whereas vertical demand a borehole up 400 meters. Nowadays, GHE consist of one or more pipe loops made of a high-density polyethylene (PE-HD) with appropriate mechanical, physical, and rheological properties. Development of new exchanger types is oriented on application of a new arrangement, build materials and design of heat exchangers.

## Aims

In this work composite composed of polyethylene (PE) and expanded graphite (EG) will be further examined. Main goal is to achieve multiple increase of thermal conductivity by adding nanoparticles of EG in PE matrix.

## Methods

Preparation of composite will be achieved by melting matrix in kneader, adding compatibilizer and stabilizer to compound and finally mixing it with EG. Composite will be blended in various ratios, hot pressed and cooled. Samples are then a subject of a thermal conductivity testing as well as a mechanical testing.

## Expected scientific contribution

Research of composite preparation and physical properties of it. Process of blending will be performed by using a standardized mechanisms and test so it can be repeated and further developed by adjusting other compounds or with different ratios.

## Keywords

polyethylene/graphite composite, thermal conductivity

# Grouping Vibration Sensors into Pre-Set Clusters Using Only Lp Norms

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## Introduction

For many years now, Sensor Placement Optimization (SPO) is a topic that is being actively researched and developed. It is applicable to many technical fields, the one important for this thesis being Structural Health Monitoring (SHM). While SPO is continually improving, the topic is nowhere near exhausted as it is still not feasible to encompass all the physical parameters of a structure that play a role in its behaviour, due to financial and computational limitations.

Research on SPO is usually focused on getting best results with very limited sensor inputs, and an interesting way to contribute is with cost functions that group sensors in a particular way first, and then optimise the number and position of groups (clusters). Clustering can be strict or not strict (not strict clusters can still be only partially populated). Sensor selection for clustering can be arbitrary, but here it will be done so that all the possible sensors that correspond to a real location on the structure are grouped into one cluster. Benefits of clustering include reducing the number of variables for the optimisation process, and in case of grouping all the sensors from a physical location together it ensures having data of all available axis in each sensed location, which is useful for multi axis data like vibration.

## Aims

Developing an algorithm for SPO with the ability to force grouping of possible sensor positions from individual physical locations into sensor clusters (or even arbitrarily defined clusters), and then optimize the number and position of said clusters. Whole clustering procedure is to only use Lp norms, keeping the clustering as mathematically simple as possible.

## Methods

Algorithm will take stiffness, damping and mass matrices of a discretized model and transform them into a continuous time state space system. State space format will be utilized for finding best sensor positions with minimising observer error, while also grouping sensors into clusters. A strict clustering method using a relaxed L0 norm of L2 norm grouped sensors will be developed and tested numerically on various structures, with some testing advancing to experimental.

## Expected scientific contribution

A numerically simple but effective method of optimising positions of strict groups of sensors instead of optimising single sensor positions.

## Acknowledgments

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## Keywords

Sensor placement optimization, Convex optimization, Mixed L0/L2 norm, L0 norm relaxation, Observer error

# Hybrid Energy Systems of Fishing Vessels

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## Introduction

Energy efficiency and environmental friendliness are important aspects of all transport sectors, including maritime. To reduce Greenhouse Gas (GHG) emissions and mitigate the effects of climate change, the Paris Agreement, an action plan to limit global warming, has been signed. The aim of the agreement is to keep the increase in average world temperature below 2°C compared to pre-industrial levels and to make efforts to limit this increase to 1.5°C. The maritime sector emits significantly lower levels of harmful emissions compared to land transport, but it also causes negative consequences for the environment. Due to the weaker climate impact, the fisheries sector, compared to larger ships (passenger, container), was relatively neglected, both in terms of regulations and the development of advanced technical solutions in the ship's energy system. Given that most of the fishing activities are near coastal areas, the negative impact on the coastal population and the environment should be taken into account. The research will be focused on the environmental friendliness improvement of the Croatian fishing fleet. By replacing obsolete diesel engines with hybrid energy configurations, the optimal solution that will satisfy the economic criteria of production and operation, but also ensure the environmental friendliness of such vessels, will be found. Alternative fuels are a very promising research area and are generally considered more environmentally friendly compared to traditional fossil fuels. Their share in the hybrid energy system can play a significant role in achieving the above goals, which will also be assessed.

## Aims

The aim of the research is to develop a model of an alternative power configuration on fishing vessels, considering energy efficiency, environmental eligibility and economic output.

## Methods

Based on the data on fuel consumption and exploitation scenarios of different fishing vessels operating in the Adriatic Sea, mainly trawlers and purse seiners, vessel emissions will be determined, and a review of emission reduction technologies will be provided. A detailed analysis of the Croatian energy mix will provide insight into the share of Renewable Energy Sources (RESs) and the contribution that their implementation would ensure. Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCCA) of different power options will be used to compare the power configurations and chose the optimal one.

## Expected scientific contribution

The activities of the research will be focused on assessing the energy efficiency and environmental friendliness of the proposed energy configurations. The final goal is to develop a mobile application that will be used to configure the hybrid energy system according to the needs of the fishing vessel.

## Acknowledgments

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## Keywords

Hybrid energy systems, fisheries, emission mitigation, alternative fuels, environmental friendliness.

# Recognizing and Predicting Activities During Human-Robot Collaboration

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## Introduction

The fourth industrial revolution known as Industry 4.0 has been developed and implemented for more than 10 years. Industry 4.0 requires digitalization of production to enable real time interoperability between workers, machinery and other equipment. In addition to interoperability, Industry 4.0 is characterized by several other features, including modularity and mass customization, which aim to ensure easy adaptability of production to a large number of different products and their variants. In order to effectively enable modularity and mass customization within new smart factories, they must make optimal use of all available resources and their benefits. Human-robot collaboration, which implies that man and robot perform the same task together, is one of the ways to make good use of the advantages of both human and robot and thus contribute to easier achievement of modular and customized production. Joint task execution implies that a human and a robot work in the same space at the same time, which makes it difficult to implement human-robot collaboration due to safety issues. The safety of human in collaboration with the robot is ensured by the use of various sensors that monitor the operation of the robot and the common working space and thus allow control of the force and speed of the robot and stop it in case of human entry into its path. Slow robot operation and potentially frequent stops can negatively affect production efficiency. In order to reduce such situations, it is necessary to increase the awareness of human and robot about space, task and mutual actions. Recognizing and predicting human actions when performing a particular task can facilitate the choice of robot actions and trajectories to avoid collisions with humans and increase work efficiency. This presentation is a brief overview of the most important research and achievements in recognizing and predicting human activities in the human-robot collaboration and presents current situation, trends and the proposed future research directions in this area.

## Keywords

Human-robot collaboration, Activity recognition, Activity prediction, Machine learning

# Analysis of the Effects of Hydrodynamic Forces Affecting Ship Collision

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## Introduction

Ship collisions are rare but one of the most important events which can lead to serious consequences, such as loss of human lives, ships, and cargo, as well as significant environmental impact. Due to that, significant research effort is made to understand the dynamics and mechanics of ship collisions. On top of that, events that are prior to the collision are just as important as the collision itself. These events determine the impact area which can influence collision outcome greatly. They are determined by ship manoeuvrability which is described by hydrodynamic derivatives. Manoeuvrability and collision are numerically expensive to analyze even separately so to combine them, a modified approach should be taken.

## Aims

The main goal is to successfully combine manoeuvring and collision analysis while the simulation time is greatly reduced. The trajectory of the vessel is defined by using the set of analytical formulas and combining them with finite element mesh. This will decrease simulation time and keep the correct ship trajectory, velocity, and energy balance.

## Methods

This approach combines both numerical analysis and analytical expressions. Instead of modelling fluid domain, the analytical expression for hydrodynamic forces is introduced through the LS-DYNA subroutine extension. In general, two sets of hydrodynamic forces are relevant in the ship collision simulation: hydrodynamic forces due to the presence of the fluid (inertia forces, restoring forces, viscous forces) and hydrodynamic forces generated due to the manoeuvrability of the ship (surge and sway forces and jaw moment). Former can be successfully modelled in the LS-Dyna using MCOL subroutine, while manoeuvrability is solved by the user-defined code in LS-Dyna which solves ship equations of motion. These forces determine ship trajectory during every ship manoeuvre and final impact area with another ship. Therefore, the study focus on simplifying long and physically complex events calculation by combining numerical and analytical approach. KVLCC2 ship is considered in the study case. While hydrodynamic coefficients for KVLCC2 ship are available in the literature, ship hydrodynamic properties required for MCOL subroutine (added mass, viscous damping etc.) are calculated using Hydrostar software. KVLCC2 numerical models are done by combining rigid bodies with a deformable structure that can capture the basic damage occurring in a collision. This enables monitoring of the collision contact forces and the internal energy development while keeping the focus on the study of the effects of hydrodynamic forces on the collision consequences.

## Expected scientific contribution

This research will provide better insight into the risk-assessment situation prior to the collision and reduce simulation time greatly. Finally, outcomes may add to the last-moment decision algorithm in the future.

## Keywords

Hydrodynamic derivatives, maneuverability, collision, FEM

# Impact of Borehole Heat Exchanger Configurations on the Performance of a Ground-Source Heat Pump

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## Introduction

Shallow geothermal energy is a renewable form of energy which can be utilized for heating and cooling applications. In such systems fluid circulates through a ground heat exchanger and exchanges heat with the ground. However, temperatures that can be achived with such heat exchange are usually not sufficiently high (in heating mode) or low (in cooling mode) for a direct use in buildings. Therefore, ground heat exchangers need to be coupled with ground-source heat pumps. Because of limited space, heat exchangers are in most cases installed vertically in boreholes which is very expensive due to the drilling cost. According to literature, the drilling cost can take up to 50% of total investment costs and usually makes the utilization of geothermal energy unaffordable to the majority of population. In order to reach full potential of utilizing shallow geothermal energy, these systems should be more efficient and cost-effective. One of the possible options to increase the efficiency of such systems and decrease the investment cost is by changing cross section or area of heat exchanger pipes. Altough there are many analyses in the literature regarding the optimisaton of the pipe configuration, usually those analyses focus solely on the thermal performance of pipes in terms of borehole thermal resistance, which can be misleading. Here we argue that the investment and operational costs are much more realistic criteria for evaluating the effectiveness of proposed configurations.

## Aims

Various types of pipe will be modeled in order to optimize heat exchanger characteristics. First, the impact of shape, size and material on heat pump efficiency will be analyzed for a whole year, including the impact on the heat pump power consumption. Secondly, a required borehole depth for each configuration will be compared, assuming the same heating/cooling demand on the overall system. Consequently, this will allow the esstimaton of the economic feasibility.

## Methods

Borehole thermal resistance of borehole is important parameter used for simulating borehole heat exchanger performance. To determine borehole thermal resistance of each heat exchanger configuration, model of borehole heat exchangers is developed in ANSYS Fluent software package. Model has been validated using available measurement data conducted on 100 meters deep borehole located in Zagreb. Calculated borehole thermal resistance is used in order to calculate outlet fluid temperature from borehole, which depends on heating and cooling needs. For that purpose model containing typical NZEB single-family house coupled with borehole heat exchanger needed to be developed, which is done using TRNSYS software. In the end, heat pump efficiency, which is dependent on fluid outlet temperature, is calculated using model developed in MATLAB.

## Expected scientific contribution

Evaluation of different pipe configurations by calculating total system efficiency and investment cost savings will be given. That is more accurate method for determining economic feasibility of innovative pipe configurations compared to observing only thermal performance of those.

## Acknowledgments

This research is part of “Development of innovative systems for utilization of geothermal energy sources and energy from biological waste” IRI project in cooperation with Telur d.o.o.

## Keywords

Shallow geothermal energy, borehole heat exchanger, ground-source heat pump, energy performance optimization

# Modelling of Wear Rate Including Variability in Dry Organic Friction Clutches

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## Introduction

Dry friction clutches are still very common in automobile drivetrains because of its simplicity, efficiency and low cost. They are mostly used for manual transmissions but with increasing harmful emission regulations, automated manual transmissions with dry friction clutch can become more common. The clutch components need to be replaced once the friction surface is worn down which is time consuming and costly process. Wear of the clutch is highly influenced by the driving style of the driver so if the clutch wear is predicted solely on vehicle travel distance the clutch can be replaced prematurely or cause vehicle malfunction if the clutch is worn down before replacement. The accurate wear prediction procedure will therefore be useful for reliable and efficient vehicle maintenance program.

## Aims

The aim of this research is to analyze wear of the dry friction clutch with organic friction linings in different conditions of the clutch closing cycle and to determine the main influencing parameters on clutch wear. Also wear prediction model will be proposed which will alongside expected wear rate value for given input parameters incorporate confidence interval for more robust wear predictions.

## Methods

Wear characterization experiments will be performed on disk-on-disk tribometer with varying friction surface temperature, clutch torque, initial slip speed and cycle closing time. The certain input parameter combination will be repeated a set number of cycles and wear will be measured based on mass difference of the friction plate. Wear prediction model structure will be chosen with best subset feature selection method using polynomial approximation with parametrization being made by least square method. Wear rate variability will be described by maximum likelihood method using the same experimental points as for model of the expected wear rate value.

## Expected scientific contribution

The results of this research will contribute to clutch wear mechanism understanding and make clutch life expectancy prediction more accurate with possibility of online wear calculation using data from mostly existing sensors on the vehicle. The developed method will also make characterization of different clutch linings material and its comparison easier. The generated wear rate prediction models will be useful in transmission control algorithm development.

## Acknowledgments

It is gratefully acknowledged that this work has been supported by Ford Motor Company through "Developing Dry Clutch Coefficient of Friction and Wear Model Database" project.

## Keywords

wear, dry friction clutch, modelling, variability, tribology

# An Algebraic Approach to Stable Online Parameter Identification and Fault Detection

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## Introduction

An algebraic approach to online parameter identification allows unknown parameters to be represented via an analytic expression containing only measurable input and output variables. By using the derivative operator in Laplace domain, it is possible to eliminate unknown initial conditions and generate linearly independent equations in the unknown parameters. Unlike the traditional approaches, the algebraic approach enables almost instantaneous convergence toward true values of the parameters. The algebraic estimators do not require statistical knowledge of the measurement noise, nor do they need standard persistency of excitation conditions. The usage of the derivative operators for the elimination of initial conditions, with the invariant filtering, results in the unstable time-varying state-space realization of estimator filters. To prevent the unbounded growth of the estimator variables, a switch-off mechanism is needed. Recently, the frequency-shifting-based (FSB) approach was proposed as a solution to the inherent instability of algebraic estimators. The classical FSB approach uses a difference operator with the real frequency shift. But the same benefits can be obtained by using the complex frequency shift instead. FSB method with the complex shift is especially suitable for the identification of sudden change in the parameters, which is characteristic of fault detection.

## Aims

The goal is to implement a difference operator with the complex frequency shift in the FSB methodology for parameter identification. In comparison with the classical algebraic identification methods, obtained time-varying state-space realization of the estimator will enable a simplified procedure for periodic reinitialization, required in the case of abrupt change in the parameters.

## Methods

The focus of the research will be the development of mathematical algorithms for the synthesis of the FSB algebraic estimator, where a finite difference operator with the complex frequency shift in Laplace domain will be used for the annihilation of the initial conditions. After invariant filtering, the time-varying state-space realization will be used for parameter identification where unknown parameter will be determined from state variables. In the case of a sudden change of the parameter, periodic reinitialization will be implemented, which means that after each reinitialization, the identification process starts from the beginning, ensuring the detection of the changes in the parameter. The algorithm will be implemented in Matlab and simulation results will be given in the case of the mechanical oscillator for identification of the stiffness coefficient.

## Expected scientific contribution

FSB algebraic approach to parameter identification was proposed relatively recently. The classical approach can estimate only parameters with a constant value in time. Here, the modification in the form of periodic reinitialization will be implemented for the identification of the parameter when there is an abrupt change in its value. FSB approach with the complex shift will enable a simplified resetting procedure because it results with periodic functions in the input matrix.

## Keywords

algebraic parameter identification, frequency-shifting-based approach, fault detection

# Application of Cmt Process for Wire and ARC Additive Manufacturing

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## Introduction

Due to the constant development and progress of modern industry, the process of wire and arc additive manufacturing - WAAM was developed and put into use. WAAM is a new concept of additive manufacturing in which with the combination of electric arc and wire, metal products are built by depositing metal materials layer-by-layer. The main advantages of additive technology over conventional ones are the reduction of production time, costs, and loss of materials, and also the fact that additive processes do not require intermediate steps such as the molds production or some specific devices. The goals of the research represent a new step in the development of innovative technology for wire and arc additive manufacturing. Process optimization significantly affects the mechanical and corrosion properties of the product. It is possible to obtain the appropriate properties of the final product with the correct selection of welding parameters and use of a certain heat treatment. The main disadvantages of this technology are residual stresses and deformations caused by the high heat input and a high thermal gradient between subsequent layers, which can lead to unacceptable distortions and degradation of mechanical properties.

## Aims

The objective of the work is to significantly reduce the number of passes to reach the desired height by applying different parameters at a constant ratio of wire speed and welding speed. It also aims to reduce the heat input by using a modified welding process called Cold Metal Arc - CMT.

## Methods

Three specimens are fabricated by wire and arc additive manufacturing using a robotic station with CMT welding process, each with its own set of parameters using the same ratio of wire and welding speed, and their mechanical properties will be examined. With the help of 3D scans, the parameters of the surface structure will be examined. The BTF (buy to fly) ratio will be determined and macroanalysis will be performed on the obtained samples. The hardness of the sample is determined using the Vickers hardness test method. The materials used for the experiment are low-carbon steel obtained from a wire SG2, which according to the standard EN ISO has the designation 4341-A: G 42 4 C / M 3Si 1.

## Expected scientific contribution

With this approach, the goal is to obtain a significant reduction in the number of passes to reach the required height. Also, the research will contribute significantly to the understanding of the WAAM process parameters and the suitability of the application of the CMT welding process in WAAM technology.

## Keywords

CMT process, Wire and Arc Additive Manufacturing, WAAM

# Development and Challenges in Production of Composites with Biodegradable Thermoplastic Matrix Reinforced with Industrial Hemp Fibers

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## Introduction

Ensuing from the growing awareness of the need to reduce non-biodegradable waste, many studies have focused on reinforcing polymers with natural, biodegradable fibres. Most often, these are flax fibres, while industrial hemp fibres are still not widely used. Poly(3-hydroxybutyrate-co-3-hydroxyvalerate (PHBV) is a poorly studied biodegradable plastomer. Its use to date has been limited due to its fragility, though this could be improved through reinforcement. Since hydrophilic hemp fibres are incompatible with the hydrophobic polymer matrix, an optimal treatment for the plant fibres is needed to resolve this issue. Plastomer processing involves heating to above the melting point, and therefore the composite should be formed at a temperature that achieves the desired viscosity of the material matrix, without any thermal decomposition of the fibre.

## Aims

In the process of developing a PHBV biocomposite reinforced with industrial hemp fibres, the aims are to improve and strengthen matrix bonds to enable the transfer of load from the matrix to the reinforcement, and to optimised production conditions to achieve the desired viscosity with minimum fibre damage.

## Methods

Physical processing methods, such as heat processing, often require sophisticated and expensive equipment. The literature recognises chemical treatments as the most effective means of preparing natural fibres, as they modify surface chemistry to achieve better separation of fibres from the bundle, remove undesired surface compounds, increase fibre rigidity and strength, improve heat stability, and improve binding to the matrix/strengthener interface. This study examines the optimum chemical treatment for hemp fibres using a sodium hydroxide (NaOH) solution at different concentrations, temperatures, and exposure times. This method removes hemicellulose, lignin, pectin, wax and fat from the fibre, enabling better separation, with increased exposure to hydroxyl groups on the fibre surface that improves interface binding. The obtained fibres can then be mixed into the polymer matrix.

## Expected scientific contribution

The potential of PHBV as a matrix for making composites has been poorly studied, with limited data concerning the addition of natural strengtheners to this matrix. The expected scientific contribution of this study is to overcome the challenges of creating a biocomposite of the PHBV matrix and industrial hemp fibre as a reinforcement, while enabling compatibility of the hydrophilic filler with the hydrophobic matrix by applying the most suitable chemical treatment of fibres.

## Keywords

Biodegradable PHBV polymer, hemp fibres, biocomposites, alkaline fibre treatment

# Stochastic Optimal Control of Autonomous Vehicles Approaching Uncontrolled Crosswalks

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## Introduction

The complete integration of fully autonomous vehicles in everyday traffic is a difficult and challenging task. Ensuring safe interaction with pedestrians is especially challenging since pedestrians' behavior is influenced by a wide range of environmental, social, and demographic factors, which makes it hard to predict future pedestrian actions. In order to increase the safety of pedestrians, which are one of the most vulnerable road users, it is necessary to design a control strategy which would then be utilized by autonomous vehicles in the vicinity of high-risk traffic locations, such as unsignalized crosswalks, where neither pedestrians nor vehicles have a definite right of way. Pedestrian behavior includes some level of uncertainty, which makes the autonomous vehicle control strategy a good candidate for stochastic optimal control methods. While designing the stochastic control strategy and optimization algorithm, special care will be given in order for the final algorithm to be computationally efficient.

## Aims

The aim of this research is to propose an autonomous vehicle control strategy which ensures safety of all traffic participants, and high comfort and efficiency for autonomous vehicle passengers. Additionally, a detailed simulation environment including autonomous vehicle control algorithms and pedestrian behavior model is going to be developed.

## Methods

The research will be predominantly numeric (i.e., computer analysis, data processing, simulations) and it will include designing and calibrating a multi vehicle multi pedestrian interaction model, training a neural network for pedestrian behavior prediction and designing the autonomous vehicle control system based on stochastic model predictive control. The whole control strategy will be tested and validated through detailed simulation-based experiments.

## Expected scientific contribution

It is expected that the developed control strategy based on the stochastic model predictive controller, neural network, and the vehicle pedestrian interaction model, which will include a wide range of possible scenarios (i.e., number of pedestrians, road configuration), will be beneficial for autonomous vehicles in terms of providing a save, comfortable and efficient drive. It is also expected that the control strategy will benefit pedestrians in terms of increasing total traffic safety and minimising the risk of traffic accidents.

## Acknowledgments

It is gratefully acknowledged that the research work of the author is supported by Ford Motor Company and the Croatian Science Foundation through the "Young researchers' career development project – training of new doctoral students".

## Keywords

autonomous driving, pedestrians, modelling, stochastic model predictive control

# Development of Titanium-Copper Alloy by Powder Metallurgy for Biomedical Application

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## Introduction

Powder metallurgy is a newer but extremely important branch of modern industry. The production of a wide range of materials as a product from a compacted mixture of powders shaped into an almost final shape is applied. Biomaterials are commonly used in biomedicine to repair, replace, and regenerate body tissues, and their antibacterial activity is of great importance as an increasing number of implant failures are known. More recently, copper has been used in metal alloys as an element of antibacterial activity. Titanium and titanium alloys are widely used in biomedicine, but due to the high cost of production they are not used in even greater quantities. Since copper is a cheap metal, as an alloying element of titanium, it contributes to the achievement of cheaper, and thus more affordable, biomedical materials.

## Aims

The aim is to produce a titanium alloy with the addition of copper using cost-effective powder metallurgy technologies that will have satisfactory properties for use in biomedicine as an implant material. It is necessary to determine the process parameters that will result in an alloy of satisfactory microstructure and consequently of properties. For this purpose, the produced samples will be characterized by appropriate methods in order to determine the chemical, physical, structural, mechanical, thermal, and corrosion properties aiminig the evaluation of the potential for biomedical application.

## Methods

The chemical and physical properties of starting powders will be determined. By mixing in a ball mill, a mixture of the required composition will be prepared which will be further subjected to other technological processes of powder metallurgy. Sintered samples will be characterized by a number of methods. Their density will be determined by the Archimedes method. After appropriate metallographic preparation, the porosity and microstructure of the sintered samples will be analyzed by light and scanning electron microscope. The chemical composition and distribution of the elements will be analyzed by energy-dispersive spectrometry. The structure analysis will be performed by X-ray diffraction method. Mechanical properties, such as microhardness and modulus of elasticity, will be determined by the nanoindentation method. Corrosion properties will be measured by anodic cyclic polarization method, while biocompatibility will be assessed by ion elution method. The thermal properties of the sintered samples will be determined by differential scanning calorimetry and differential thermal analysis, while the thermal diffusivity and conductivity will be measured by the laser pulse diffusivity method.

## Expected scientific contribution

The scientific contribution of this research is in the production of new titanium-based materials with the addition of copper by cost-effective powder metallurgy technology to produce affordable biomedical implants, which would then be acceptable for wider application.

## Keywords

powder metallurgy, Ti-Cu alloys, biomedical materials, microstructure

# Influence of Production Parameters on Cavitation Erosion Resistance of Composite Materials

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## Introduction

Being critical to the ships' propulsion system, the design and manufacture of the propeller has always strived towards a more conservative approach. Families of nickel-aluminum bronzes and stainless steels have for over a century been the only materials of choice. With increasingly stringent requirements, however, problems with nickel-aluminum bronze propellers began to emerge; poor anticavitation ability and prone to fatigue-induced cracking, being heavy and with relatively poor acoustic damping properties that can lead to noise problems from vibrations, and finally, it is very expensive to machine (mill) it into a complex shape. The above issues made the designers assess the feasibility of fiber-reinforced composite materials. Fiber-reinforced composites had higher specific strength and stiffness, lighter weight, good damping properties and "design-ability", and those properties provided the foundations for the reduce in weight, noise, and increase in fuel efficiency. But, fiber-reinforced composites hadn't satisfactory resistance to cavitation erosion to which the propeller is constantly explosed. In order for composite propellers to become further widespread, it is necessary to analyze the erosion mechanism effects, and develop a method to prevent it.

## Aims

The aim of this research is to give an overview of the current state of the art, explore the range of currently available types of fibers and resins, investigate influence of production (hand lay-up, VaRTM) process parameters (thickness, type, orientation and distribution of reinforcement and type of polymer matrix etc.), and perform progressive systematic tests on samples in laboratory conditions with regards to the loss of material due to erosion, surface roughness and morphology, and scaling of cavitation erosion progression.

## Methods

Cavitation types on scaled down propeller models is typically observed in cavitation tunnels and erosion damage estimated, but for the purpose of estimating cavitation erosion damage on material samples, in laboratory conditions, vibratory apparatus (oscillating horn) will be used in accordance with ASTM G32 standard, surface roughness and morphology and development of surface damage observed, with measurements.

## Expected scientific contribution

For a pre-defined, proper geometry, initiation and development of cavitation erosion damage is highly influenced by the surface condition. By observing and investigating influence of various production parameters that affect the surface condition, the damaging scope of cavitation erosion can be partially mitigated.

## Acknowledgments

I wish to thank prof. Pilipović for her constant encouragement and support.

## Keywords

cavitation erosion, composite materials, production parameters, marine propeller

# Design of Experiment for Vertical Centrifugal Casting

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## Introduction

In modern industry, design of experiment is applied to quickly find optimal parameters with as short a time as possible and a lower cost of work. Vertical centrifugal casting is influenced by many parameters and the analysis of their results is very expensive and long – lasting process. In order to reduce the time and eliminate possible irregularities (casting defects), casting simulations are necessary. Defects on castings are closely related to the purity of the melt and with the parameters of casting. The main parameters that will be studied in this workshop are: pouring temperature, preheating mould temperature, rotational speed of the mould, pouring rate and coating thickness. Using optimal parameters, there is less chance of defects occurring on the casting and the requirement of this research is to get as small a dendrite size as possible. The size of the dendrite is affected by the solidification time and a shorter solidification time gives a finer grain size. The solidification time is reduced by increasing the cooling rate of the casting but taking care that internal stresses do not occur. With a good design of experiments, it is possible to find the most significant factors and accordingly, for example, it can be defined which parameter will most affect on solidification time.

## Aims

The main aims are to get casting without shrinkage porosity, non-metallic inclusions, accurate geometries, uniform distribution of alloying elements and finer size of dendrites. Define the relationship of individual parameters that directly affect the solidification time.

## Methods

The casting is made by the vertical centrifugal casting process. The design of experiment was developed in the software DX expert and Regular Two-Level Factorial Design was applied. The alloy used in the experiment is AISI 304 stainless steel. Before casting it is necessary to preheat the mould and coat it with aqua – layer. The analysis was carried out on the following casting parameters: pouring temperature (1480 and 1550 °C), preheating mould temperature (300 and 500 °C), rotational speed of the mould (1300 and 1700 min-1), pouring rate (0.5 and 1.0 s) and coating thickness (100 and 500 μm). The results were obtained by simulations in the ProCAST software. The results analyzed are: shrinkage porosity, maximum melt velocity in mould and solidification time.

## Expected scientific contribution

Shrinkage porosity is affected by all parameters except pouring rate. The solidification time is reduced by lower coating thickness, lower pouring temperature and lower preheating mould temperature. A finer grain size casting was obtained with lower solidification time. Such castings have better mechanical and tribological properties.

## Acknowledgments

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## Keywords

vertical centrifugal casting, simulation, design experiment, casting parameters, solidification time

# Optimization Methods of Walking Mechanisms

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## Introduction

Walking mechanisms are type of lever mechanisms whose structure imitates human gait. Such mechanisms are considered when wheeled drives are not applicable, mostly on uneven or stepped surfaces. Depending on the number of linkages and joints, as well as the desired leg trajectory, several types of mechanisms were developed. For each type, the leg trajectory is affected by linkage lengths; therefore, default lengths are provided to ensure stable walking motion. Modern research on such mechanisms most often involves various kinematic analyzes for the purpose of adapting loci, i.e., the characteristic of walking are being adapted to a particular problem. In addition to analytical methods of analysis, some aspects of such mechanisms are increasingly being optimized, with the frequent use of meta-heuristic algorithms that are adapted to solve certain types of optimization problem.

## Aims

The aim of this research is to give an overview of some existing methods of optimizing walking mechanisms using meta-heuristic algorithms, and to list their essential features. As there are infinitely many combinations of lever length ratios for each mechanism, the same locus can generally be obtained with multiple lever length combinations. Finding a combination of levers that give a target locus with a minimum total lever length, and consequently the smallest dimensions and mass, can be considered as an optimization problem. Most used meta-heuristic algorithms are Genetic (GA), Firefly (FA) and Cuckoo search (CSA) algorithms. Their main advantage is their computational efficiency, and the main challenge is the lack of reliability of convergence towards the global optimum for which a reliable mechanism needs to be discovered.

## Methods

Using the software packages MATLAB and Simscape Multibody, first step of research would be to develop an optimization method for simplest known walking mechanism which is Chebysev Lambda mechanism. Using known algorithms such as GA, the lengths of the levers of the mechanism would be varied. Assuming that the sum of the lengths of the levers in each tested configuration of the mechanism is constant, main goal is to obtain the longest possible step through a predetermined number of iterations. Second step of research would involve developing a method which would work in same way, but on much more complex walking mechanisms. Finally, last step would involve developing a method which would evaluate the mechanisms depending on the given input parameters (mass, loci, number of joints). Simulation of optimized mechanisms would give some validation of the required input parameters.

## Expected scientific contribution

Based on a review of the literature in the field of walking mechanisms, it is possible to conclude that by varying the ratio of the lengths of the levers of the walking mechanisms can significantly change its locus. As there are infinitely many combinations of lever length ratios for each mechanism, the same locus can generally be obtained with multiple lever length combinations. Finding a combination of levers that give a target locus with a minimum total lever length, and consequently the smallest dimensions and mass, could be considered as a significant contribution towards development of an algorithm for choosing an optimum mechanism for a specific task.

## Keywords

walking mechanism, mechanism analysis, optimization, genetic algorithm

# Pore Size Analysis of Metal Foams Using Computed Tomography

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## Introduction

Metal foams are highly porous material whose properties are highly dependent on the shape and size of the pores. Production processes are still not perfected, resulting in pores of uneven shape and size, which worsens their mechanical properties. To gain insight into the internal structure of the foamed metal, i.e. to find out the arrangement of the shape and size of the pores, the sample needs to be cut, which actually leads to its destruction and the impossibility of further mechanical tests. To avoid destroying the samples, computed tomography (CT) can be used to analyze the arrangement and size of the pores, which involves scanning the sample with X-rays and obtaining a three-dimensional model of the foam in the software. From the three-dimensional model, an insight into any part of the metal foam sample can be obtained, and the analysis of different cross-sections can calculate the average size of pores. To obtain the most accurate data on the average pore size, it is necessary to analyze as many cross-sections as possible. The scanned model remains on the computer, which is good if one later needs to check something again. After scanning, the sample can be mechanically tested, unlike the sample that was cut to gain insight into the structure of the pores. This also gives the most accurate insight into the influence of pore size on mechanical properties.

## Aims

The aim of the use of computed tomography in the analysis of metal foams is to avoid destructive methods to gain insight into the cross-sections of the sample. Also, by using computed tomography, each part of the sample can be examined, while when cutting the sample, one is limited to a minimum thickness that can be cut. In addition, the walls of the cells are deformed during cutting, so the obtained results are not most accurate.

## Methods

CT scan was performed on the ZEISS Metrotom 6 Scout device. After scanning, the reconstruction algorithm merges the obtained images and generates volume. This volume can then be polygonized, and the end result is a polygonal grid of triangles. Measurement of the size and number of pores of individual cross-sections of the sample was performed in the ImageJ software using the Analyze Particles command.

## Expected scientific contribution

Analysis of pore sizes and their distribution can provide insight into the influence of their size on mechanical properties of foams, especially because the scanned sample can later be subjected to compression or some other test. This is not the case when cutting the sample, as the sample is then irretrievably destroyed.

## Keywords

metal foams, computed tomography, pore size, pore distribution

# Influence of Pre-Chamber Volume on Combustion in a Turbulent Jet Ignition Engine

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## Introduction

It has been proven that the usage of lean mixtures can increase thermal efficiency and reduce pollutant emissions in spark ignited (SI) engines, especially nitrogen oxides (NOx). Lean mixtures in a SI engine require high energy sources for ignition and result in unstable combustion. A solution for those problems is an active pre-chamber ignition system. This mode of combustion is often called Turbulent Jet Ignition (TJI) where the lean mixture in the main combustion chamber is ignited by the penetration of multiple turbulent jets of combustion products from the pre-chamber. Since the combustion process depends on the pre-chamber volume, together with the operating parameters (spark timing, pre-chamber fueling, excess air ratio), it is necessary to define which volume and operating parameters are most favourable in order to achieve high thermal efficiency and low emission. In this paper, an experimental study of the influence of different pre-chamber volumes and operating parameters on combustion was performed.

## Aims

The aim of this study is to experimentally determine the influence of pre-chamber volume and operating parameters on combustion, engine performance and harmful emissions in a turbulent jet ignition engine.

## Methods

The experimental research and combustion analysis was made using the experimental setup at the Laboratory of IC Engines and Motor Vehicles of the Faculty of Mechanical Engineering and Naval Architecture at the University of Zagreb. The experiments were performed on 3 different pre-chamber volumes while engine speed and pre-chamber fuel injection duration and timing were kept constant. The 3 developed pre-chamber geometry designs differ in volume and nozzle diameter, but all pre-chamber variants have 6 orifices and approximately the same orifice cross section area to volume ratio. All experiments were conducted at engine speed of 1600 rpm. The variation of engine load was achieved by the change of excess air ratio in the main chamber from stochiometric mixture ($\lambda$=1.0) to lean limit ($\lambda$=2.2). For each operating point, a spark sweep was performed to obtain the highest indicated efficiency.

## Expected scientific contribution

The results of this study will give a better understanding of the influence of pre-chamber volume and operating parameters on engine performance and harmful emissions which will then help in determining the optimal pre-chamber design and operating parameters which result in high efficiency and low emissions.

## Acknowledgments

This work was supported by the Croatian Science Foundation within the project Research of More Efficient and Environment-Friendly Pre-Chamber Spark Ignition Combustion (Project no. IP-2019-04-4900) and „Young researchers' career development project – training of doctoral students ".

## Keywords

Pre-chamber volume, turbulent jet ignition, combustion, efficiency, emissions.

# Experimental Research and Modeling of Segmental Evaporator Defrosting

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## Introduction

High relative humidity and low air temperature in the winter months lead to formation of ice on the heat pump evaporator surface. Accumulation of ice between copper tubes and aluminum fins decreases the air passage and represents resistance to heat exchange. At reduced flow, the ice is distributed unevenly, and efficiency is significantly reduced. That is why it is important to melt the ice from the surface of the heat exchanger. Traditional defrosting techniques, reversing the cycle or usage of electric heaters, are either stopping the heating process or using a lot of electrical power which strongly reduces the overall energy efficiency of the device.

## Aims

To overcome existing problems of interrupting the core purpose of the heat pump - heating and increase energy efficiency this research will develop advanced segmental defrosting system for heat pump evaporators and enable uninterrupted supply of heat energy to the conditioned space. Analysis and experimental confirmation of the start and stop defrost time will reduce the energy invested in melting the ice and evaporating water from the surface.

## Methods

The first phase of laboratory testing consists of the psychrometric chamber construction used to test the heat pump's operation. Psychrometric chamber is composed of air conditioning chamber, which serves to set the desired testing conditions of temperature and humidity in the second part - the conditioned space. The conditioning chamber consists of fans that drive air into a conditioned space, two adjustable heaters serving as a counterweight to the negative heat flux of the tested evaporator to maintain stationary conditions, and steam humidifiers which compensate for the frozen moisture on the tested evaporator.

The entire system will be equipped with measuring equipment that allows collecting temperatures and pressures at characteristic points of the heat pump process, as well as measuring heat energy, humidity, and the required electricity for the operation of the heat pump. All measurements are performed with the aim of energy balancing the heat pump system and assessing the quality of the defrost system.

During experiments impact of inclination angle and distance between fins on defrost efficiency will be tested.

## Expected scientific contribution

The behaviour of heat pump with a segmental evaporator under a wide range of outdoor conditions will be described. Impact of geometry and process control parameters, e.g. start and stop times, on the energy efficiency of the segment evaporator heat pump will be estimated.

## Acknowledgments

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## Keywords

Partial defrosting of evaporator, Cyclic losses, Defrost control model

# Re-Calculation Model of Measured Combustion Results from Pre-Chamber Spark Ignited Engines

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## Introduction

Nowadays, when consequences of air pollution on our planet and human health are known, it is important to reduce greenhouse gas emissions from internal combustion engines (ICE) as much as possible. Fully electric vehicles with great greenhouse gas reduction potential still have issues such as long charging time and low driving autonomy that should be solved. One possible solution to overcome a transition from ICE powered vehicles to fully electric could be highly efficient conventional ICE such as pre-chamber spark ignited (PCSI) engine. PCSI engine operates with lean mixtures which reduce both fuel consumption and pollutant emissions, especially nitrogen oxides. Advantage of such engine is that a pre-chamber can be easily integrated into the existing conventional spark ignited engines. Pre-chamber can be either active, with additional fuel injected into pre-chamber, or passive, without additional fueling. In the Laboratory of IC Engines and Motor Vehicles at the University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, a PCSI engine with an active pre-chamber is developed and used for experimental testing.

## Aims

The aim of this work is to upgrade an existing MATLAB model developed for conventional spark ignited engine to work with a PCSI engine. Upgraded model is used for combustion analyzes of the experimental data measured on PCSI engine to get an overview of combustion stability, rate of heat release, efficiency, etc. The future work will be directed to optimization of pre-chamber geometry and working parameters where the MATLAB model will accelerate procedures of obtaining results which can be mutually compared.

## Methods

To ensure that the MATLAB model works correctly, results from MATLAB are compared with results from verified IC engine simulation software, AVL Boost. Comparison is made for 5 different operating points where mass flows, temperature profiles, excess air ratios and rate of heat release are being compared. After the verification of the developed MATLAB model, experiments can be conducted, and engine performance can be easily evaluated.

## Expected scientific contribution

Pre-chamber spark ignited engine could be a short-term solution for reduction of greenhouse gas emissions while efficiency of the engine remains the same level as conventional IC engine or even gets higher. The reduction of NOX emissions according to literature could be more than 93%. By improving the combustion quality, reducing heat losses and providing higher compression ratios, indicated brake efficiency could be increased up to 49%. Also, it has been proven that the fuel consumption could be reduced by 18% in comparison to conventional engine. Despite all that, more detailed research is needed to improve the PCSI engine and implement it for usage in road vehicles.

## Acknowledgments

The research is funded by the Croatian Science Foundation (HRZZ).

## Keywords

Pre-chamber spark ignited engine, combustion analysis, MATLAB model upgrade

# Automation of Energyplan with Python with the Goals of Conducting Large Scale Energy System Serial Simulations

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## Introduction

Modelling and planning the development of energy systems has become crucial during the ongoing climate crisis as well as the result of energy crisis, especially in Europe. In this research, prominent tool - EnergyPLAN is used. EnergyPLAN is energy system modelling and simulation software. Defining characteristics of this model are relative simplicity as well as quick running times. Therefore, its use provides a possibility to conduct detail simulation.

## Aims

Overall goal of this research is to provide the modelers with the tool and capability of rapidly testing out different energy system configurations and observing the influence of variations in installed capacities or used system strategies on the outputs such as curtailment of renewable energy, emission levels as well as system cost. In relation to this goal, the problem often encountered with EnergyPLAN is the inability to run extensive simulations with variations in input parameters.

## Methods

For the purpose of filling out the goals stated as the aims, python-based tool has been developed. The tool can perform most of the tasks related to conducting the simulations automatically following the determination of input parameters. The developed tool uses functions that enable external inputs of data into the model as well as multiprocessing to sped up the process.

## Expected scientific contribution

Use of this method has enabled the sped up of the calculation time by more than 300 % in relation to the previous attempts at the same problem. Simulation time per case now comes to around 0,3 s/case. The use of the improved model is demonstrated at the example of European energy system and its projections for future development. Scientific contribution can be observed in presenting the influence of additions of flexibility options as well as renewable energy generating capacities on the parameters of energy system. The observed parameters include capacity factors of renewable energy generating technologies, levels of emissions, share of renewables as well as the total system annual cost.

## Acknowledgments

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## Keywords

EnergyPLAN, python, multiprocessing, energy planning

# Development of Experimental Setup for Characterization of High-Pressure Biofuel Sprays

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## Introduction

Since biofuels are a renewable energy source and have a favorable characteristic related to greenhouse gas emissions, they are currently in the focus of various studies, especially due to new regulation RED II of European Union. The overall target for the consumption of renewable energy sources must be raised to 32% by 2030, with a minimum of 14% of energy consumed in road transport as renewable energy. The physical properties of biofuels differ from those of standard diesel fuels, which is why it is necessary to study their impact on the characteristics of high-pressure injection spray. The objectives of this study will be to characterize advanced biodiesel fuels produced from new raw materials such as coffee and algae. The necessary experimental configuration consisting of fuel injection and optical measurement components will be assembled, providing input for further numerical research into biofuel combustion in engines.

## Aims

The objective of this research is to develop experimental setup for characterization of high-pressure biofuel injection spray at various conditions such as injection pressure, duration or environment. This will provide better understanding of advanced biodiesel behavior which is related to application in internal combustion engines.

## Methods

Within this investigation, a high-pressure fuel injection system from commercially available vehicle will be implemented. It consists of supply pump, high-pressure pump, common- rail and injector. For optical measurements the high speed camera will be used incorporated with laser and sheet optics or high-power spotlight. The former method is known as LIF (Laser Induced Fluorescence), and the latter is MIE (Elastic scattering). In the high density spray area near the nozzle the additional SLIPI (Structured Laser Illumination Planar Imaging) module will be used for the reduction of excessive light dispersion effect.

## Expected scientific contribution

The experimental setup will provide the ability to measure the differences in spray characteristics of various advanced biofuels from new feedstock and compare them to conventional diesel for different injection conditions. Such quantified characteristics will provide input for the next step - numerical simulations in internal combustion engines.

## Acknowledgments

This work was funded under the auspice of the European Regional Development Fund, Operational Programme Competitiveness and Cohesion 2014–2020, KK.01.1.1.04.0070.

## Keywords

Experimental Investigation, Biofuel, Spray, Internal Combustion Engine

# Numerical Simulation of T-Joint Welding Process Using Prescribed Weld Temperature Approach

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## Introduction

Fusion welding is one of the cheapest and the most widespread production process of joining steel parts. Arc welding was invented at the end of the 19th century and it gradually replaced riveting. The welding is not the simplest industrial process of joining metals because it is defined by parameters like current, voltage and welding speed, which have significant influence on quality of the welded joint, residual stresses, angular distortion and production costs. With that being said, improvement of the existing welding technologies is of great importance. In recent years, researchers have been trying to improve the efficiency of welding processes and mechanical properties of the welded joint. Efficiency of the welding process is related to the number of welding passes, or in other words, the deposition rate of the weld bead.

## Aims

The aim of the research is to develop a computationally more effective numerical model which could be used for analysis of residual stresses (RS) in large welded structures.

## Methods

The most accurate way of obtaining data is by conducting experimental testing and measuring, but those require significant amount of time and resources. One of the alternative approaches is to develop numerical model which should be verified on data obtained by experimental testing.

Numerical simulations can be quite computationally demanding because welding is highly non-linear and non-stationary process. Sequentially coupled analysis is used in order to address this problem. The first step is transient thermal analysis and the result is the temperature field which is used as loading in subsequent mechanical analysis to calculate residual stresses. Element birth and death method is used in thermal analysis to simulate the weld bead deposition.

Since these simulations are quite computationally demanding, one needs to simplify the transient heat transfer differential equation. Prescribed weld temperature (PWT) approach will be used in order to avoid calculation of weld temperature from the heat flux defined by the parameters of the welding process.

## Expected scientific contribution

Numerical prediction of residual stresses distribution is very important from aspect of fracture mechanics and fatigue. With the goal of reducing the welding-induced residual stresses, one must conduct another numerical simulation which further increases the total computational time. By assigning weld temperature to finite elements in the weld zone, one can reduce total computational time for the welding process, but without sighificant discrepancy of the results.

## Acknowledgments

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## Keywords

Welding, T-joint, Prescribed Weld Temperature Approach, Residual stresses

# Research of Refrigeration Systems of LNG-Powered Container Ships

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## Introduction

With global economic growth, it is expected further increase in demand for transportation of goods. Consequently, shipping industries will be challenged between profit and securing the latest regulations regarding the environment. Until new alternative fuel technologies, such as electric batteries, biofuels, and hydrogen, which all can reduce greenhouse gas emissions, become more developed and widely available, fuels like liquefied natural gas (LNG) are gaining more and more attraction which can be seen in increasing number of LNG-powered ship. LNG also has the potential of improving refrigeration systems thanks to the cold waste heat which is a byproduct of LNG regasification. LNG-powered ships have many possibilities of using waste cold heat such as cooling ship cabins and cargo or using waste cold heat for improving the energy efficiency of ship power and refrigeration systems. The development of waste heat utilization on LNG-powered ship could reduce the size of existing vapor compression systems and therefore reduce energy consumption which will lead to more ecological maritime transport.

## Aims

The aim of this research is to develop a refrigeration solution that can be implemented on different LNG-powered ships based on the required cooling load. The special focus will be on developing refrigeration systems that will use LNG waste cold heat as a medium for increasing the energy efficiency of refrigeration/power systems on the vessel. Moreover, for developed solutions technical, ecological, and economic analysis based on the operational profile of the ship will be conducted. Finally, the dependence of developed solutions and their feasibility on different ships will be established.

## Methods

The first step in this research includes energy and exergy analysis of refrigeration systems and LNG waste cold heat. After that data will be collected on refrigeration load depending on the operational profile of ship. Secondly, a simulation of different refrigeration system on the ships will be performed to assess the impact of utilizing waste heat in refrigeration systems on energy consumption. Finally, a method for comparing different refrigeration systems on ships will be developed for the propose of selecting the best refrigeration system based on defined criteria.

## Expected scientific contribution

This research will result in a model that will serve as the basis for developing refrigeration systems on LNG-powered ship. The developed model will for given input data, propose an optimal refrigeration system, based on the operational profile of ship, that will incorporate energy efficiency, feasibility, and cost-effectiveness.

## Acknowledgments

The author is grateful for the financial and logistical support from the CEKOM project from the European region development fund, referent number KK.01.2.2.03., subproject IRI 4, in the scope of which this study is conducted.

## Keywords

Refrigeration systems, waste heat, liquified natural gas, maritime technologies

# Hybrid Composite Joints Optimization

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## Introduction

Polymer composite materials are used by various industries due to their advantages over steel or aluminum. Improving vehicle efficiency and lightweight design have been one of the goals achieved by composite materials application in transportation industry. These materials are not only used for parts of the interior but for vehicle structure elements as well. Due to the increase in application composite joints are becoming a key aspect in structure optimization as a joint is a weak link of any structure. Wider application in vehicle structure for vehicles in mass urban transportation is key to reducing emission of harmful gases. Bolted or adhesive joints are common way of connecting elements made from various materials, but they both have disadvantages which become a significant factor for joint strength and rigidity in case of polymer composite materials. Hybrid composite joints represent a synergy between adhesive and bolted joints and are a research subject in the last couple of years.

## Aims

Hybrid composite joints are defined by numerous parameters. Optimal load distribution and adequate rigidity of the joint elements (bolted and bonded connection) are considered crucial for lightweight design of composite structures. bolt and adherend. Aim of this research is better understanding of joining methods of composite materials and development of methodology for hybrid composite joint optimization.

## Methods

Since various parameters have influence on the overall performance of the joint an artificial neural network model will be implemented to analyze the relationships between parameters. Application of one form of this method can be found in material testing and in most recent studies in case of bolted joints. Test specimens for static and dynamic tests will be produced by optimal production process. Machining of moulded laminates will be conducted to minimize delamination and fibre pull out damage. Since strain distribution is a valuable information in composite performance assessment an optical measurement methods will be applied during the tensile and flexural testing. Optical measurement is useful for strain measurement and secondary bending effect assessment and acquiring valuable data for material properties determination (Poisson's ratio). Numerical model will be created in available FEA software and validated by experimental results.

## Expected scientific contribution

It is expected that this research will contribute to a better understanding of hybrid composite joint performance under cyclic loading. Analysis of multiple production and geometric parameters on the optimal load distribution will result in an innovative joint design which is expected to have reduced secondary bending effect. Proposed design has potential to have significantly lower stress concentration but requires additive manufacturing during the production process. Combination of resin infusion process and additive manufacturing is another contribution to the development of precision production methods.

## Acknowledgments

The author wishes to express gratitude to Chair for polymer processing by Faculty of mechanical engineering and naval architecture for financial support and usage of the lab equipment to carry out this research

## Keywords

hybrid composite joint, optical measurement, load sharing, secondary bending

# Modelling the Elastoplastic Behaviour of Heterogeneous Materials Using Neural Networks

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## Introduction

Due to increasing usage of new materials with heterogeneous microstructure and due to increased exploitation of known materials, there is a need for more accurate and better description of the material constitutive behaviour. Multiscale methods, which are usually used to describe the constitutive behaviour of heterogeneous materials are efficient but slow and computationally expensive. For this reason, many reduced homogenization methods have been developed that seek to find the optimum between the accuracy of the results and the complexity of the calculation. These new multiscale methods have proven to be extremely useful for obtaining a large database that will be used to create neural network-based material models.

## Aims

The aim of the research is to develop a constitutive model of heterogeneous materials using neural networks based on input data obtained by numerical simulations of microstructural behaviour.

## Methods

Large databases, obtained by the validated finite element numerical simulations under different loading conditions and using self-clustering multiscale method, replace classical experimental measurements. This data is used for neural network training and learning. Strains and strain energy are used as input data for neural networks, while the goal is to accurately predict the homogenized stress, and other necessary state variables. Once trained, neural network-based model can be improved if more data is available. The training goal is to minimize the difference between known and predicted output values (stress) using a backpropagation algorithm. Two most common neural networks are used to predict mechanical behaviour of materials: feedforward (FNN) and recurrent (RNN). Efficiency of both network architectures is compared to experimental measurements and validated numerical results. Neural networks are built using open-source software TensorFlow and Keras API based on the Python programming language

## Expected scientific contribution

The developed neural network-based model should adequately replace the classical multiscale analysis of heterogeneous materials. This could lead to significant reduction of computational time and resources. Moreover, neural networks make possible to describe the mechanical behaviour of materials without need for classical constitutive expressions and without a priori assumptions about the constitutive model.

## Keywords

neural networks, heterogeneous materials, machine learning, elastoplastic behaviour

# Towards Integrated Planning of an Intelligent Disassembly System for End-of-Life Products

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## Introduction

As the technology and life standard in global human society rapidly progresses, so does the consumerism culture grow. People buy more than ever before as the projected life cycle of a product keeps shortening, so with it the production amounts grow yearly, with the alarming consequence being the fact the world produces more waste than ever before. Vast majority of recycling processes would benefit from the inclusion of a disassembly stage, since a large portion of End-of-Life (EoL) products is an assembly rather than a single part, and more important, disassembly improves the overall recycling process itself by allowing reuse, avoidance of environmental risks and hazards, and finally better sort-ing of materials. Therefore, the huge quantities and variety of EoL products raise the need for a methodology to suggest the most appropriate disassembly system.

## Aims

The aim of the research is to develop a methodology for the choice of the most appropriate disassembly system for an EoL product. Based on the real-time status of the product, an optimal disassembly system suggestion is given, ranging from manual disassembly to fully automated disassembly. When (or if) a product is changed (thus differing from the original specification, either geometrically or by material), the system tracks the change and notes it. This sufficient change can be either mechanical damage, material damage (such as corrosion) or simply a non-standard component (differing both in material and geometry), all of which notify the dis-assembler to reconfigure the disassembly plan. Re-search still has to be done on the key parameters for product monitoring and the limit values between declared states (what amount of change is enough to declare a product as non-standard, which would then change the suggested disassembly system).

## Methods

The research contains the knowledge of a wide-variety of existing approaches and methods, some of which are Concurrent Engineering (CE), Design for Disassembly (DFD), Design for Assembly (DFA) and Design for Life Cycle (DFLC). The technology of a Digital Twin would be used as well, for the dis-assembler to monitor the real-time status of a product in order to keep the suggested disassembly system up to date. Finally, mathematical models shall be used to generate the disassembly sequence of a specific product.

## Expected scientific contribution

A developed methodology for the choice of optimal disassembly system would greatly improve the disassembly process in recycling facilities, enabling our civilization to better handle the growing quantities of waste. Such improvements will shorten the preparation time and thus improve their productivity, as the disassemblers will have a ready suggestion (enabled with high-level traceability based on the real-time tracking of the product) before the EoL product even arrives to the facility, also changing the result if a large enough change has been tracked.

## Acknowledgments

I would like to thank my mentor prof. dr.sc. Zoran Kunica for his continuing support and guidance.

## Keywords

disassembly, recycling, planning, automation, traceability

# Multi-Criteria Ship Structural Design Considering Technological Production Aspects

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## Introduction

Since a ship is an exceptionally complex structure, its design and manufacturing process demands the collaboration of various experts. The development of optimization methods and their inclusion in the design process has a fundamental role in the rational design of a ship structure. There is constant work to upgrade optimization methods and one of the reasons for that is the pressure to reduce CO2 emissions, and therefore to manufacture lightweight ships that will use less fuel. Structural design optimization is one of the solutions to this problem. Naval architects focus mainly on weight minimization as an objective in the optimization process while shipyards' interest is to succeed financially which means minimal production costs. Usually, production aspects (material, required welding procedures, man/hours, negative effects on the environment…) of preferred designs are not considered during the ship structure optimization process. To approach both objectives, a design problem should be formulated and multi-objective optimization needs to be applied to find a surface of non-dominant Pareto solutions that provide insight into various design solutions. Generating such solution surfaces opens the possibility to find the best compromise solution in the joint interaction of the ship structure designer and the production process engineer (technologist), depending on the set preferences of the specific project.

## Aims

The aim of the research is to develop a mathematical model for the estimation and calculation of different technological aspects of ship production and their integration into multi-criteria design procedures. The addition of technological-production attributes to the optimization process would expand the project space, considerably improving the quality of decision-making on the choice of the preferred project. The developed mathematical model would be flexible in terms of easy incorporation of new data, and the possibility of updating and expansion.

## Methods

The mathematical model would be developed using available data from the literature as well as the information collected from shipyards and design offices. Multi-objective optimization will be carried out using some of the methods developed in the last few decades, such as genetic algorithms, evolutionary strategies based on the theory of experiments and response surfaces, and particle swarm optimization. For the formulated problem and the generated Pareto surface, the selection of the preferred designs will be carried out systematically. Sensitivity and robustness analysis and identification of influential design variables and parameters on design attributes will be performed using some of the available statistical methods such as analysis of variance (ANOVA), etc. evaluated on several examples of ship structure of different complexity (stiffened panel, pontoon, midship section).

## Expected scientific contribution

The proposed research would result in an original mathematical model for estimation and calculation of technological aspects of ship production (material cost, cost of production, number of working hours, etc.) and which would be suitable for including in multi-criteria design procedure.

## Keywords

Multi-criteria optimization, ship structure, ship production

# Systematic Approach for Incorporating Tier 3 Method of Non-Road Mobile Machinery Emission Reporting in Croatian Greenhouse Gas Inventory

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## Introduction

Emission inventories should provide realistic data of submitted values with as little as possible discrepancies and deviations. If that is not primal and most important objective, in vain do we take all measures to protect the environment, in our case to reduce air pollution. As a part of Croatian greenhouse gas inventory, emissions from non-road mobile machinery (NRMM) are spread among different presentation sectors and calculated according to Tier 1 or Tier 2 method depending on accessible input data.

## Aims

Main objective of this research is presenting NRMM exhaust emissions with the most accurate method on disposal - Tier 3 method. On the other hand, this method requires more input data which should be collected with satisfactory accuracy, precision and reliability to get valuable output data. Any assumptions or lack of data will cause bigger dissent from real values.

## Methods

Initially, all national data - inventories, legislation, policies - associated with this topic, will be gathered from multiple sources that are involved in providing them. Existing NRMM emission inventories and other documentation from six European countries, who are reporting quoted emissions according to specific country-depended Tier 3 methodology, should be used as guidance and help.

Since the Finnish NRMM emission model is the most comprehensive, it will be thoroughly studied and, if possible, used as a base for Croatian NRMM Tier 3 emission inventory.

Finally, with all collected data and testing under real operating conditions, obtaining actual representative emissions of NRMM's internal combustion engines.

## Expected scientific contribution

Defining fundamental steps towards creation of the Croatian NRMM emission inventory and establishing at least one fully processed NRMM type with calculated and real-time undergo approved emission factors for various working conditions. Proposal for organizing national designated institution responsible for conducting large scale surveys about condition and usage of NRMM, gathering information needed for compiling national NRMM repository.

## Keywords

Croatian national greenhouse gas inventory, non-road mobile machinery, air pollution, emission inventory

# Properties of Nanocellulose-Polymer Composite Gears

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## Introduction

Gears are the most used machine elements for power and motion transmission. They are mostly made of steel because of its good mechanical properties such as high strength, hardness, modulus of elasticity etc. Given that the mechanical properties of the polymer materials are inferior to steel, their use in gear manufacturing is mainly reduced to the production of gears used for the transmission of motion and limited power. One way to improve the mechanical properties of polymer gears is to make them out of a composite with a polymer matrix. The most commonly used reinforcements are glass and carbon fibres. Gears made of such composite materials have much better load capacity than polymer gears. Alternative to polymer composites with carbon, glass and other similar fibres are nanocellulose-polymer composites. In these composites cellulose nanofibres, which are obtained from natural sources, such as wood, are used as reinforcements. Fibre reinforced polymer composites have particularly good properties, and since nanocellulose-polymer composites use cellulose nanofibres instead of artificial fibres, they represent an environmentally acceptable alternative.

## Aims

The aim of the research is to determine whether the gears made of nanocellulose-polymer composite can achieve mechanical properties equal to or better than the gears made of pure polymers and to conclude whether such gears are more cost-effective than the polymer gears. The research should provide insight into the properties of the gears made of nanocellulose-polymer composites and the impact of different parameters of the material itself on the load capacity and lifetime of the gears.

## Methods

Gears made of nanocellulose-polymer composite would be produced as a part of the research and an experimental examination of their mechanical properties on a closed-loop testing rig would be carried out. This test would also give insight to gear's behavior in working conditions, working temperature, load capacity and material fatigue properties. Additionally, test specimens would be produced from different types of nanocellulose-polymer composites and static tensile tests would be carried out to determine tensile strength and elastic modulus.

## Expected scientific contribution

The research should study gears made of nanocellulose-polymer composite in working conditions to determine main cause of gear failure (tooth flank damage, tooth root fracture, overheating) and their cost effectiveness when compared to polymer gears in same operating conditions. The findings obtained through the research could serve to better understand the behavior of the gears made of nanocellulose-polymer composites, which would result in the improvement of the gear design itself with respect to the specific properties of the composite material.

## Keywords

Composite, gear, polymer, nanocellulose

# Small Hydropower Plants for Sustainable Development

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## Aims

The main goal (contribution) of the dissertation is to develop a model for assessing the sustainability of SHP projects based on a method or combination of several methods of multi-criteria analysis (decision-making) that will more comprehensively consider various relevant influencing factors and criteria and all potential actors. in the available literature. Also the results obtained by the model will be able to rank alternatives while setting different goals and criteria. The partial goals required for model development are:presentation of the State of the Art technology and application of SHPP;-describe the existing methods of multi-criteria analysis (decision-making) and select the most suitable one /s for application in SHPPs;define influential factors and decision-making criteria, including those not used in previous research (eg administrative (legislative)) and determine their severity.

## Methods

The conducted research methods will be of a theoretical nature. Some of the known methods of Multi-Criteria Analysis (MCA) or Multi-Criteria Decision-Making (MCDM) from the literature in the phase of techno-economic analysis will be used with softwares for SHPP programs. The research plan is as follows: 1) represent the technology (technical characteristics) of SHPPs and their economic, legislative and environmental aspects; 2) describe multicriteria decision-making methods suitable for application in SHPPs; 3) give an overview of previous research in the field of multicriteria decision-making at SHPPs; 4) select the most appropriate method of multi-criteria decision-making; 5) define decision-making criteria, including those not used in previous research (eg legislative) and determine their weights; 6) development of a decision matrix, ie. calculation of individual criteria; 7) based on the previous accessible model, develop a model for assessing the sustainability of the SHP project; 8) test the project on a specific SHPP project or compare the sustainability of individual projects in a particular territory.

## Expected scientific contribution

Planning, development and implementation of SHPPs is a complex, interdisciplinary and integrated process because the implementation is influenced by many and different factors. Although SHPPs are renewable energy sources, there is pressure and suspicion on their construction from environmental groups, as well as from the local community and investors. Therefore, the sustainable development of hydropower systems and SHPPs involves connecting and analyzing many, different and often contradictory factors, so evaluating or deciding on SHPP projects is a complex process. In doing so, multicriteria analysis (decision making) can be a reliable methodology for assessing the sustainability of SHPPs and ranking alternatives in the presence of different objectives and constraints.

## Acknowledgments

company HEP for financing support

## Keywords

Small hydropower plants (SHPs), technical and economic aspects, sustainability, methods of multi-criteria analysis (decision making).

# Algorithm for Gear Pair Weight and Efficiency Optimization

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## Introduction

In recent years, growing demand for lightweight, efficient and quiet transmissions, fueled by the introduction of electric vehicles is observed. This calls for simultaneous gear optimization regarding efficiency, mass, and NVH (noise vibration harshness). NVH behavior can be assessed in terms of transmission error, which is the main contributor to gear vibrations. Manual optimization is tedious due to a large number of variables and trade-offs, such as the mass/efficiency trade-off reported by Miler et al. or efficiency/transmission error trade-off reported by Younes et al. Generally, optimization for any two of the above-mentioned parameters independently results in the deterioration of the third one. The aforementioned reasons emphasize the need for optimization algorithms in finding the optimal design. Researchers mostly omit pressure angle as an optimization parameter with the exception of Kim et al. and Hammoudi et al. This is also evident in a field of study review by Miler and Hoić who have not identified any additional publications using this parameter. Additionally, studies using pressure angle as a variable tend to allow only discrete values, thus limiting optimization possibilities. Since they are standardized in ISO53, pressure angle and tooth profile parameters are rarely used as optimization variables. This allows for tooling inventory reduction and calculation simplification but restricts optimization possibilities. Herewith gear macro-geometry was optimized for efficiency and mass using pressure and helix angles, gear width, modulus, tooth count, profiels shift, addendum and root radius coefficients as variables.

## Aims

Aim is to develop a gear optimization algorithm which will not be constrained by standard basic rack geometry limitations enabling it to take into consideration much larger number of possible solutions making it possible to identify optimal geometry for given application.

## Methods

Algorithm will be continuously upgraded with additional objective functions and constraints which will broaden its applicability. Results will be compared to those obtained by third party gear design software to verify the mathematical model. At later stage of development gear samples will be produced and tested to validate the model.

## Expected scientific contribution

It is expected that this algorithm will contribute to novel gear design methodology in which gear geometry is not driven by standard basic rack geometry. Such gears will be more appropriate than standard gears for specialised applications in which extremely high efficiency, low noise or high load carying capacity is required. Also it will be possible to explore the influence of various basic rack parameter modifications on before-mentioned properties of a gear pair.

## Keywords

gears, multi-objective optimization, weight, efficiency

# FPs | Frost Protection System

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## Introduction

The problem of climate change is a global problem that affects the entire world. The consequences of climate change are more and more evident every day. One of the consequences of climate change is the occurrence of extreme weather conditions. Early spring frosts are a phenomenon that significantly affects the yield. The onset of frost mostly results in the loss of the complete crop for the upcoming season. Therefore, it is necessary to apply active protection measures and reduce the risk of food production. One such protective measure is the frost protection system (rain), which is based on the phenomenon of water anomaly when energy is released during the change from liquid to the solid-state of water. This energy is used to maintain the temperature of the flower and young fruit in the range of 0 to 2 degrees Celsius. During such protection of plantations, ice crust is formed over the flower and fruit, whose temperature is 0 degrees Celsius. This ice protects the plantation with an igloo effect (ideal insulator). Modern protection systems apply the technology of creating fully saturated air (100% relative humidity) within the protected microclimate, which results in significant savings in the required amount of water during protection, thus eliminating evaporation and saving energy needed to maintain thin-walled ice crystal structures at 0 degrees Celsius. The main goal of this research is to analyze the influence of water freezing parameters on the thickness and transparency of the protective ice structure. The obtained results would be the basis for the development of advanced management of the frost protection systems and the development of new types of sprinklers with variable rainfall intensity. AIMS The main goal of this research is to analyze the influence of water freezing parameters on the thickness and transparency of the protective ice structure. The obtained results would be the basis for the development of advanced management of the frost protection systems and the development of new types of sprinklers with variable rainfall intensity.

## Methods

The research will be conducted by the experimental method. The experimental method is the only method that allows us to establish a cause-and-effect relationship. The research was carried out in the experimental field of Vrtovi Voća, Velika Ludina. The experimental setup consists of a measuring station, a sprinkler, and a weather station. The measuring station is a closed space of 1 $m^3$ with a sprinkler located in the middle of a closed space of 1 $m^3$. The sprinkler is controlled by a weather station that controls the parameters of temperature and humidity.

## Expected scientific contribution

The research results will be the basis for the development of advanced management of the frost protection systems and the development of new types of sprinklers with variable rainfall intensity. It is expected that this research will contribute to a better understanding that the thickness of the ice layer depends on the intensity of the water flow, the size of the water droplets, the temperature, and the humidity. The transparency of the ice layer depends on the size of the water droplets and the intensity of the water flow.

## Keywords

insulator, crystal ice, latent heat, frost protection system, water

**APPROVED TOPIC**

# Ant Colony Optimization Algorithm Performance for Solving Dynamic Vehicle Routing Problems

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## Introduction

The goal of the Dynamic Vehicle Routing Problem (DVRP) is to find routes with minimal cost or travel time for multiple vehicles that are visiting n locations while all relevant information is not known before the planning process begins and can change after initial routes have been planned. As the optimal solution cannot be calculated by exact algorithms in a time acceptable for practical use, it often requires the use of metaheuristics such as the Ant Colony Optimization (ACO) algorithm, which is considered by many authors to be a reliable, efficient, and overall good choice for solving DVRP, due to its ability to adapt to dynamic changes. Due to the nonexistence of a universal evaluation system, it is not known which of many ACO variants is the best for solving a particular variant of the DVRP and in which conditions. This thesis aims to provide an answer to that question by testing different ACO variants on different DVRP datasets.

## Methods

Because an optimal solution cannot be calculated in a time acceptable for practical use by exact algorithms, finding an optimal solution require the use of heuristic or metaheuristic algorithms. Among lots of different approaches, Ant Colony Optimization (ACO) algorithm is considered a reliable, efficient, and overall good choice for solving DVRP.

The research plan consists of four steps:

1. The systematic literature review by researching relevant scientific databases to find new variants of DVRPs and create updated categorization of the DVRPs,
2. The systematic literature review by researching relevant scientific databases to find and classify classic and newly proposed variants of the ACO algorithm used to solve DVRPs.
3. Applying chosen variants of the ACO algorithm to DVRP benchmark and/or created datasets.
4. Ranking ACO algorithms for each class of the problem based on several criteria (convergence rate, average quality of solution, percentage of generating the optimal solution, standard deviation, and maximum deviation from optimum).

## Keywords

DVRP, ACO

# Influence of Alternating Current Parameters on Weld Joint Properties at Tig Welding of P91 Steel

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## Introduction

Environmental awareness and aspiration for higher efficiency has led to development of existing and new process plants, especially thermal power plants which require application of creep resistant steels. With increasing operating parameters plants became more efficient and the emission of harmful gases is reduced, but modern creep resistant steels are much more difficult to weld and technology requires precise determination of heat input. This research investigates possibility and new approach for welding P91 steel with use of alternating current (AC) for improving overall weld joint properties and residual stresses decrease.

## Methods

The influence of shielding gases for welding, frequency and polarity balance of the AC TIG welding process will be observed through the analysis of macroscopic specimens and dimensional quantification of the welded joints, including the heat affected zones (HAZ). The hardness test of the welded joints will be performed by the Vickers method HV10 in accordance with HRN EN ISO 15614-1. The microstructures of welded joints with different heat input will be checked by analysis of polished microscopic specimens, while specific phases, precipitates and grain sizes will be analysed by electron microscopy. Due to mostly harmful effects of residual stresses on welded joints of martensitic steel P91 which are manifested through the potential formation and propagation cracks and other imperfections that may occur in welded joints, reducing the service life and integrity of the welded structures, residual stresses will be tested by non-destructive X-ray diffraction method. Analysis of results, statistical processing and formation of a mathematical model will be carried out using RSM-Response Surface Method.

## Preliminary results

First part of the experiment has been done with automatic TIG welding without filler metal with three values of frequency (30 Hz, 265 Hz, 500 Hz) and balance polarity (-20 %, 0 %, 20%), two values of welding current (75 A, 150 A) and use of one shielding gas (100% Argon). Two samples for comparison were welded within standard use of direct current (DC) and welding current values as mentioned above. All the other welding parameters like rectangular shape of balance polarity, welding speed, distance between electrode and workpiece, weld joint length, shielding gas flowrate, time of pre and post flow of shielding gas, welding position and one layer welding were constant. Preheat temperature and post weld heat treatment (PWHT) are excluded in this research. On the welded samples geometrical evaluation, hardness testing and microstructure analysis have been performed.

## Discussion

Performed visual examinations showed that finest welding process and electric arc stability is given with -20 % balance polarity regardless used frequency. Lowest heat input is measured with these values as well and with referential samples welded with DC. Macro specimens analyze indicate that with AC TIG welding is possible to achieve same or even better weld penetration in comparison with conventional DC TIG welding with the narrower width of HAZ. Micro specimens and hardness testing analyzes confirmed necessity of using PWHT. AC TIG welding is capable to produce weld joints that could be an attractive alternative process which allows heat input increase, larger weld puddle and increased penetration rate with possibility of residual stresses decrease.

## Keywords

P91 steel, TIG welding, alternating current, weld joint properties, residual stresses.

# Improving the Scalability of Predictive Control in Buildings

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## Introduction

Many studies have proven that using predictive control for buildings reduces energy consumption and cost, increases thermal comfort, and improves grid flexibility. However, developing the predictive control for each specific building is extremely time-consuming and costly. The objective of this research is to compare different problem formulations, technical systems in buildings, and different occupancy patterns regarding the easier scalability of predictive control.

## Methods

The first part of the research includes an extensive literature review about the implementation of predictive control in the building sector and the identification of research gaps. The second part of the research includes the development of multiple building models for predicting the building thermal dynamics, occupancy patterns, and external disturbances in the programming language MATLAB. The final part of the study will be the experimental validation of different predictive control formulations in a real building, which will include both the longer and shorter monitoring periods to evaluate the problems regarding seasonality, adaptive techniques, as well as the effects of different heating and cooling elements, ventilation systems, sensors and meters, and occupancy patterns.

## Preliminary results

Five different RC models were developed based on the training data acquired by using the TRNSYS simulation software. The models were of increasing complexities, where their inputs stay the same, but their structure changes from R1C1 structure to R4C3 structure. Each model was trained based on 52 different training periods and tested on 182 validation periods. Five different initial guesses densities were applied to improve the probability of reaching the global minimum. The training errors represented by RMSE range from 0.15°C for the best models to 15°C for the worst models. The lowest mean errors considering all validation periods are around 0.3°C.

## Discussion

It has been shown that the global training minimum might not be an optimal solution for most validation periods and that some local minimum that performs better for different parts of the year might be more applicable. Different initial guesses densities do not greatly influence the acquirement of the global training minimum, but greatly influence the number of acquired local minimums which is beneficial for finding the best model for most validation periods. The dependence of the model training error on training input characteristics decreases as the complexity of the model increases. The parameters of the RC model were not found to be physically interpretable, contrary to what has been stated in literature so far, putting the RC model more in the category of black-box models than grey-box models. Further research is needed to assess the optimum building excitation patterns because it has been shown that some training periods produce better models than others.

## Keywords

predictive control, building modeling, optimization

# Experimental Study of Electrochemical Hydrogen Compressor with Modified Proton Exchange Membrane and Metal Foam

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## Introduction

Renewable energy sources in conjunction with hydrogen are recognized worldwide as a perspective direction for the ongoing energy transition. One of the requirements for hydrogen technology's large-scale implementation is efficient storage, which necessitates accompanying processes, such as compression. This is due to hydrogen's low energy density per unit volume under normal conditions. Compared to mechanical compressors, an electrochemical hydrogen compressor (EHC) is a relatively new promising technology due to its noiseless and vibration-free operation, modularity, absence of moving parts, higher efficiency, and multiple usages, such as hydrogen purification and its extraction from gaseous mixtures.

## Methods

Theoretical research concluded experimenting with a novel EHC design that will incorporate materials not yet introduced to this technology. The experimental research is conducted at the Power Engineering Laboratory. The experimental results will be a verification of a developed mathematical model of EHC operation in MATLAB/Simulink Software. To further back up the research objectives, obtained data from the experiment will be compared to the results from the collected scientific papers with a standard EHC design.

## Preliminary results

The EHC drawbacks derived from theoretical research are membrane-electrode assembly deformation and molecular hydrogen back diffusion due to considerable pressure differences. Further research emanated new paths for EHC performance improvement - infusing PEM with hydrogen proton permeable material that is stronger than polymer and replacing standard flow field plates with channels for metal foam. The preliminary technical drawings for a novel EHC design and developed experimental path scheme are being processed for purchasing the necessary materials and equipment. Also, a literature gap was found for mathematical models of EHC operation. For this reason, a mathematical model was developed that successfully generates output parameters of a conventional EHC described in the collected paper.

## Discussion

EHC technology isn't sufficiently developed and should be further studied due to its limitations. Theoretical research indicates that the advantageous properties of the metal foam and modified Nafion could positively affect the operation of EHC. Therefore, a doctoral thesis is based on the experiment aiming to determine if the implementation of metal foam instead of flow fields plates with channels and filler / Nafion mix instead of the conventional membrane, will improve the EHC performance.

## Acknowledgments

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## Keywords

Hydrogen, electrochemical hydrogen compressor, proton exchange membrane, metal foam

# Numerical Model of Lubricated Wear in Rotating Machinery

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## Introduction

With modern system design moving towards increased efficiency and optimisation, certain machine elements are expected to operate under conditions (e.g. mixed-mode lubrication or direct surface-to-surface contact) where understanding the wear phenomena becomes of great importance.

Wear can be defined as the removal of material from one or both solid surfaces in contact, when the surfaces are in relative contact (sliding, rolling or impact motion). Surface interaction at asperities is thought of as the main mechanism behind the occurrence of wear. Adhesive wear is identified as the most common type of wear. In adhesive wear the sliding contact between surfaces leads to the formation of cold welds at asperity junctions and shearing action leads to breaking of the cold welds and formation of fragments. These fragments may be transferred to the original surface or may form loose wear particles.

## Methods

The Archard wear model is recognised as having a high general applicability and is widely used in wear research. A numerical framework based on the Archard wear model and the Finite Area Method (FAM) is presented as a viable tool for calculating wear of contacting rough surfaces in relative motion. The elastoplastic contact model, first presented in the PhD dissertation by Škurić (FSB, 2019.), is modified to be compatible with the implemented wear model and is used to resolve the contact between rough surfaces. The resulting wear algorithm is implemented in foam-extend and is capable of calculating parameters relevant in wear analysis of surfaces under dry contact conditions, while being able to consider the evolution of contact due to wear.

## Preliminary results

The wear algorithm is used in numerical simulations of relevant test cases, such as the simulation of a spherically tipped pin sliding over a disc. The results show that acceptable accuracy may be achieved for numerical simulations of wear for contacting surfaces in relative motion.

## Discussion

The analysis of the results shows that the wear algorithm, based on the Archard wear model, may be used to calculate the depth of the worn material using the real contact area, contact load, hardness of the materials in contact and the experimentally determined wear coefficient. Such data is invaluable for the study of the failure of mechanical components in mechanical systems, without the need to rely on experimental measurements. The algorithm will be developed further, as to better take into account the presence of lubricant and to be applicable to real rough surface topologies.

## Acknowledgments

This work was supported by the Croatian Science Foundation (project number DOK-2020-01).

## Keywords

Sliding Wear, Finite Area Method, FVM, foam-extend

# Aerodynamic Characteristics of Tall Buildings with Porous Double-Skin Façade Systems

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## Introduction

A porous double-skin façade (PDSF) is a building cladding system which consists of two skins separated by a small gap. The inner skin is impermeable, while the outer skin is porous, i.e. it allows for the flow of air through the skin and into the gap between the two skins. Given the relative novelty of such systems, it is important the investigate their effect on aerodynamic loading of buildings.

## Methods

The experimental research is performed in a boundary layer wind tunnel on scaled building models of different outer skin porosities under various inflow characteristics and flow incidence angles. The model of the atmospheric boundary layer is created in the wind tunnel. The measurement equipment encompasses Prandtl-Pitot tubes and hot-wire anemometers for recording of the mean and fluctuating flow velocity in the test section of the wind tunnel, respectively. Flow velocity measurements are performed in multiple points at various heights to determine the characteristic ABL profiles. A high-frequency force balance is used for measurements of integral wind loading of the building model, while pressure sensors are used for recording of surface pressures on the building models inner skin. The building model is subjected to the ABL simulation at flow incidence angles from 0° to 45° with an increment of 5°, while additional flow incidence angles of 12.5° and 17.5° are also studied. The experimental results encompass mean and fluctuating integral along-wind and across-wind moment coefficients, power spectral densities of integral moment coefficients, mean surface pressure distribution on the inner skin and their standard deviations. All of the results are available for two ABL models, four different porosities of building model PDSF systems (single-skin and three different porosities), and 11 different flow incidence angles.

## Preliminary results

The implementation of a PDSF system of any porosity causes a decrease in the maximum mean across-wind moment coefficient in the order of ~13% regardless of the outer façade porosity, which was observed at the 12.5° flow incidence angle. The effect of the PDSF system on the mean integral along-wind moment coefficient is negligible. The 25% porosity PDSF causes a decrease in the peak pressure coefficient by ~10% to ~20% for all building surfaces depending on the flow incidence angle. An increase in the PDSF porosity reduces the effect of the PDSF system on maximum inner surface pressures. More turbulent ABL causes a decrease in both the integral loading and surface pressure distribution for all flow incidence angles.

## Discussion

The implementation of porous double-skin façade systems on tall buildings favorably affects aerodynamic characteristics of these complex engineering structures by causing a decrease of their integral across-wind loads and surface pressures on the inner façade.

## Acknowledgments

The Croatian Science Foundation IPHRZZ-2016-06-2017 (WESLO) support is gratefully acknowledged. The work of doctoral student Petar Škvorc has been fully supported by the "Young researchers' career development project – training of doctoral students" of the Croatian Science Foundation.

## Keywords

Tall building, porous façade, wind load, experimental aerodynamics, wind-tunnel experiments

# A Method for Designing Power Systems for Autonomous Ships

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## Introduction

Modern shipbuilding and maritime industries are under continuous pressure to reduce operating costs and environmental impact, as well as to enhance safety. A higher degree of ship autonomy also implies meeting at least equal safety and reliability standards as in the case of conventional ships, which has a significant impact on both the design and operation. Technological development, enhanced data collection, and interconnectivity enable complex automated systems to be controlled remotely and/or autonomously. This research is related to the development of design procedure for power systems of autonomous vessels. For this purpose, it is fundamental to identify differences in design requirements for power systems of conventional and autonomous vessels, as well as to develop a mathematical model to represent power system design that incorporates a higher autonomy degree.

## Methods

Although autonomous vessels are expected to be as safe as the conventional ones, it is obvious that removal of crew from ship leads to savings in operational costs, but at the same time it significantly reduces possibility for corrective maintenance during the voyage. Therefore, it is necessary to analyse key activities of the crew related to the operation of ship power system and to define effect of lack of crew on potential safety reductions. This research includes development of a mathematical model that incorporates energy efficiency, safety, environmental friendliness and costs for the selected autonomy level. In this sense it is necessary to formulate key performance indicators (KPIs) of mentioned parameters and their functional relations for different power system layouts (serial, parallel, etc.). Beside diesel engine-powered options, a set of alternatives will be considered.

## Preliminary results

The feasibility of autonomous ro-ro passenger ships combined with the application of alternative power options, where the Croatian short-sea shipping sector is taken as an illustrative example, is analysed. An analysis is conducted for heavy fuel oil, marine diesel oil, liquefied natural gas, methanol, electricity, and fossil and renewable hydrogen for three different ro-ro passenger ships operating on short, medium, and relatively long routes. For the ship lifetime of 20 years, through five KPIs, the environmental and economic impact of the considered options is evaluated and the potential for their autonomous application is investigated. Taking into account the contrasts between conventional and autonomous ships, the differences in the costs for autonomous and conventional ro-ro passenger ships are outlined, and the KPIs are compared.

## Discussion

The results indicate that from an environmental and economic point of view, methanol and electricity-powered ships are the best option for all three routes. Regarding autonomous shipping, the ecological and economic benefits are obvious for all the considered power options and ships, except for the renewable hydrogen-powered ship operating on the longest route.

## Acknowledgments

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## Keywords

Autonomous ship, power system, degree of auton-omy (DoA), safety

# Biomechanical Impact of Thread Type in Complex Bone Fixation Systems of Favourable Mandibular Angle Fracture: a Finite Element Pre-Study

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## Introduction

Approximately 33% of all types of mandible fractures occur in the mandibular angle. These fractures often appear as a result of interpersonal violence, falls or motor vehicle accidents and can be roughly divided into two groups: favourable and unfavourable fractures. Their treatment is often problematic due to the mandible's complex bone geometry resulting in post-treatment complications present in nearly 26% of the patients. The most common fixation treatment of such fractures is a bendable plate with screws. Although several studies describing various biomechanical impacts of screw's thread on bone have been conducted, there is currently no information about thread behaviour on a geometrically complex bone such as a human mandible. Therefore, the aim of this study is to determine the difference of biomechanical stability between four types of screw thread definitions in Abaqus simulations on a human mandible with a favourable fracture using conventional locking plate system.

## Methods

A mandible of an 83-year-old male was reconstructed using computer tomography and Materialise Mimics software (Materialise NV, Belgium). The model consisting of cortical and trabecular bone was imported into SolidWorks 2020 software (SolidWorks, Dassault Systèmes, Massachusetts, USA) where it was integrated in an assembly with a bendable plate and four screws. The bone – implant assembly was then imported into Abaqus software (version 6.14-5, Dassault Systèmes, France) where a total of 36 simulations was conducted. Two groups of the simulations had screws with a thread, while the other two had a smooth cylinder instead. Each of those groups comprised different percentage of the screw thread tied with the plate, resulting in four main simulation groups with the position of the screws continuously remaining the same. Three individual bite force cases applied vertically on the incisal and molar region were defined within those groups. Another six simulations within groups consisted of forces applied only on the left and right part of the mandible, respectively. Von Mises stress and displacement distribution as well as relative displacements along the fracture site were observed in all models.

## Preliminary results

The differences between maximum displacements in groups with molar and incisal forces among all models are less than 1% while the differences in maximum von Mises stresses are more than 80%. For the models with only molar forces applied, the differences between maximum displacements are also less than 1%, while differences in von maximum von Mises stresses climb up to 90% in some cases. The same 1% difference between relative displacements can be observed on the fracture site of the mandible.

## Discussion

The conducted simulations show that the thread on screws which will be used for further comparison studies involving the design of novel osteosynthesis material for mandibular angle fractures can be a smooth cylinder with a 65% tied surface to the bendable plate. Needless to say, research involving experimental validation of this model will be conducted in the upcoming analyses, but using the forementioned screw's thread definition will substantially lower computing time while simultaneously remaining the models' accuracy.

## Keywords

mandibular angle, favourable fracture, finite element method, medical implant, maxillofacial surgery

# Human-Centered Predictive Control in Buildings Using Personalized Comfort Data-Driven Models

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## Introduction

Human-centered control systems in buildings have gained increasing attention as they primarily focus on occupant satisfaction and wellbeing. One kind of such control strategy is Human-centered Model Predictive Control (HC-MPC), which takes into consideration human comfort preferences as an input in the control algorithm. This is facilitated by collecting direct feedback from occupants through an interface (e.g., smartphone application), where the preference on the indoor conditions is reported for thermal, visual, and indoor air quality (IAQ) comfort. Data-driven personalized comfort models are used to predict the individual comfort preference based on previously reported data, to reduce fatigue and burden from continual feedback-reporting. However, when introducing new technologies that depend on human interaction and occupant-provided data, it is important to know the interaction willingness of the occupants. Hence, since the feedback-reporting presents a behaviour in itself it can be analyzed using social science approaches that are used to analyze general human behaviours. Furthermore, there is a lack of research on the implementation of HC-MPC especially involving multi-occupant and multi-aspect comfort (thermal, visual, IAQ). This control strategy also enables users to interact with demand-response actions. Hence, the impact of HC-MPC on grid flexibility needs further exploration.

## Methods

This is an interdisciplinary research study that combines technical and social sciences. The technical part is the implementation of HC-MPC in a real school building and data-driven personalized comfort model development using Artificial Intelligence with MATLAB and Python. The social science part involves the adaption of psychological theoretical frameworks such as the Theory of Planned Behaviour that employs surveys as a tool which is used for qualitative, quantitative, and analytical research using Structural Equation Modelling through Smart PLS statistical software.

## Preliminary results

The results from the first part of the research present the analysis and prediction of the feedback-related behaviour of the occupants in the case study school building. The yielded results from the survey show that the main influences in such behaviour are the attitude of occupants towards reporting feedback, the social norms, and their perceived control or ability to interact with the system. Furthermore, the analysis showed that the feedback-reporting behaviour can be predicted with a 60% explained variance.

## Discussion

The results show that the intention of occupants to interact with the control system exists and it can be predicted. This will be useful during the future implementation phase of the HC-MPC. The aim of this research is the integration of human comfort preferences as an input in the MPC algorithm of a real pilot building. This facilitates regulating the indoor environment by developing data-driven models from collected multi-aspect comfort and multi-occupant data provided by occupants through an interface using a customized smartphone application. Future steps also include defining the impact of HC-MPC on the electrical grid flexibility.

## Keywords

Human-centered control systems, personalized comfort data-driven models, human behaviour, advanced building control

# Multimodal Emotion Analysis Based on Visual, Acoustic and Linguistic Features

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## Introduction

Human interaction is comprised of two distinct methods, verbal and nonverbal. Most of the time nonverbal communication is based on subtle movements of facial muscles and subtle changes in tone and intonation of voice. Secondly, verbal communication relies on different cues inside sentence formations and usage of different words to convey additional information outside pure worth of spoken word. Both communications can be affected by changes in an emotional state of a person in the interaction.

## Aims

In this paper I present a computational reasoning framework that can interpret the social signals of the person in interaction by focusing on the person's emotional state. To achieve better communication between a human and computer agent, the agent should be capable to interpret acoustic and visual cues and emotional conditions and respond accordingly.

## Methods

For this study, two distinct sources of social signals are used: facial and voice emotion modalities. As a part of the first modality, a Convolutional Neural Network (CNN) is used to extract and process the facial features based on live stream video. Visual sub-modality was defined through methods of Transfer Learning (TL) with the usage of the VGG16 pretrained network. Dataset for training was taken from open-source dataset libraries for emotional analysis and combined into one large set.

The voice emotion analysis containing two sub-modalities is driven by CNN and Long Short-Term Memory (LSTM) networks. The networks are analyzing the acoustic and linguistic features of the voice to derive the possible emotional conditions. Acoustic sub-modality is relying on a Convolutional Neural Network (CNN) architecture has eight dedicated layers and eight outputs. Linguistic sub-modality is achieved on a Long Short-Term Memory (LTSM) neural network architecture, containing four distinct layers and four outputs.

Relying on the adaptive multimodal information fusion algorithm, the system then fuses data into a single hypothesis. The algorithm is based on the weighted factor approach where all three sub-modalities are multiplied with factors and then summed (summation of all factors should be 1). For near-ideal environment conditions, all factors are weighted equally, which can be changed and adapted to changing environmental conditions.

## Expected scientific contribution

Results of algorithm reasoning are used to autonomously generate the robot responses which are shown in a form of non-verbal facial animations projected on the 'face' surface of the affective robot head PLEA. Built-in functionalities of the robot can provide a degree of situational embodiment, self-explainability and context-driven interaction.

## Acknowledgments

This work has been supported in part by the Croatian Science Foundation under the project "Affective Multimodal Interaction based on Constructed Robot Cognition—AMICORC (UIP-2020-02-7184)."

## Keywords

Nonverbal Behavior, Multimodal Interaction, Artificial Intelligence, Cognitive Robotics, Social Signal Processing

# Numerical Modelling of Self-Propulsion Using the Actuator Disc and Fully Discretized Propeller Approach

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## Introduction

Accurate prediction of the self-propulsion point of a ship represents a challenging task in the field of naval architecture. The significance of this task is high considering the new regulations regarding lower greenhouse emissions. Computational Fluid Dynamics (CFD) based on the Finite Volume Method (FVM) is often used to describe the ship-propeller interaction and to predict self-propulsion characteristics due to the higher costs and complexity of the experimental methods, especially in the preliminary design stage. In this study, a detailed analysis of the global and local flow characteristics of a self-propelled ship at Fn=0.26 is presented. The ship used in the present study is a model-scale KRISO Container Ship (KCS). A fully discretized propeller and actuator disc models for propeller modelling are used and compared in this study. Two different implementations of the actuator disc models were used: a model which mimics the thrust effect only via the pressure jump, and a model where both thrust and torque effects are taken into account, by applying pressure and tangential velocity jump boundary conditions. The actuator disc approach is usually sufficient for obtaining accurate self-propulsion integral values such as thrust and torque. However, if detailed local flow features are important, the ship propeller needs to be modeled as fully discretized and rotating. Therefore, to reduce overall computational time while achieving an accurate representation of global and local characteristics at the same time, a procedure combining the actuator disc and discretized propeller methods with the use of dynamic overset grids and proportional-integral (PI) controller is proposed.

## Aims

The main objective of this research is to develop and validate an efficient procedure for numerical calculations for the accurate prediction of global and local flow characteristics with application to self-propulsion calculations.

## Methods

A proportional-integral (PI) controller is implemented within the Naval Hydro Pack library, which is based on foam-extend, a community-driven fork of the OpenFOAM software. Overset mesh approach uses multiple separately meshed grids, usually one background and one or more body-fitted grids, to discretize the computational domain. Interpolation of the field data between the grids is performed in the fringe layers. An incompressible, two-phase, viscous numerical model is applied in this study. Turbulence is taken into account with the k-omega Shear Stress Transport (SST) model. Level Set (LS) approach is applied in order to capture the interface between two simultaneously solved phases, while the Ghost Fluid Method (GFM) is employed to ensure sharp distribution of pressure and density at the free surface. The coupling of the pressure field and rigid body motion is resolved with an enhanced approach, while the coupling of flow and rigid body equations is resolved with the PIMPLE algorithm.

## Expected scientific contribution

Development of an advanced numerical procedure for prediction of integral and local flow characteristics based on actuator disk and discretized rotating propeller methods with application to self-propulsion calculations.

## Acknowledgments

The authors are thankful for the financial support from the CEKOM project from the European regional development fund, referent number KK.01.2.2.03., sub-projects IRI 2 and IRI 6, in the scope of which this study is conducted.

## Keywords

Self-propulsion, Actuator disc, Discretized propeller, Overset grid, Level Set

# Development of Steel Deep Boriding Process

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## Introduction

Boronizing is a type of thermal diffusion process with primary goal of increasing the surface hardness, wear resistance and product life cycle. Along surface hardness, thickness of the achieved layer is also important for increasing the wear resistance and life cycle of the product. To increase surface layer thickness, existing boronizing process needs to be modified. The proposed research is focused on the development of new boronizing processes, by modifying the existing processes, developing a new boronizing method with the aim of increasing the layer thickness and wear resistance. In addition to modifying the formation of boride layer on the steel surface, the proposed study plans to explore the possibility of increasing the hardness of the substrate material itself, which would achieve a much better base on which the boride layer is formed further increasing the wear resistance of the samples.

## Methods

The methodology of the proposed research consists of different phases: experimental plan, preparation of test samples and examination of various parameters for modifing boronizing methods. After experiments with regular methods and finding parameters that give best results, research will move to test two or more (duplex) different methods for achieving the best mechanical properties (surface hardness, layer thickness, wear resistance). After experimental tests, mechanical, tribological and metallographic properties of samples will be analyzed using several methods. Characterization of the surface layer composition will be tested using GDOES and XRD methods. Examination of the microstructure will be carried out using light and electron microscopy.

## Preliminary results

For the beginning of experimental research C45 steel was boronized for 2, 4 or 6 hours and then subsequently annealed (deep boronizing) in a vacuum furnace at 700 or 900 °C, or boronized using variable temperature of process. Results show an increase of up to 68% in effective boriding depth (EBD) for samples heat treated with modified boronizing processes. Duplex process of boronizing and quenching was researched on X90CrMoV-18 steel, samples were first boronized for 2, 4 or 6 hours and then quenched in oil (right after boronizing) or subsequently heated in vacuum furnace and then quenched in inert gas (N2). Results show a decrease in abrasion wear of up to 20 times for boronized and quenched sample in comparison with annealed sample.

## Discussion

The aim of the research is to develop modified boronizing method in order to increase layer thickness and wear resistance of samples which would result with increase product life cycle. In addition to modifying the formation of boride layer on the steel surface, the proposed study plans to explore the possibility of increasing the hardness of the substrate material itself.

## Keywords

boronizing, deep boriding, quenching, annealing

# Influence of the Particle's Shape and Orientation on the Mechanical Properties of Ductile Heterogeneous Material

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## Introduction

The mechanical properties of heterogeneous materials are in a direct link with their microstructure. Orientation, shape, spatial distribution, volume fraction, and mechanical properties of the microconstituents that make up the material will determine its behaviour during the exploitation. With the use of different types of production processes, it is possible to alter the previously mentioned parameters of the microstructure, and thus obtain optimal mechanical properties. In order to determine the impact of microstructural altering on the mechanical behaviour of heterogeneous material, experimental analysis needs to be performed. However, the implementation of different types of production processes as well as the experimental analysis itself represents a cost in terms of money and time. Therefore, numerical simulations, which are supported by the exponential growth of the computational resources, are imposing themselves as a possible alternative.

## Methods

Heterogeneous material, present in this study, will consist of two microconstituents – matrix, which will exhibit elastoplastic behaviour, and particles, whose behaviour will be purely linearelastic. With the particle's volume fraction set at 30%, the study will examine the influence of the particle's shape and orientation on the overall properties of the material. In total, eight different microstructures will be generated and analyzed – four different particle shapes and four different particle orientations. The multiscale analysis will include horizontal tension and pure shear loading with the assumption of small strains in a 2D plane. At the microlevel, a newly developed reduced-order homogenization method will be implemented in order to ensure computational efficiency and accuracy of the multiscale analysis.

## Preliminary results

For each of the eight different microstructures configurations, a multiscale analysis has been conducted to determine the mechanical properties of ductile heterogeneous material. The results include linearelastic properties, i.e., the module of elasticity and Poisson's ratio, elastoplastic properties, i.e., yield strength and hardening parameters, as well as the force-displacement diagrams.

## Discussion

Preliminary results serve as an indicator to what extent a particle's shape and orientation affect the overall mechanical behaviour of ductile heterogeneous material. This is particularly important in material design – where a specific microstructure configuration gives optimal mechanical properties. By generating multiple microstructures and applying multiscale analysis it is possible to determine the true impact of the microstructure on the overall mechanical behaviour of the material, without the need for different production processes or experimental analysis.

## Keywords

Microstructure, ductile heterogeneous material, reduced-order homogenization method,

# Validation of 3D-CFD and 1D/0D Pre-Chamber SI Engine Simulation Models

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## Introduction

The numerical simulations of different fidelity are used in variety of applications during the internal combustion engine development process. The 3D-CFD models offer the most accurate results but are time consuming and therefore inconvenient for extensive analysis across the engine operating map. In such cases the cycle-simulation models, based on 1D/0D approach, are applied as a compromise between the computational effort and accuracy of the simulation results. The numerical framework combining both modelling approaches is especially useful for the research of new combustion concepts and engine designs such as the pre-chamber SI engines, which rely on the lean-burn combustion approach to increase the efficiency and reduce the harmful emissions of IC engines. In this work, the validation of such numerical framework that will support the research of the pre-chamber engine is performed.

## Methods

For 3D CFD modelling the AVL Fire™ code is employed, where the full-cycle model of the experimental engine is prepared. For the 1D/0D modelling approach, the AVL Boost™ was used, but the existing 0D combustion model was extended to take into account the multiple flame propagation in the main chamber. The validation of the simulation models is performed with the experimentally obtained results on three different operating points, covering the change in both the engine speed and engine load to test the predictive capability of the models.

## Preliminary results

The validation of the simulation models is performed by the comparison of the simulated and experimentally obtained in-cylinder pressure profiles, as well as the indicated specific fuel consumption (ISFC). The 3D-CFD model required small adjustments of one combustion model constant but achieved a near-perfect match of the in-cylinder pressure profiles. The 1D/0D model results with a slightly lower accuracy due to many simplifications implied by such modelling approach. However, a good match is still achieved on each operating point with a single set of model constants. Comparing the ISFC, both 3D-CFD and 1D/0D models show a very good accuracy resulting with an average error of under 2%.

## Discussion

The validation of the simulation models shows a very good accuracy of both 3D-CFD and 1D/0D modelling approach and, although presented for a limited number of operating points, indicate a good predictability of the models as well. This is especially important for the 1D/0D modelling approach to enable the use of such models across the entire operating map. The 3D-CFD model provides the results that have a big impact on the combustion process and the performance but cannot be measured experimentally. It also provides insight into some important physical phenomena that occur in such engines but cannot be captured by the 1D/0D model. That is why both modelling approaches will be used according to their respective advantages to complement the experimental research in the best possible way.

## Acknowledgments

This study was made within the project EF-PRECOM (IP-2019-04) "Research of More Efficient and Environment-Friendly Pre-Chamber Spark Ignition Combustion", funded by the Croatian Science Foundation (HRZZ).

## Keywords

Pre-Chamber, SI Engine, Cycle-Simulation, 3D-CFD, Combustion

# Valorisation of Muti-Layered Plastic Waste via Pyrolysis

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## Introduction

Multi-layered plastic waste is found in a great share of separately collected post-consumer waste. Mechanical recycling of multi-layered plastic waste is challenging because of its various composition, which often leads to landfilling. Pyrolysis process will be conducted to use the potential of such waste. Pyrolysis is defined as thermochemical recycling technology for obtaining valuable products (fuel, chemicals) from plastic waste. The goal of this PhD research is the study of an impact of different operational variables (temperature, polymer and catalyst ratio, polymer waste composition, duration of the process) on the pyrolysis process of multi-layered plastics in order to obtain quality products and the assessment of the economic viability of such a process.

## Methods

Identification of the multi-layer plastic waste composition (Fourier-transform infrared (FTIR) spectroscopy combined with microscopy) and physico-chemical properties (proximate and elemental analysis). Determination of the multi-layer plastic waste's thermal stability using thermogravimetric analysis (TG). Determination of kinetic models (reaction mechanisms) that can describe the thermal decomposition of multilayer plastic waste. Pyrolysis of the multi-layer plastic waste in the fixed bed laboratory reactor. Analysis of the pyrolysis products using gas chromatography-mass spectrometry (GC-MS), Fourier-transform infrared (FTIR) spectroscopy, Nuclear magnetic resonance spectroscopy (NMR) and bomb calorimetry to determine the higher heating value (HHV).

## Preliminary results

In previous research, the goal was to analyse the waste plastics that cannot be mechanically recycled and are usually disposed or sent to incineration. The post-consumer waste plastics were collected after secondary separation (mechanically non-recyclable plastics). That waste was manually sorted into categories according to the resin identification code (RIC) found written on the packaging and then each fraction was weighed. The visual separation according to RIC labels was confirmed by FTIR-ATR. Plastics labelled as "other" under label 7 were recorded on both sides since they are usually made from more layers. The results of this FTIR analysis of plastics under label 7 are presented in the paper „Catalytic pyrolysis and kinetic study of real-world waste plastics: multi-layered and mixed resin types of plastics"

## Discussion

The results presented in the paper confirmed how the fraction of waste plastic under label 7 is actually made from at least two layers. Catalytic pyrolysis yielded products of satisfying quality which was confirmed using analytical methods. To further improve this research, thorough identification of the multi-layer plastic waste composition using Fourier-transform infrared (FTIR) spectroscopy combined with microscopy is being performed. The preliminary investigations will set the operational variables for laboratory pyrolysis (TG and kinetic analysis). Additional experiments using this composition will be conducted in a fixed bed reactor using a catalyst that will yield the best quality of the pyrolysis products.

## Acknowledgments

This work has been fully supported by Croatian Science Foundation under the project Neoplast (IP-2018-3200) and the project Career development of young researchers - the training of new Doctors of Science (DOK-2018-09-6944). This support is gratefully acknowledged.

## Keywords

multi-layered plastic, plastic waste, pyrolysis, catalyst

# Modelling Error Estimation for Reduced Order Coupled Dynamical Systems

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## Introduction

Modelling of coupled dynamical systems represents a cornerstone in many applied technical sciences. Demands for control of spatially distributed dynamical systems is also increasing. Examples include flexible multibody systems (FMBS) such unmanned aerial vehicles (UAV), satellites and aircrafts, micro electro-mechanical systems (MEMS), very large-scale integrated (VLSI) circuit design and similar. Choosing the appropriate discretization mesh (grid) for the coupled dynamical system to be controlled is not trivial: spatial discretization error increases with the reduction of mesh resolution and the order of the resulting coupled dynamical system dramatically increases with mesh refinement. Model order reduction (MOR) methods plays an essential role here - at the cost of introducing the MOR error.

## Methods

There exist many techniques that deal with the error estimation of a specific spatial discretization technique and/or MOR method. However, it is was shown that those are usually hard to be combined and implemented for efficient controller synthesis. To deal with this, author proposes to model the coupled system affected by discretization and MOR errors as an uncertain dynamical system – where each error (from both spatial discretization and MOR) is modeled as a full-block unstructured additive uncertainty model. With the novelty of the procedure being the modelling of the uncertainty at the level of a subsystem – i.e structure preservation. Robustness analysis of the resulting uncertain system can be carried out using the classical tools, such as $mu$-tools or using the integral quadratic constraints (IQCs).

## Preliminary results

For a special class of spatially distributed dissipative dynamical system, modelling of the uncertainty at a subsystem level, was proven to be practically useful: (i) uncertainty modelling at the level of a subsystem preserves the structure of the coupled system, (ii) for coupled systems with many interconnected dissipative subsystems, uncertainty at the level of a subsystem, can often be reduced – taking into account dissipative properties of the subsystems' surroundings – resulting in a less conservative uncertainty models, (iii) it is possible to fine tune the required discretization level of each subsystem as well as to choose appropriate (or even different) MOR method per subsystem, and (iv) using the IQCs it is possible to take into consideration the different types of uncertainties into the overall robustness analysis – such as parametric uncertainties and nonlinearities.

## Discussion

It is shown possible to find a low-order approximation of the coupled uncertain dynamical system. The obtained low-order coupled system is robustly stable and the overall dynamics are well correlated in comparison to the original high-order (nominal) coupled system – and as such suitable for modern decentralized or distributed controller synthesis.

## Keywords

spatial discretization error, model order reduction error, robustness analysis, integral quadratic constrains

# Modelling the Shipbuilding Process Through Applying Digital Lean Management

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## Introduction

Knowledge and skills in ship design and construction, as one of the most complex industrial products today, in addition to the requirements for continuous innovation, in particular with regard to meeting the ever-increasing criteria for the energy efficiency and environmental friendliness of ships and their autonomy in navigation and maintenance ("Smart Ship"), contribute with their high added value not only to the scientific research potential of the society but also to the entire chain of accompanying service and production activities. In competition with the Far East not only in the construction of cargo ships but today in the niches of highly sophisticated cruise ships and special purpose vessels, the European shipbuilding industry is faced with the need for continuous but intensive business improvement to at least maintain its competitiveness and cost-effectiveness. In addition to ensuring profitability, advances in shipbuilding processes are necessary to achieve sustainable growth and development, not only to meet EU strategies on climate neutrality over the next three decades but also due to current customer demands for "green" production.

This paper will present research on the model of the development, design, and construction process of ships to transform the process from a traditional environment to a smart environment by implementing applicable Industry 4.0 trends and technologies, which achieves productivity improvements of at least 10%. The digital transformation is preceded by improving conditions to realise shipbuilding projects by removing or reducing losses from the process and introducing selected Lean tools: the savings achieved in this way include those of energy, which, with the assumed use of renewable energy sources and applying circular economy principles, defines the process as green.

## Aims

This paper aims to define a model of a competitive and profitable shipyard with motivating working conditions and the delivered value to the client's high satisfaction, i.e., - Shipyard 4.0, analysing also model's applicability in the conditions of prototype/small series construction, and those oriented to larger series of new builds. Finally, the estimated volume of investments in the subject twin transformation research model will be discussed and their expected return.

## Methods

The paper will apply the Research Methodology according to the following: (i) synthesis through analysis of prior knowledge, (ii) preliminary research - review and analysis of literature and prior research, (iii) prototype process modelling, (iv) analysis of existing processes and (v) model optimisation.

## Expected scientific contribution

The expected scientific contributions of the proposed research are (i) a developed model of realising shipbuilding projects which ensures the employment capacity of the shipyard and (ii) the developed structure of the shipbuilding system organisationally supporting "smart realisation" as a key business process for ensuring the shipyard's competitiveness.

## Keywords

Smart Ship, Industry 4.0, Lean, Shipyard 4.0

# Unsteady Vortex Wake of Thin Airfoil with Leading Edge Vortex Model

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## Introduction

Flight capabilities of insects has generated a growing interest in their flight research. Complexity of underlying aerodynamic phenomena make mathematical modelling of insect-type flapping flight a challenging task, limiting our ability to develop aerial vehicles that could exploit same flight principles.

## Methods

Very important phenomenon in insect-type flapping flight is the leading edge vortex (LEV). The approach presented here is capable of capturing aerodynamic effects, while also being numerically efficient. Aerodynamic effects are captured by modelling point vortices, which are being shed from both trailing and leading edges of the airfoil.

## Preliminary results

Developed time-stepping algorithm, based on potential flow theory, consist of vortex shedding, wake evolution and load calculation at each time step. New leading edge vortex is shed at the beginning of the time-step only if threshold angle of attack criteria is met, while trailing edge vortex is shed in every time-step. Wake vortices keep constant intensity and move freely based on the velocity induced by both bound and wake vortices. Aerodynamic load induced by vortices can be calculated based on the Kutta–Joukowski theorem at the end of each time-step and split into lift and drag force. Numerical experiment of a thin airfoil periodical motion modelled with two angles resulted in good overall forces results compared to experimentally validated quasi-steady aerodynamic model.

## Discussion

It is important to note that the results for aerodynamic forces should mainly be compared based on overall forces and not on the evolution over flapping period.

## Keywords

unsteady flow, leading edge vortex, free wake

# Model Uncertainty of Closed-Form Expressions for Wave-Induced Ship Motions

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## Introduction

Practical seakeeping methods are based on the potential theory and include strip methods and 3D panel methods. The transfer functions of wave-induced motions and loads can also be quickly estimated by semi-analytical closed-form expressions (CFEs). As the accuracy of the CFEs has not been studied yet, vertical ship motions (heave and pitch) obtained by CFEs are systematically compared to the model-scale experiments, enabling the definition of the model uncertainty of the method.

A typical example of the possible practical applicability of CFEs is in the risk-based ship decision support system (DSS) for heavy weather maneuvering. For such a system, because of the time constraint, rapid seakeeping calculations are necessary.

## Methods

The method consists of a comparison of the transfer functions obtained by CFEs to those obtained by the model-scale experiments for 10 ships of different types and quantification of the Frequency Independent Model Error (FIME), which is used as an uncertainty measure. For different heading angles, ship speeds, and block coefficients, FIME is then approximated by the multivariate linear regression equation. Such an approach enables the improvement of the original CFEs. In the probabilistic approach, FIME is considered as a Gaussian random variate, with the bias calculated by the regression equation, and standard deviation calculated from the dispersion of FIME around the regression line.

## Preliminary results

Preliminary results include calculated intercept and regression coefficients using block coefficient, Froude number, and heading angle as the variables. When the results of the regression analysis are compared to the initial FIME values, it appears that regression analysis provides a perfect best estimate of the FIME. However, significant dispersions of original FIME values around regression results are found, which is an indicator of the uncertainty. Expressed in terms of standard deviation $\sigma$, the proposed model for heave and pitch results in $\sigma$=0.28 and $\sigma$=0.20 respectively.

## Discussion

It is expected that multiplying transfer functions by FIME will improve the average agreement of CFEs with seakeeping experiments. Such an approach is simple to implement in a wide range of practical applications.

This research will be continued in three directions. Firstly, a database will be enriched with more ship models, thus improving the reliability of the regression equations.

Secondly, the analysis will be employed for the transfer functions of vertical wave bending moment at midship, which is also provided as CFE.

Finally, the analysis will be extended to the strip theory and the 3D panel method, as those results are also available for most of the studied ships.

## Acknowledgments

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## Keywords

Seakeeping, Closed-form expressions, Frequency independent model error

# Use of Natural Zeolite-Based Adsorbents for Organic Micropollutants Removal from Water Media

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## Introduction

Nowadays, the emerging contaminants, such as organic micropollutants (OMPs), cause serious environmental problems, affecting primarily the aquatic organisms, but the human health as well. Since OMPs cannot be efficiently remove from wastewater by conventional wastewater treatment processes, it is of great importance to investigate and develop an alternative technology. Regarding this, adsorption process is found to be an acceptable one, since it is simple, environmentally friendly, and cost-effective method with a wide range of available adsorbent materials. Among different adsorbents, natural zeolites showed to be perspective due to their availability, non-toxic nature, and economic acceptability. Clinoptilolite (CLI) is the most abundant natural zeolite which is mostly studied for the removal of inorganic pollutants from water. With high thermal stability and unique physico-chemical properties, CLI can be easily modified without disturbing its lattice. Thus, CLI adsorption capacity for different types of pollutants, such as OMPs can be increased.

## Methods

The antibiotic ciprofloxacin (CIP) will be used as model compounds. Clinoptilolite-rich zeolitic tuff (Z) obtained from the Serbian deposit Slanci will be used in the experiments. The conventional co-precipitation method and microwave-assisted method will be used for magnetite-CLI composite synthesis. Magnetite should enable easier separation of adsorbent from water media after adsorption. Modified CLI-based adsorbents will be characterized in detail with different techniques (XRD, TEM, BET, FTIR, zeta potential, VSM etc.). The adsorption tests will be performed by a batch method. The adsorption capacity of CLI and CLI-based adsorbents toward CIP will be studied for different initial CIP concentration, temperature and pH.

## Preliminary results and discussion

The XRD pattern of Z clearly showed that CLI is the main mineral phase in the Z. Presence of quartz is evident from characteristic diffraction at $2\theta = 26.6°$ whereas feldspar displays diffraction at $2\theta = 27.1°$. Elemental analysis of CLI showed that the Si/Al molar ratio is 5.03 that is common value for natural clinoptilolite. The specific surface area (SBET) was 23.57 m2 g–1 that is in accordance with reported values for SBET (usually in the range 15-40 m2 g–1), and it significantly increased with modification with magnetite. ZP measurements showed that CLI and MAG-CLI surface is negatively charged in the whole range of pH values. According to the obtained experimental data from adsorption study, adsorption capacity of CLI and MAG-CLI increase with the initial CIP concentration increases, but no significant cahnges were observed with temperature increases. Among the two-parameter models the Langmuir model gave the best results.

Taking into account assumptions of the Langmuir model [9], it could be concluded that one active site at the CLI surface is occupied by only one CIP molecule. Application of the two reaction-based kinetic models on the experimental data for the adsorption of CIP showed that satisfactory fits were obtained only by the pseudo-second-order kinetic model.

## Acknowledgments

The research is supported by EU Horizon 2020, Nowelties project MSCA-ITN-2018 - innovative training network (Joint PhD Laboratory for New Materials and Inventive Water Treatment Technologies. Harnessing resources effectively through innovation).

## Keywords

clinoptilolite, ciprofloxacin removal, adsorption, water treatment

# Numerical Phase-Field Modelling of Fatigue

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## Introduction

Fatigue is one of the most common modes of failure. Therefore, it is one of the major engineering design constraints and limitations. Assessment of fracture and fatigue in engineering problems is traditionally done by suitable engineering methods. However, the application of those methods is usually limited to a narrow range of relatively simple cases. With an increase in complexity of structure, the necessity for robust, versatile and universally applicable methods increases. Various methods have been developed to satisfy such necessity, including extended finite element method, cohesive zone models, nonlocal damage methods, etc. The method that gained the most attention last decade is the phase-field method. Foundations for this method are the variational description of fracture and diffusive description of the crack using a scalar field called phase-field. Due to the variational description of fracture, the method is capable of reassembling Griffith's theory of brittle fracture. Also, since an approximative description of the crack using a scalar field is used, there is no necessity for tracking of crack's geometry. The method automatically captures complex cracking phenomena, such as crack initiation, propagation, merging, branching, etc. In addition, the original brittle fracture formulation is extendable to various phenomena, including ductile fracture, dynamic fracture, fracture of shells, finite-strain fracture and is recently extended to fatigue. Developed fatigue methods are mostly based on the concept of degradation of fracture toughness. Those methods are shown to be able to naturally reproduce some basic fatigue phenomena, such as Paris' curves and Wohler's curves. However, as only basic fatigue features are reproduced so far, there is still a lot of potential for the development of fatigue methods based on phase-field.

## Aims

The aim of this research is to develop a new fatigue method based on the phase-field method that is capable to reproduce basic fatigue features accurately. Those features would include both crack initiation and propagation laws under arbitrary complex loading conditions. Research is focused on the modelling of high-cyclic fatigue. In addition, it is aimed to develop a numerically efficient procedure that will incorporate an efficient solver, cycle skipping procedure and adaptive remeshing algorithm.

## Methods

Developed numerical models and procedures will be implemented as an extension to already developed MATLAB/Fortran finite element code. The solver procedure will be based on a staggered approach with convergence control. To speed up fatigue calculations, the cycle-skipping procedure will be utilized. Anisotropic adaptive remeshing procedure will be developed and utilized to minimize mesh induced computational costs.

## Expected scientific contribution

The main contribution of this work will be a novel fatigue method based on the phase-field method for fracture. The method will reproduce various fatigue phenomena. The developed numerical procedure will guarantee numerical efficiency. Adoption of this method would lead to an increase in the safety of dynamically loaded structures.

## Keywords

phase-field method, fatigue, crack growth, crack initiation, numerical efficiency

# Corrosion Properties of 6xxx Aluminium Alloy in Marine Environment Under the Flow Condition

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## Introduction

The 6xxx series aluminium alloys are extensively used in many different types of industries and constructions like bridges, marine facilities, ships, trains, automobiles, etc. Reason for that is their good mechanical properties (i.e. high strength to weight ratio), excellent formability and weldability, reasonable price and generally good corrosion resistance when not exposed to aggressive halide ions. It is well known that many of mechanical properties can be improved by alloying of pure aluminium but alloying elements, irrespectively, have negative impact on protective oxide layer and aluminium alloys are prone to localized types of corrosion when exposed to halide ions present in marine environment. To be able to predict severity of corrosion and to prevent it is necessary to perform laboratory testing and simulate outdoor environment as well as to link greatest influential parameters such are salinity, temperature and fluid flow. The aim of this work is to investigate the corrosion behaviour of AA6060 under the laminar flow regime as well as effect of temperature elevation on it.

## Methods

Research will be conducted in simulated laboratory conditions on aluminium alloys AA6060 that have application in marine environment. Laboratory tests will include different DC and AC electrochemical methods such as monitoring of open circuit potential, linear polarisation, potentiodynamic polarization, cyclic polarisation and electrochemical impedance spectroscopy followed by metallographic examination of corroded samples using metallographic microscope. All experiments will be performed in flow corrosion cell and flow system created for the purpose of this research. The system was composed of: two tanks, one for cooling and the other for heating purpose of the electrolyte, flowmeter, pump, thermostat and a flow cell connected with a tank filled with seawater/brackish water.

## Preliminary results

Laboratory testing of AA6060 in seawater/brackish water mainly includes various electrochemical tests under stagnant condition. In marine applications one specific point is test solution. Mainly all reported laboratory research were conducted using NaCl solution or artificial prepared seawater. Preliminary tests on AA6060 shows significant difference in corrosion behaviour while using freshly sampled seawater compared to artificial seawater in stagnant as well as under the flow condition.

## Discussion

Corrosion of aluminium alloys in seawater is very complex and demands holistic approach in order to be able to understand why and when some localized type of corrosion will occur. All parameters that can affect corrosion such as salinity, temperature, seawater flow rate and alloy microstructure need to be monitored and linked. For some preliminary screening and some comparison purposes, straight NaCl solutions are good enough but, in order to get results as realistic as possible, tests in natural and freshly sampled brackish and seawater under the flow condition are highly desirable.

## Keywords

aluminium alloys, seawater, corrosion

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