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Summer
2022

The Simulation Based Engineering & Sciences Magazine

SPOTLIGHT
Back to Nature

- Editor's Note

Welcome to the second release of the new look of our magazine Futurities. We would like to thank you for your enthusiastic feedback on our new look, as well as for all the compliments about the new focus and organization! We are pleased that the new thrust of the magazine has been so well received and we warmly invite you to write to us with more feedback, observations, suggestions, and requests for future editions.

Just to remind you and help you to find your way around our new sections, the content is organized into several focused areas including the *Spotlight*, that focuses on an aspect of simulation, presenting leading edge approaches, techniques and technology developments; *Technology Transfer*, that covers technical or mathematical analyses of different engineering problems, as well as academic papers; *Know-how*, that presents industrial use cases describing the engineering challenge faced, the approach taken, and methodology used in resolving it; *Research & Innovation*, that offers updates and insights from research projects, as well as providing a showcase for interesting innovative applications; *Product Peeks*, that provides an overview of some of the latest software products on the market and there are more to follow in the editions to come.

This issue's *Spotlight*, which we named *Back to Nature*, investigates greener applications of technology and innovations to achieve greater sustainability. ***We look at engineering design inspired by nature and that attempts to capture and leverage natural characteristics in the engineering world, in terms of shapes, structures and properties.*** Of particular interest in this regard are the articles about a European project on composite materials using recycled tyres, and a discussion of bio-inspired lattice structures.

In the *Technology Transfer* section we look at foundry digitalization, while our Know-how section covers a comparison of the Johnson Cook and Barlat material models for 316L stainless steel and a simulation of the blast furnace process using Rocky-DEM's API. Also in this quarter's edition, we have an interview with Marco Baroero vice president of Engineering Systems and Configuration Management at of Leonardo Aircraft division, and news from the world of *Research & Innovation* including an indepth article on the FORSAL project to increase the ergonomic comfort of workers in the grinding and finishing process of the metal working sector. Our *Product Peeks* in this edition presents Ansys Chemkin.

In spite of increasing inflation and the concerning indicators and events affecting the immediate future of manufacturing and production, the market remains in growth (for now), but the challenges of doing more with less are set to become tougher and ever more present. These are challenges where problem solvers like engineers come into their own. We will be there to accompany you in facing them head on. In the meantime, I wish you an interesting read and a good summer.

Stefano Odorizzi
Editor in chief

> "The challenges of doing more with less are set to become tougher and ever more present.
>
> These are challenges where problem solvers like engineers come into their own.

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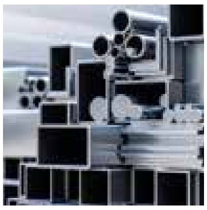

TECHNOLOGY TRANSFER

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NEWS & TRENDS

SPOTLIGHT

SPOTLIGHT

Back to nature

Greener innovations, bio-inspired ideas and recycling trends

Climate change and our global response, or its insufficiency, was brought under sharp focus at the Cop26 summit in Glasgow, Scotland in November last year. Recent dramatic climate events around the world are keeping attention high. Increasing consumer pressure on businesses to help solve the problems and become better custodians of the planet in their use, reuse and recycling of natural resources and raw materials, as well as policy decisions, particularly in the European Union, in support of the transition to green or sustainable energy and the circular economy, are all driving interest in finding innovative solutions to help business and industry become more sustainable.

This renewed interest in the natural world and being more responsible for it is the thrust of this edition's **Spotlight** which concerns various aspects of this growing trend in going Back to Nature. What are some of the greener applications of technology? Which are some of the emerging innovations to achieve greater sustainability? How is engineering design being inspired by nature? How can engineers capture and leverage natural characteristics in terms of shapes, structures and properties, and apply these to the industrial and manufacturing world?

We have placed the **Spotlight** on a variety of areas. One article concerns a European project involving the University of Trento that is using recycled tyres to create composite materials; another is a discussion of bio-inspired lattice structures and touches on how these are being used for heat exchange in industrial contexts.

Being good custodians of our natural environment also involves cleaning up the messes that we've made in the past. Therefore, another article discusses the optimization of a marine litter hunter to increase its efficiency in tracking and collecting litter at sea.

Finally, no current discussion about sustainability efforts would be complete without touching on electric vehicles (EVs) which are the major answer at present to creating cleaner transport. There are two articles in the **Spotlight** in this regard: the first is from TotalEnergies and proposes a simulation method for comparing cooling methods for EVs and the second concerns the design optimization for electric powertrain units.

Taking inspiration from nature

Applying the features of bio-inspired lattice structures to engineering challenges

by Andreas Vlahinos
CTO at AES and EnginSoft USA

Nature, an incredible and highly experienced designer, makes extensive use of lattice structures: repeating, three-dimensional open-celled structures composed of webs, trusses or surfaces that are topologically ordered. Visually stunning manifestations of lightweight biological nanostructured materials can be seen in insects, birds, and plants. One example of the exceptional achievements of evolutionary engineering is the formation of the biphotonic gyroid material in butterfly wings.

In industry, lattice structures are remarkably effective for creating lightweight structural panels and energy absorption devices, for thermal insulation, acoustic and vibration control, high-performance heat exchangers, ballistic protection, and for porous implants with osseointegration.

We can learn about energy absorption designs by closely observing ram horns. Fig. 1 shows the geometry of a ram horn with its rope-like orientation along the growth direction which coils up into hollow, elliptically shaped tubules.

A mantis shrimp attacks by striking the lower edge of its dull, calcified claw with such speed that it can pulverize a snail shell, break off pieces of a rock wall, or even break a finger. Its claw reaches speeds of 274 kph (170 mph) and accelerations of up to 10,000 g. This Dactyl club filters ω shear waves to resist damage. Fig. 2 shows the mantis shrimp, a section of its club claw, and a CAD representation of the helicoidal organization of the fibres.

Nature also has many examples of segmented natural armour. Fig. 3(a) shows juxtaposed fish scales (scutes) connected by fibres. Fig. 3(b) shows the juxtaposed plates of an armadillo's osteoderm connected by keratin, while Fig. 3(c) shows crocodile scales overlapping with imbrication.

Taxonomy of lattice structures

The taxonomy of lattice structures in nature is based on their dimensionality: a dragonfly's wings exhibit on-surface Voronoi stochastic lattices while honeycombs have 2½ D lattices and corals, and glass sponges have 3D beam lattices (see table 1).

Minimal surfaces minimize the total surface area subject to some boundary or volume constraint. Soap bubbles, catenoidal soap film surfaces, and gyroids on butterfly wings are some examples found in nature. In the early 1970s, mathematicians discovered the mathematical expressions of minimal surfaces however these surfaces could not be used in product design because they could neither be generated

Fig. 1. Lattice structure in ram horns.

Fig. 2. Mantis Shrimp and the lattice structure of its club claw.

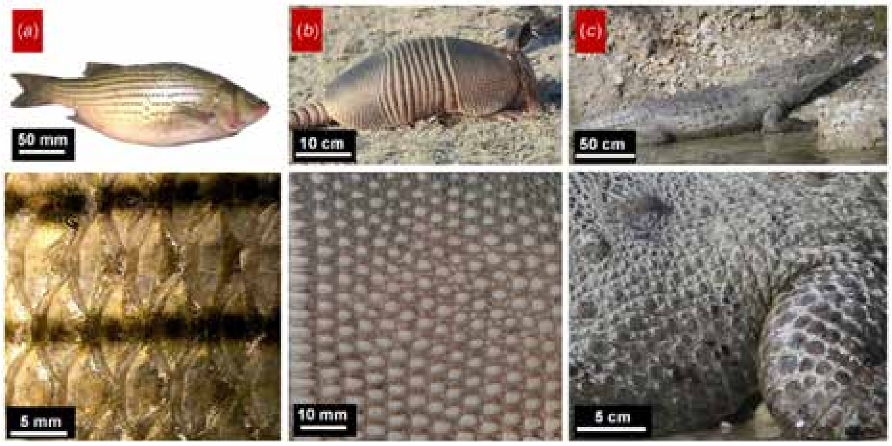


Fig. 3. Examples of segmented natural armour.

in CAD nor produced. Recent advances in CAD systems and additive manufacturing however allow designers to design and manufacture these amazing designs.

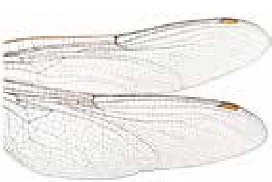
Minimal surfaces such a gyroids, Schwarz, lidinoid, diamond, splitP, and Neovius have remarkable strength, heat transfer, and manufacturability properties. Table 2 shows the taxonomy of lattice structures in modern CAD systems.

When a volume is filled with a minimal surface area, it is divided into separate continuous volumes that intermingle. This property makes minimal surface geometries ideal for heat exchangers.

Furthermore, at any point the angle of these surfaces measured with respect to the normal of the print tray is less than the 45 degrees and thus these geometries can be 3D printed without supports.

Using generative design and lattice structures for high performance products

Generative design is the automatic process of creating optimal feasible designs from a set of performance requirements and design rules. Using manufacturing constraints, the generated organic designs can be printed using additive manufacturing. Generative design is a fundamentally disruptive paradigm shift: for the last 3 000 years, people conceived a design and then built physical or virtual



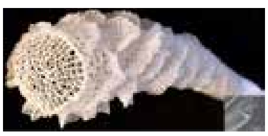
Dragonfly Wings

On Surface Lattice
PERIODIC
- Triangle, Square, Hexagon,Octagon, etc.

STOCHASTIC
- Voronoi Tessellation
- Delaunay Triangulation
- Uniform
- Spatially Varied

Honeycomb

2 ½ D Lattice
PERIODIC
- Cartesian Trimmed:Triangle, Square, Hexagon,Octagon, etc.
- Cartesian Conformal Edge
- Polar
- Herringbone



Venus flower basket glass sponges Amorphous biological silica with concentric layers

3D Beam Lattice
PERIODIC
- Cartesian, Triangle, Square, Octagon, etc.
- Polar

STOCHASTIC
- Voronoi Tessellation
- Delaunay Triangulation
- Uniform
- Spatially Varied

Butterfly gyroid

3D Surface Lattice TPMS
PERIODIC
- Uniform thickness
- Variable thickness
- Variable cell size
- Spatially Varied

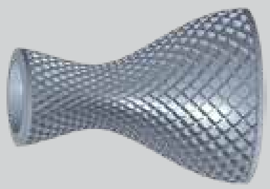
Examples: Gyroids, Diamonds,Octets, Lidinoid, Schwarz D, Schwarz P, Neovius.

Table 1: Taxonomy of lattice structures in nature

Surface Delaunay Triangulation

On Surface Lattice
PERIODIC
- Triangle, Square, Hexagon,Octagon, etc.

STOCHASTIC
- Voronoi Tessellation
- Delaunay Triangulation
- Uniform
- Spatially Varied



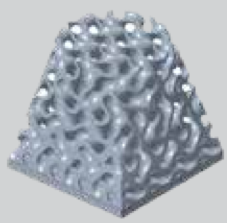
Rocket Nozzle with Ribs

2 ½ D Lattice
PERIODIC
- Cartesian Trimmed:Triangle, Square, Hexagon,Octagon, etc.
- Cartesian Conformal Edge
- Polar
- Herringbone

High Performance Heat Exchanger

3D Beam Lattice
PERIODIC
- Cartesian, Triangle, Square, Octagon, etc.
- Polar

STOCHASTIC
- Voronoi Tessellation
- Delaunay Triangulation
- Uniform
- Spatially Varied



TPMS High Performance Heat Exchanger

3D Surface Lattice TPMS
PERIODIC
- Uniform thickness
- Variable thickness
- Variable cell size
- Spatially Varied

Examples: Gyroids, Diamonds,Octets, Lidinoid, Schwarz D, Schwarz P, Neovius.

Table 2: Taxonomy of lattice structures in modern CAD systems.

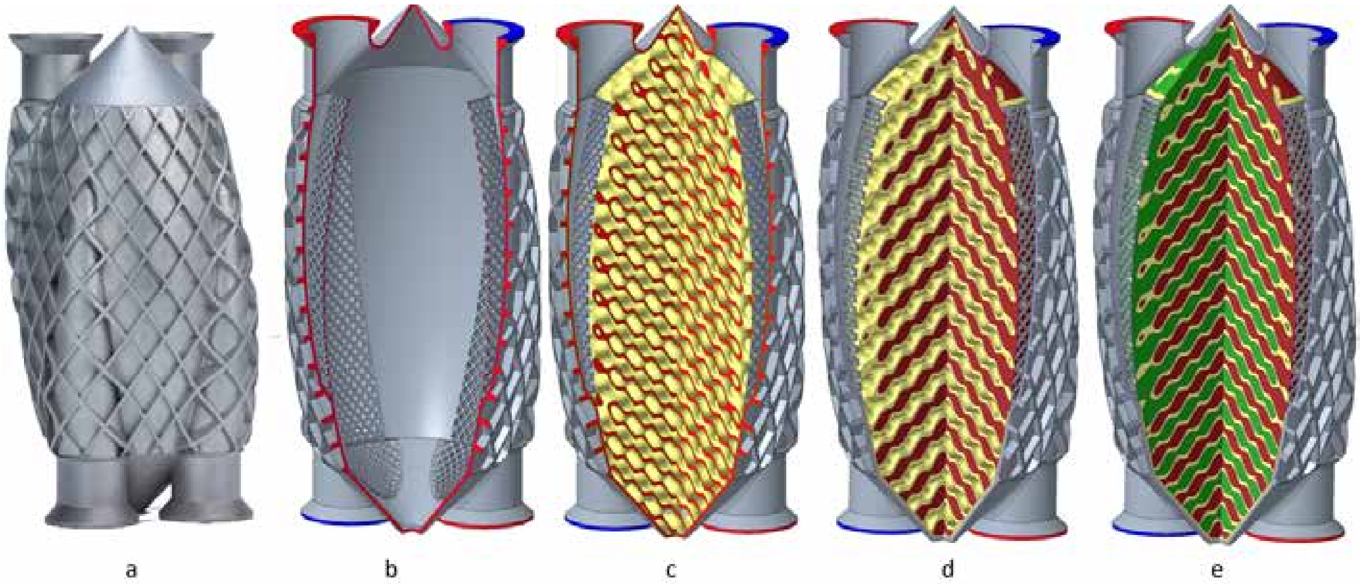


Fig. 4. High-performance avionic heat exchanger. (a) The printed heat exchanger on an EOS M290 printer; (b) the model of the exterior shell structure; (c) with the interior gyroid lattice; (d) with the cold fluid domain; (e) with the hot fluid domain.

prototypes to evaluate the design's performance against the requirements. Today, generative design enables designs to be created that even experienced and skilled practitioners could never have imagined. There is no prefabricated geometry to use as a starting point and the geometric complexity of producing these designs can be addressed using additive manufacturing.

As the additive manufacturing industry continues to grow adding new machines, faster processes, and a wide selection of materials, design practitioners can now unleash its full potential by combining generative design and lattice structures.

Generative design uses topology optimization but goes far beyond traditional topology optimization. In the mid-1980s the first structural topology optimization code, GENESIS, was introduced.

Since then, several other topology optimization codes (i.e. Optistruct, TOSCA, Ansys Topology, etc.) have been introduced. In the last three decades, the capabilities of these codes have been enhanced with:

- new elements – shells, beams, contacts, etc.
- new physics – thermal, fluid etc.
- manufacturing constraints – extrusion, stamping, etc.
- user optimization criteria – mass minimization, frequency maximization, stress or displacement constraints.

Although these capabilities were innovative and practical, topology optimization codes were mainly used to create conceptual designs in advanced automotive and aerospace groups. They were not widely used in product development for the following reasons:

- The codes are very sophisticated limiting their use to the specialist only.
- The interoperability of their results was limited to output in a Standard Triangle Language (STL) that required further substantial manual work to generate a CAD body. This was a serious limitation since it broke the automation of design and, if performance requirements changed, the manual reconstruction of the CAD had to be repeated.
- The designs generated were organic but exceedingly difficult or impossible to manufacture using traditional manufacturing techniques.
- The material was usually isotropic, and the structure was solid, without any cavities or reticulated structures.

In recent years a new generation of tools (Autodesk's Fusion 360, nTopology's nTop Platform, PTC's Generative Design, Ansys' Discovery Live, and many others) have extended the traditional topology optimization and lattice generation tools with may new capabilities:

- Inputs to topology optimization are discrete numbers (i.e. volume fraction, margin of safety, etc.). In generative design, inputs are variables with a given range. A DOE (design of experiments) can be performed on the input variables. Therefore, the output is not a single solution but many feasible solutions corresponding to each experiment. The user can use Pareto diagrams or parallel coordinate plots to filter designs, perform trade-off studies, and select an optimal design.
- The STL output can be automatically wrapped with B-Rep surfaces to generate a CAD model. This is a lightweight model that can be modified to include product manufacturing information (PMI), semantic geometric dimensioning and tolerancing (GD&T), and inspection information.
- The generative design process can use the homogenized material properties of the assumed lattice structure and establish the optimized topology. The stress field of this geometry can be captured. This topology can be filled with

a uniform (i.e. Diamond) or stochastic (i.e. Voronoi) lattice structure. The density and size of the struts can be guided by the three-dimensional stress field of the optimized topology.
- The challenge is how to select the best design from several hundred feasible designs. AI can use deep learning technology to combine art and business with design. Deep learning shape detection can evaluate the artistic degree of a design. Neural networks can be trained using the large databases of existing components to calculate the cost, lifetime, and performance of designs.
- Generative design tools can calculate the shape, geometry, topology, size, and combination of conventional materials. This calculation gives metamaterials their tunable properties. Metamaterials or architected materials are structural configurations of repeating patterns that have material properties not found in natural materials.

Heat exchangers

As mentioned previously, minimal surfaces minimize the total surface area subject to some boundary or volume constraint, such as can be seen in soap bubbles, catenoidal soap-film surfaces and gyroids on butterfly wings. The recent advances in CAD systems and the developments in additive manufacturing now enable designers to design and manufacture structures where the volume is filled with a minimal surface area whose separate continuous volumes intermingle endowing them with properties that make them idea for heat exchangers.

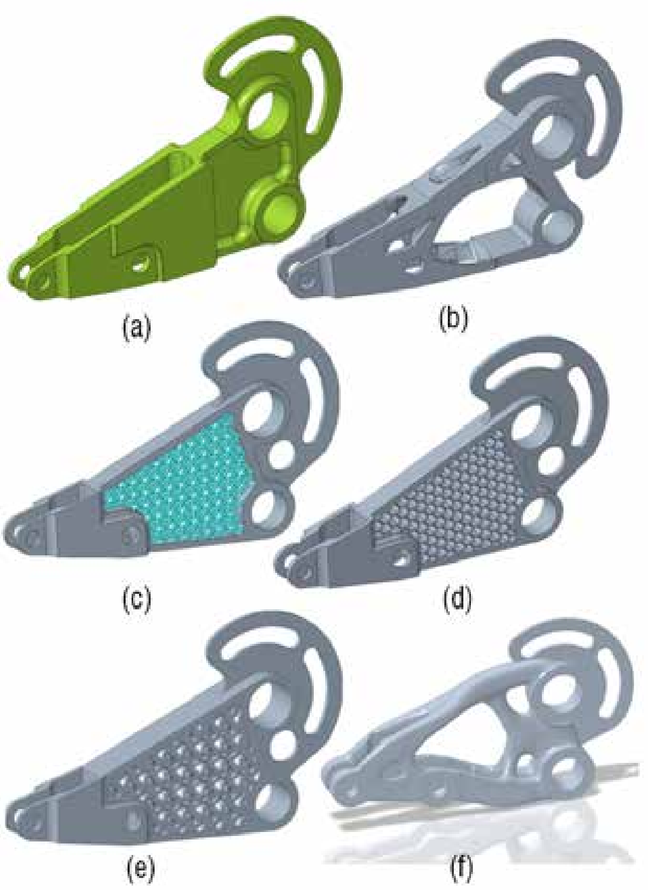


Fig. 5. Multiple feasible generative design solutions for a bell crank. (a) Basic design; (b) results of a traditional topology optimization; (c) beam lattice option; (d) honeycomb filling; (e) gyroid lattice design; (f) high-performance organic generative design solution.

Bell cranks

Bell cranks are a good example of weight reduction using generative design, lattice structures and additive manufacturing. Fig. 5. shows the evolution in the design of a bell crank to achieve a high performance, organic, generative design solution.

The specific combination of generative design tools and lattice structures is producing a further tsunami of change in the design process. There are still a lot of challenges in the process in the areas of interoperability, the simulation of lattice structures, and of manufacturing process simulation. Generative design tools, however, can leverage collaboration between humans and AI (artificial intelligence) to generate high-performance designs that were inconceivable in the past.

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Introducing TRIBO

A new code for designing the tribological properties of surfaces from University of Trento

by S. Kamal Jalali[1] and Nicola M. Pugno[1,2]

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2. School of Engineering and Materials Science, Queen Mary University of London

In recent years, an emerging area in the field of Tribology with a greater focus on the environment has attracted the attention of researchers worldwide. It is known as 'green tribology' and is a way of making tribology environmentally friendly and energy-saving. It deals with interacting surfaces in relative motion and takes energy/environmental sustainability into consideration. At the same time, modern surface modification techniques are developing with the ability to adjust the tribological properties of contact surfaces, which opens up a new need for optimal tribological designs.

This article briefly introduces the new computer code, TRIBO that was developed in our research group to predict the tribological properties of contact surfaces and has the capability of considering a wide variety of surface modifications including complex surface patterning and heterogeneity of composites with a combination of statistically based adhesion and friction properties.

It is based on the lattice-spring method which has been successfully applied for many years in our research group for simulating various practical multi-scale studies such as the friction tuning of laser micro-textured surfaces, the tribology of hierarchical composites, the friction tuning of surfaces with functionally graded changes in properties, and tribology studies on 2D nano-material coatings at the nanoscale. With its flexible user-friendly interface, TRIBO is well-suited for use in industrial problems for tuning and optimizing the performance of sliding surfaces. This makes it thus the first program developed specifically for solving industrial tribological problems.

Introduction

Macroscopic tribological properties are the result of various types of complex multiscale interactions between sliding surfaces. There is considerable scope for fine-tuning them using treatments that can purposefully modify the surface structure, such as applying artificial patterning, and using heterogeneous composite surfaces and biologically inspired hierarchical patterns.

This section presents a brief overview of our recent studies in this field using lattice-based simulations and experimental validations. A 2D lattice-based model was proposed in [1, 2] to evaluate the effect of surface patterning using arrays of cavities and pillars on the frictional properties of elastic sliding surfaces.

An experimental and numerical investigation of the effect of surface patterning on the friction properties of polymer surfaces considering the effect of sliding velocity was conducted, and good agreement between the experiment and numerical simulation was observed [3].

A prediction of the frictional coefficients of composite hierarchical surfaces was performed in [4] and it was shown that a significant reduction in static friction can be achieved by introducing hierarchical arrangements with varying local roughness values, or by introducing controlled variations in material stiffness.

Using numerical simulations, [5] investigated how the properties of graded material influence macroscopic friction behaviour, in particular, static friction values and the transition from static to dynamic friction, and the results suggested that the properties of the graded material can reduce static friction, opening up possibilities for the design of bioinspired surface materials with tailored tribological properties. Following the model presented in [6], the effect of hierarchical surface patterning on the static and dynamic friction coefficients of an elastic material was studied using lattice-based numerical simulations, and several possible mechanisms were identified to explain how hierarchical structures may significantly alter the friction coefficients of materials, providing a means to achieve tunability [7].

As the contact of two surfaces in relative rotational motion occurs in many practical applications, from mechanical devices to human joints, more recently, the 2D lattice-based model has been extended to study the friction between surfaces in torsional contact [8]. How the model describes the behaviour of an elastic surface slowly rotating over a rigid substrate was studied, comparing the results with an analytical calculation based on energy conservation.

TRIBO Numerical Simulator

TRIBO is a home-grown code written as a MATLAB app. It is a general 3D lattice-based numerical simulator that predicts the tribological properties of contact surfaces by considering a wide variety of surface modifications including arbitrary complex surface patterning, heterogeneous composite surfaces, and graded mechanical and tribological properties with the option of combining adhesion and friction. It allows consideration of constant, ramp, and harmonic sliding velocity/force.

The main idea behind the TRIBO solver is to separate the sliders from the sliding blocks connected via a spring-damper

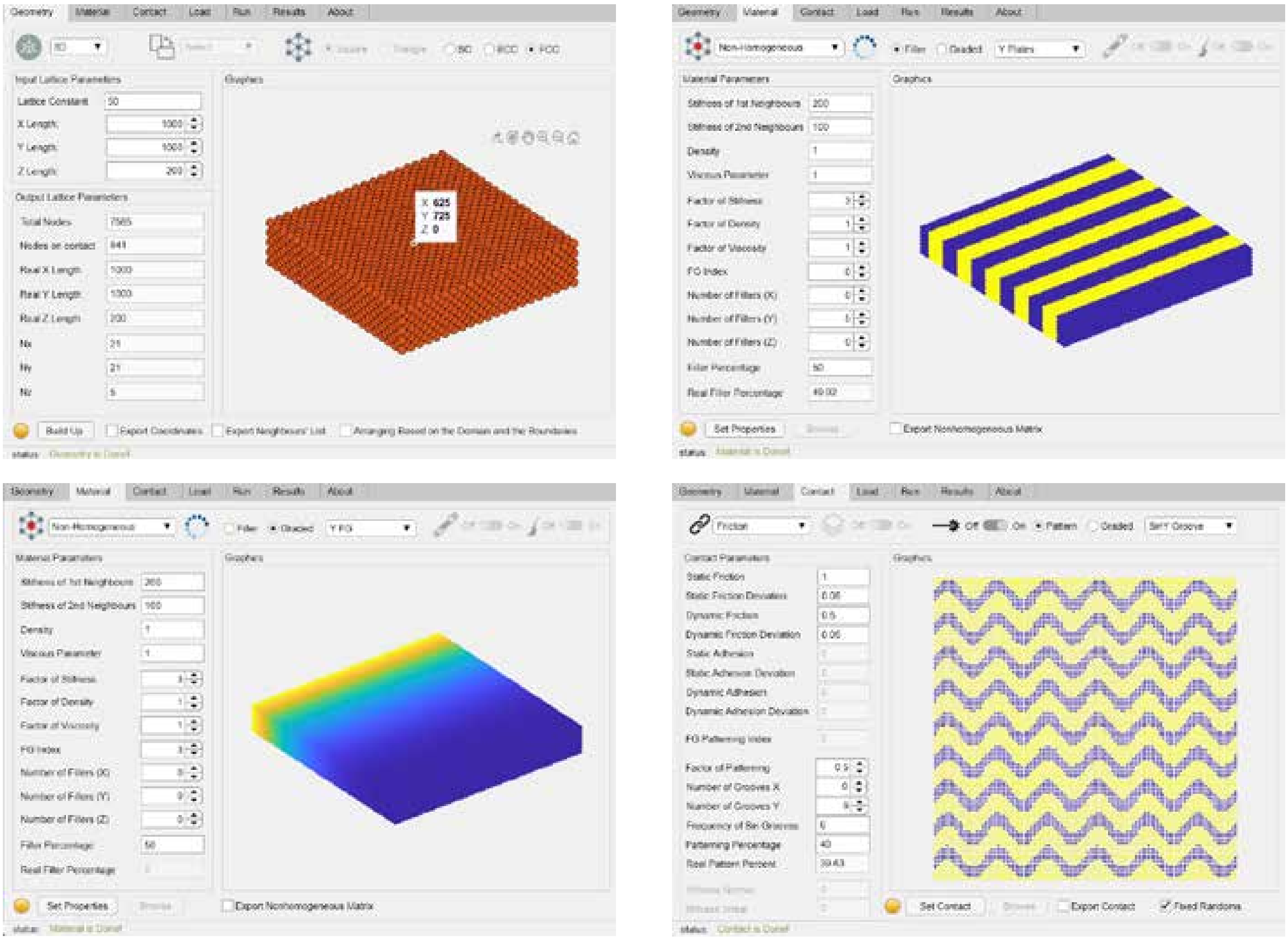

Fig. 1. Some samples of the TRIBO user interface for modelling homogeneous, composite, and functionally graded sliders with the option of defining complex surface modifications on the contact surface.

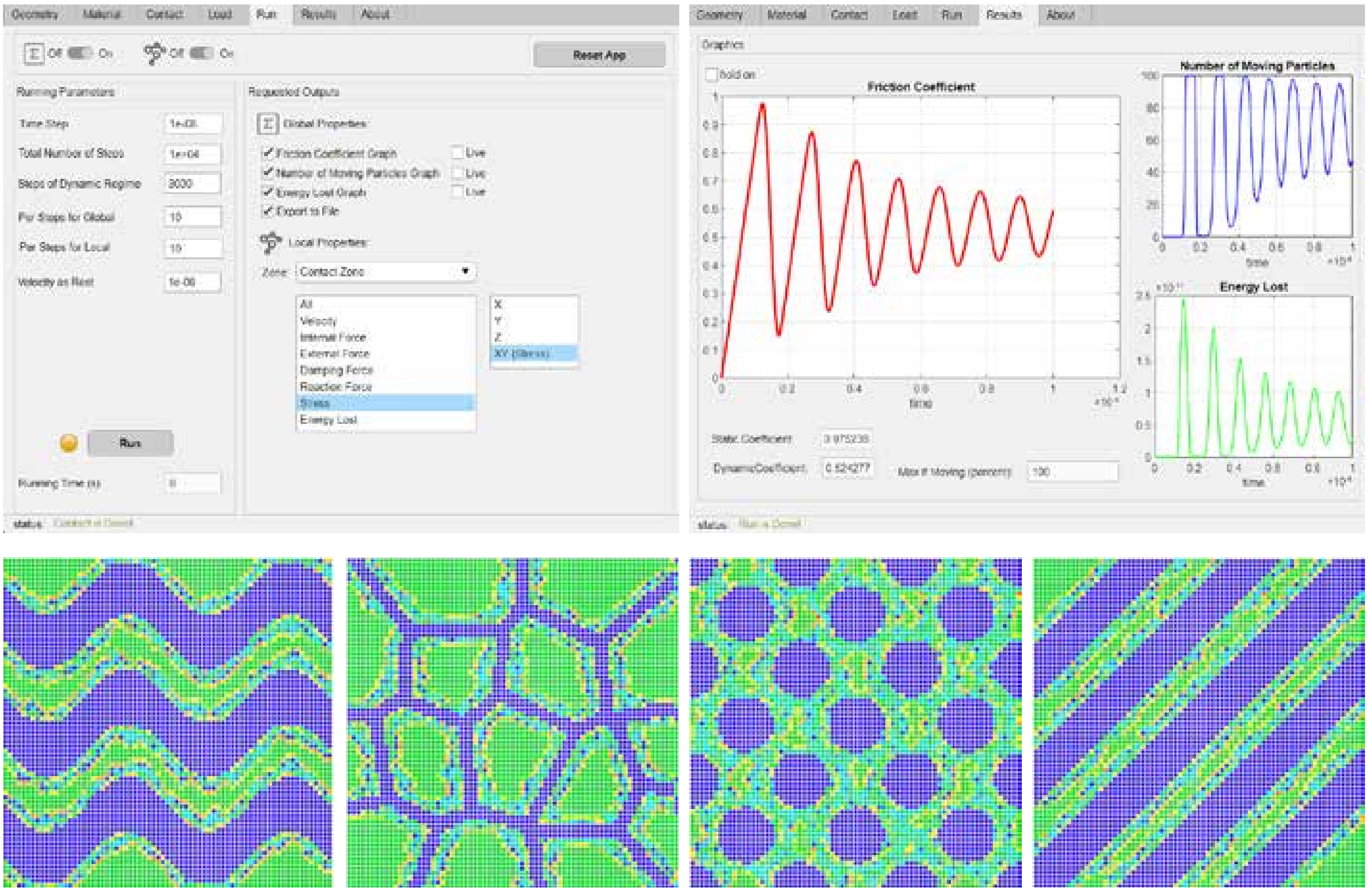

Fig. 2. Some global and local (per particle) TRIBO output samples.

network in which the spring and damper constants represent the mechanical properties of the material and the masses on the contact surfaces are also subject to the boundary reactions corresponding to the statistically distributed surface properties for each mass.

More details on the theoretical basis can be found in [1-8].
Fig. 1 presents examples of the TRIBO user interface for modelling sliders with a variety of material properties from composite to functional grade with the option of applying different surface modifications. Outputs are available for global properties such as macroscopic friction coefficients and lost frictional energy as well as for local properties (per particle), i.e. trajectories, velocities, forces, and stresses in the form of text data files compatible with well-known particle-based visualization software such as OVITO (see Fig. 2).

Conclusions

TRIBO is therefore the first program code developed specifically for solving industrial tribological problems and has already been implemented in the service of the industrial sector.

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About the Laboratory of Bioinspired, Bionic, Nano, Meta Materials & Mechanics

It is one of the world's first bioinspired nanomechanics laboratories, cutting across mechanical, structural and materials engineering, as well as physics, biology and medicine.
The laboratory designs (analytical and simulations tools), fabricates (3D printing) and characterizes (nanoindentation, nanotensile) materials and structures with superior mechanical characteristics (super-strong, super-tough, super-adhesive, self-cleaning, self-healing, frictionless, etc.), also incorporating nanomaterials such as graphene and nanotubes. The Lab also supports business for high-tech companies by developing ad hoc materials for specific needs.

Comparing cooling methods for e-motors

A simulation methodology developed by TotalEnergies

by Jonathan Raisin[1] and Michele Merelli[2]
1. TotalEnergies - 2. EnginSoft

Electrification of light and heavy-duty vehicles can help reduce global emissions by about 1 Gt CO_2-eq. The current automotive market shows a strong acceleration towards electric propulsion (plug-in hybrid and battery), with one million sales in both Europe and China and the global share of electric vehicles exceeding 10% of total sales. The rapid and technically demanding transition poses significant challenges: innovative propulsion systems must be designed quickly, considering complex fluid, electromagnetic and thermal aspects that cannot be easily decoupled or thoroughly analysed with physical prototypes.

As power density increases, standard e-motor cooling methods (based on external air or water-jackets) fail to provide the necessary heat removal performance. Because of all these issues, a direct oil cooling strategy is proposed to directly remove heat from the most critical areas of e-motors, such as the coils and rotor.
In addition, for compact and weight-efficient drive solutions, e-motors are increasingly coupled with transmissions in e-drives, forming a single gearbox, and the same oil used for lubrication is also used in the cooling of the e-motor circuit via pumping systems. Therefore, having a single simulation that can provide information on both e-motor cooling and gear lubrication can be very advantageous.

In this paper, we will present the methodology developed by TotalEnergies and EnginSoft to select, design and improve an e-motor by simulating and predicting electromagnetic losses, fluid flow behaviour and temperature distributions. After establishing the workflow, the main objective of the study is to compare the direct oil-jet strategy with the external water jacket cooling circuit.

This analysis will compare the two approaches by considering various combinations of flow rate and motor speed. In addition, we report on the influence of the oil's physical properties on cooling performance, showing how the established workflow can guide TotalEnergies in the selection and improvement of oil for better e-motor cooling and longer working life.

Mission TotalEnergies: from lubrication to cooling

The thermal properties of electric vehicle fluids are of paramount importance. For decades, the lubricant industry has sought to optimize friction and fuel economy, but today it focuses on improving the thermal properties of the fluids it offers, with thermal management replacing fuel economy as the new leitmotif. Although there are different and sometimes more compact cooling architectures, particularly for the electronic peripherals of the electronic engine, each of these assemblies is subject to different constraints that directly influence the type of fluid required for them. For example, some fluids must provide flawless lubrication, while others do not, but efficient cooling is always crucial and determines the formulation of the different fluids used.

The architecture of next-generation electric vehicles will require the development of a single type of fluid for their electric drive units (EDUs), combining high-performance lubrication of the transmission and efficient motor cooling.

First-generation electric motors were entirely air-cooled, but the low specific heat capacity of air in relation to its volume required a different approach. Thus, water cooling systems began to appear, but these were soon replaced by the use of dielectric cooling fluids, a much-needed step that was also confirmed by the simulation results reported.

Complete e-motor design and simulation: the advantages of a digital prototype

In collaboration with EnginSoft, TotalEnergies developed a simulation workflow to study the selection, design and improvement of e-motor cooling.

Thanks to the mesh-less nature of the CFD software for oil jet simulation and the Ansys integration between the different simulation tools, the complete simulation (considering geometry preparation and hardware time) took less than two weeks for the first model. Changing operating points or geometric characteristics only resulted in additional simulation time of two to five days.

The reported workflow for the complete e-motor design and analysis includes:

- The selection of electric motors for automotive applications (with Motor-CAD)
- An electromagnetic analysis (with Ansys Maxwell) fluid dynamic analysis (with Particleworks and Ansys CFX, for oil jet and water jacket cooling respectively)
- A thermal analysis (with Ansys CFX)

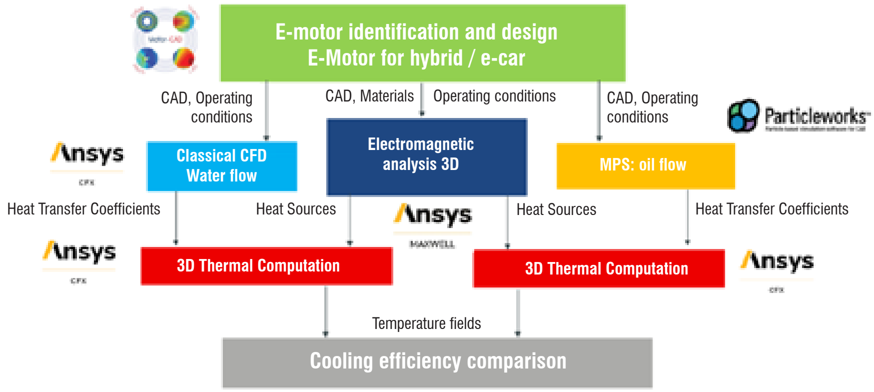


Fig. 1. Overview of the simulation workflow: e-motor identification (Motor-CAD), electromagnetic analysis (Ansys Maxwell), fluid dynamics (Ansys CFX and Particleworks) and thermal model (Ansys CFX). The arrows show the geometry / boundary conditions transferred between the software.

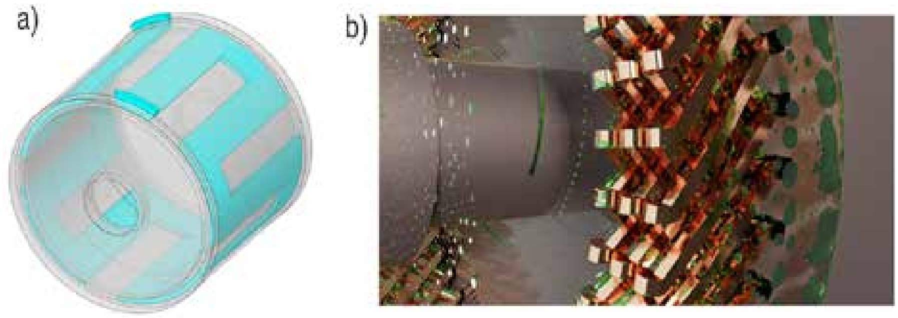


Fig. 2. a) Water jacket for indirect cooling (in blue); b) Oil jets from the rotor shaft and their accumulation on windings and casing (photorealistic rendering of simulation results)

Articulating the workflow, we first defined a realistic e-motor operating condition (selecting for output torque and rotor speed) and estimated the corresponding efficiency curves with Motor-CAD. Two e-motor operating conditions were identified at 6.000 rpm (representing a car travelling steadily at 70 km/h) and 10.000 rpm (representing temporary acceleration for overtaking). We then exported the e-motor geometry and material properties of the e-motor digital prototype for a 3D electromagnetic analysis in Maxwell. With this analysis, we calculated the electromagnetic losses and heat generation of the two operating points that we then fed to the CFX thermal model.

Direct (vs indirect) oil-jet cooling: the advantages of a mesh-less approach

We compared two cooling strategies for the e-motor: an indirect water jacket embedded in the stator, and direct oil jets hitting the coils and other critical areas (Fig. 2). Focusing on the simulation of direct oil cooling, we used Particleworks, a mesh-less CFD software based on Moving Particle Simulation (MPS) [1].

This method is suitable for the rapid analysis of free-surface flow phenomena such as jets and sprays. Due to its mesh-less nature, it is easy to manage complex geometries (such as windings) or rotating parts (such as the rotor) [2].

For these same reasons, Particleworks is also widely applied in the analysis of lubrication and cooling in transmissions and gearboxes [3], so using this software enables a complete analysis of both gearbox and e-motor systems.

When applied to e-motor analysis, Particleworks allows the following to be investigated (Fig. 3):

- **Flow split within the rotor.** Since part of the cooling circuit is integrated into the rotor shaft, it is important to investigate the flow split between the different branches at different operating speeds.
- **Windage effects.** Air and windage effects can be simulated in Particleworks with the same digital model, further speeding up and simplifying the simulation workflow.

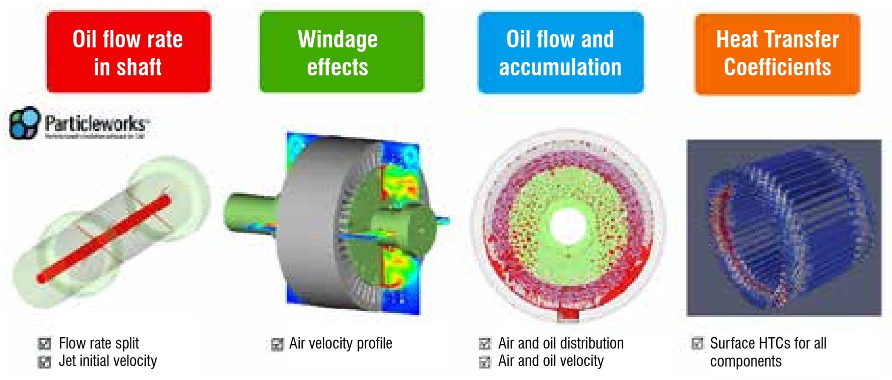


Fig. 3. Simulation steps and observables that can be investigated using Particleworks.

Generally, after the air has been modelled, the airfield is transferred to the oil jet simulation.

- **Oil jet impingement, oil accumulation and wetted surfaces.** The flow of oil jets – influenced by the imported airfield – and its accumulation inside the e-motor is modelled in this final simulation. Wetted surfaces and oil coverage can be also monitored and compared between different configurations.

After the amount of oil had stabilized in the e-motor, we used Particleworks to create maps of the average heat transfer coefficient (HTC) on the most important surfaces. We then transferred the maps to the Ansys thermal solver (Particleworks is also integrated with Ansys Workbench). We then performed a steady-state (6 000 rpm) or transient (10 000 rpm) thermal analysis on the e-motor, also integrating power losses and thermal loads due to the system's electromagnetism (from Ansys Maxwell). Once the steady-state thermal analysis was complete, we used the CFX model to predict the temperature distribution within each component of the e-motor. This methodology for predicting temperature in the e-motor was previously validated with Ricardo, using experimental data from thermocouples placed around the terminal windings [4].

Results

Comparison of direct and indirect cooling strategies

In order to maintain the same cooling capabilities, we normalized the flow rates for direct and indirect cooling accounting for the different physical properties of oil and water.

A cross-section of the e-motor coloured with the temperature profile is shown in Fig. 4 left for the direct oil cooling setup; right for the indirect water cooling configuration. Although the housing and stator are slightly cooler for the latter system, it is clearly seen that the rotor and winding regions reach higher temperatures in the water-based system. Particularly critical is the rotor, which houses the permanent magnets whose performance can be affected by temperature variations. Overall, the average temperature for direct cooling is 10 °C lower.

We tested several flow rate configurations to study the behaviour of the e-motor for the oil jet in the worst case and for indirect cooling in the best case scenarios (2 l/min vs 20 l/min). The average temperature (Fig. 5) of the windings for oil cooling is at least 14 °C lower. This

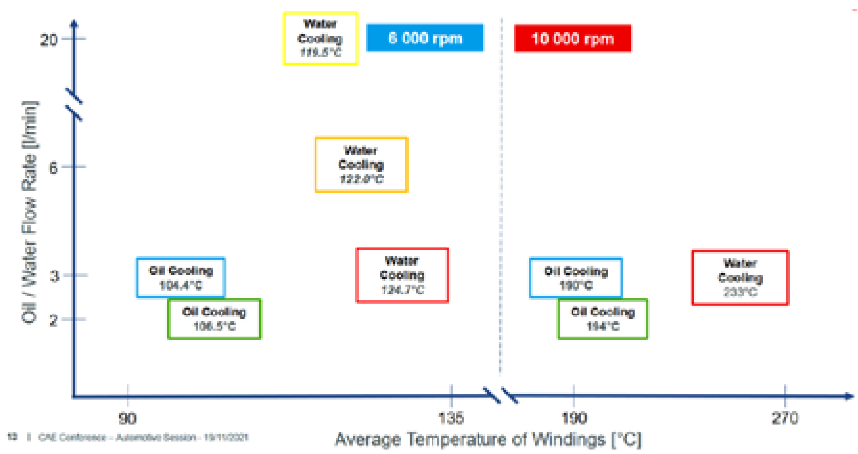
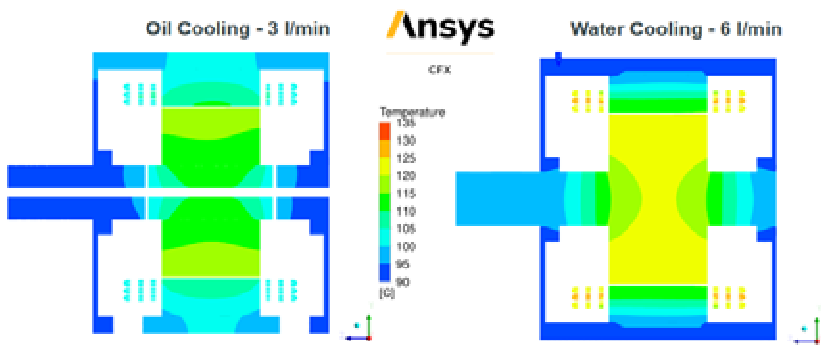


Fig. 5. Average temperature of windings for different flow rate / cooling strategies. Considering different flow rates and rotational speeds, oil cooling proved to be superior to the external water jacket strategy.



	Oil Cooling System 6000 rpm, 3 l/min		Water Cooling System 6000 rpm, 6 l/min	
	Ave. Temp. [°C]	Max. Temp. [°C]	Ave. Temp. [°C]	Max. Temp. [°C]
Housing	97.6	102	-4.3	-4.1
Stator	103.3	110.9	0.7	5.6
Resin	105.6	110.6	8.7	15.6
Windings	104.4	110.2	17.6	18.4
Rotor	115.7	125	7	5.8
Magnets	120.1	124.8	6.6	6
Shaft	98.7	113.6	6.5	7.6

Fig. 4. Temperature distribution inside the e-motor for direct and indirect cooling. In the table on the right, the average temperatures for the different e-motor regions are highlighted. The direct cooling shows lower temperatures for most of the e-motor elements.

trend is also confirmed at the higher speed condition, where the temperature can reach higher values. For this operating point, we report a higher temperature difference (40 °C) for the two cooling strategies.

Influence of physical properties

After demonstrating the superiority of the direct oil cooling strategy TotalEnergies wanted to prove the possibility of screening and selecting the physical properties of the oil to achieve better cooling efficiencies.

To do this, we varied four physical properties compared to the reference oil:

- $1/3 \times \mu$, the initial viscosity (fluid 1)
- $2 \times \lambda$,the initial conductivity (fluid 2)
- $1.5 \times C_p$,the initial heat capacity (fluid 3)
- $1.2 \times \rho$, the initial density (fluid 4)

The temperature distribution in the e-motor for the four oil variations is shown in Fig.6. As can be seen, all variations show improved cooling at lower temperatures.

This is in line with the trend between heat transfer and each physical property that can be extracted by explicitly isolating all variables in the Nusselt number:

$$h \propto \frac{(\rho u)^{\frac{1}{2}} (C_p)^{\frac{1}{3}}}{\mu^{\frac{1}{6}}} k^{\frac{2}{3}} \quad \textbf{(Eq. 1)}$$

Looking at the results in more detail, the temperatures decrease strongly for fluid 1 and 2 (reaching a reduction of 4% for the magnets). The average temperature decrease is greater than 2.5 °C for both configurations.

	Viscosity x 1/3		Conductivity x 2		Heat capacity x 1.5		Density x 1,18			
	Oil Cooling System Reference Oil		Oil Cooling System Fluid 1		Oil Cooling System Fluid 2		Oil Cooling System Fluid 3		Oil Cooling System Fluid 4	
	Ave. Temp. [°C]	Max. Temp. [°C]	Ave. Temp. [°C]	Max. Temp. [°C]	Ave. Temp. [°C]	Max. Temp. [°C]	Ave. Temp. [°C]	Max. Temp. [°C]	Ave. Temp. [°C]	Max. Temp. [°C]
Housing	97.6	102	-2.3	-2.6	-2.5	-2.9	-0.5	-1	-0.1	-0.4
Stator	103.3	110.9	-2.2	-2.7	-2.5	-3.2	-0.5	-1.3	-0.3	-0.3
Resin	105.6	110.6	-2.2	-2.5	-2.8	-3.1	-1.1	-1.3	-0.4	-0.3
Windings	104.4	110.2	-1.9	-2.3	-2.7	-3.2	-1	-1.2	-0.3	-0.5
Rotor	115.7	125	-1.5	-3.5	-2.3	-4.5	-0.8	-3.1	-0.1	0.2
Magnets	120.1	124.8	-5.4	-3.5	-6.8	-4.5	-5.4	-3.1	0.3	0.3
Shaft	98.7	111.6	-5.1	-4.3	-6	-5.6	-4.5	-4.3	0.9	0.8

Fig. 6. The average and maximum temperatures of each electric motor component are shown for the reference oil. The temperature differences found for the four different fluids tested are also shown.

This temperature difference can be considered significant, as it is greater than the sensitivity of the digital model.

It is interesting to note that the thermal capacities and temperature differences do not follow the power dependencies shown by the Nusselt correlation in Eq. 1. For instance, viscosity has a greater effect than density, although the exponential factor should be more favourable.

Overall, the results show that simulation and quantitative CFD analysis are crucial and can be more thorough than the theoretical estimates that currently guide most traditional R&D processes. Complex flow patterns and multiphase interactions may arise, resulting in oil accumulations and surface coverage that cannot be estimated without accurate digital models.

Conclusions

The numerical results obtained in this collaborative project between TotalEnergies and EnginSoft consistently demonstrated the superiority of direct oil cooling over indirect water cooling for e-motor systems. With its high dielectric properties, oil can be sprayed or splashed directly wherever heat is generated, resulting in significantly lower average and maximum temperatures of crucial components such as magnets and coils.

Direct oil cooling thus opens the way to higher power densities for the future generations of e-motors and optimized cooling control strategies.

Finally, the digital approach presented in this paper has shown real potential to serve as a versatile complementary tool to optimize the formulation of dielectric cooling fluids and will join other approaches at the core of TotalEnergies' research and development activities for thermal management of electric vehicles.

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About TotalEnergies

TotalEnergies is a broad energy company that produces and markets energies on a global scale: oil and biofuels, natural gas and green gases, renewables and electricity.

Our 100,000 employees are committed to energy that is ever more affordable, cleaner, more reliable and accessible to as many people as possible.

Active in more than 130 countries, TotalEnergies puts sustainable development in all its dimensions at the heart of its projects and operations to contribute to the well-being of people.

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face to face with Manabu Kawaji

AISIN Corporation

How AISIN Corporation achieved significant cost savings for its electric powertrain units with design optimization

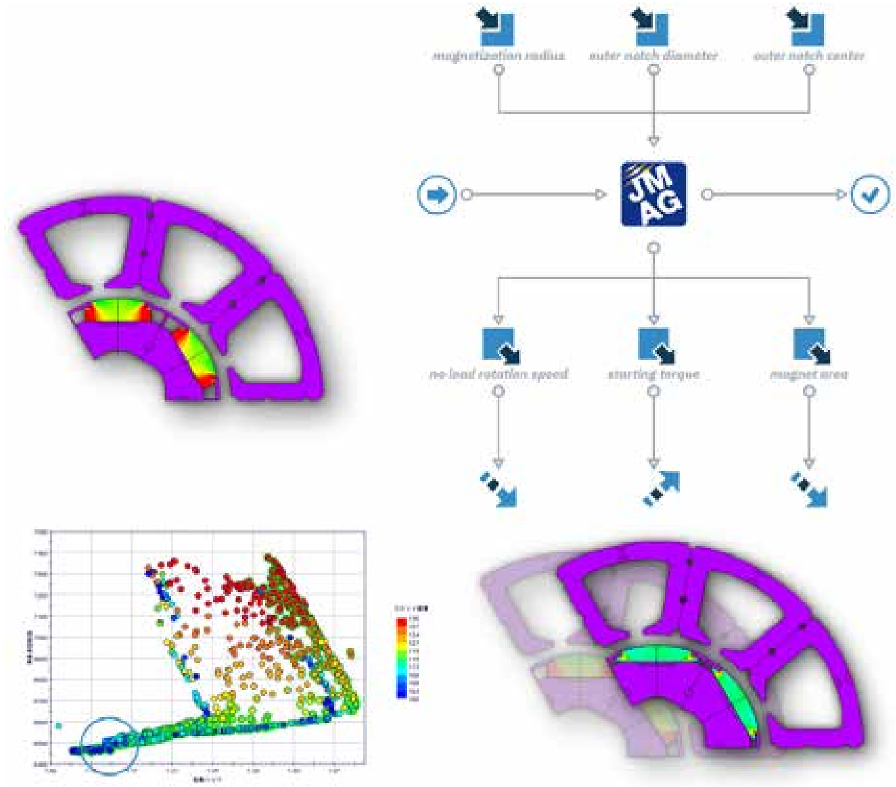
by Manabu Kawaji[1], Alessandro Viola[2]
1. AISIN Corporation - 2. ESTECO

ESTECO met Manabu Kawaji from the Component Development Group at AISIN Corporation.

He shares his experience in using modeFRONTIER design optimization software to perfect electric powertrain components.

ESTECO: First of all, could you tell us a bit more about your company and its electrification initiative?
Manabu Kawaji: At AISIN Corporation, we design, develop, manufacture, and sell nearly all components that comprise a vehicle. Currently, we are accelerating our shift to electrification to improve fuel efficiency and reduce materials that place a burden on the environment by promoting the development of electric drive units, heat management systems, and electronically controlled brake systems. In particular, the powertrain division in which I work develops a wide range of products including the eAxle, and thermal management systems among others, which are essential in the electrification of vehicles, and expands the sales ratio of electrification products to reduce CO_2 emissions and promote fuel efficiency.

ESTECO: Why is simulation important for your product development?
Manabu Kawaji: Our company is committed to reducing product development time. The classic procedure where drawings are created first, prototypes next, and then finally products, is not feasible anymore. This is why we take advantage of simulation to speed up the engineering process and virtually prove a design rationale in order to deliver high-quality products to customers within a short period of time. Since the demand for electrified vehicles is growing, we use simulation technologies such as electromagnetic analysis, thermal design, and optimization to design electric powertrain units. Our customers usually provide us with their requirement specifications to use as a product overview, although it does happen that we sometimes have to modify these specifications. This is where ESTECO's modeFRONTIER design optimization software becomes crucial for us in order to be able to present the optimal motor design to the customer based on the modified specifications.



The methodology of combining JMAG-Designer with modeFRONTIER to optimize the permanent magnet rotor for electric motors.

ESTECO: Could you explain why you chose the modeFRONTIER software to perform design optimization?

Manabu Kawaji: We are aware of design optimization techniques as one of the best approaches to develop better products. The ability to perform design exploration and optimization studies and turn data into valuable insights to decide why a particular design is better than others was one of the key points in convincing our senior management about the importance of optimization technology. In fact, modeFRONTIER has become our standard optimization tool for motor design. The software is equipped with many features that facilitate its application to a design process: from an automated workflow that makes it possible to integrate any engineering solvers or advanced post-processing analysis tools to help us to present a design rationale, and the ability to distribute the computational workload of large-scale optimization runs through grid computing. However, simulation is not easy to manage – especially when you need a lot of simulation tools to perform various engineering analyses. This requires you to buy many software licenses, and it is not always easy to prove the effective use of the software and determine the return on investment. In this scenario, modeFRONTIER's simulation process integration and automation capabilities help us to maximize our investment in engineering solvers by integrating third-party tools such as GT-SUITE, Simcenter Flotherm, JMAG-Designer, and MATLAB with the aim of performing multidisciplinary design optimization studies.

ESTECO: You said that you coupled modeFRONTIER with the JMAG software solution. Could you tell us a bit more about the benefit of this approach when performing electromagnetic field analysis?

Manabu Kawaji: Electromagnetic field analysis is necessary to visualize the invisible physical phenomena of electricity and the magnetic field and to clarify the design basis of electrified products such as motors. To do this, we chose JMAG-Designer which is the most popular software solution for electromagnetic field analysis in Japan. There are, however, a number of motor optimization problems that need to be addressed, and this is where modeFRONTIER comes into play. For example, we started with a 2D electromagnetic analysis of a magnet rotor using JMAG-Designer, which shows the amount of magnetic flux interlinkage in the permanent magnet. Then, we integrated the JMAG simulation model into the modeFRONTIER workflow to perform multiobjective design optimization. The aim was to explore the internal/external rotor and magnet shapes that satisfy the minimization of no-load rotation speed, maximization of starting torque, and minimization of permanent magnets that maintain or increase the magnetic flux interconnections. Thanks to modeFRONTIER post-processing charts, we could visualize all the optimal designs on the Pareto front and then choose the ones with the lowest permanent magnet area and reduced no-load RPM that met our key requirements for production. In the end, this optimization methodology allows us to achieve significant cost savings in the production of our electric powertrain units.

ESTECO: Do you have any future plans for simulation? Which is the impact of Machine Learning (ML) in your simulation design process?

Manabu Kawaji: We are actively investing resources to develop better products using a model-based development process that does not require physical prototypes anymore. Although we still have to figure out how to apply this methodology for thermal-related problems when designing and developing motors. On the other hand, AISIN is very interested in applying Machine Learning (ML) based surrogate models to support the exploration of possible good solutions. There are various approaches such as creating surrogate models by integrating JMAG-Designer and modeFRONTIER and using modeFRONTIER's Response Surface Models (RSMs) at least for the initial investigation phases. Indeed, we are working to reduce the simulation costs (hardware and software) by using these methods and the accuracy of the RSMs is very important to obtaining adequate results. We are in the early stages of use and are currently investigating how to improve the accuracy of the surrogate models based on our simulation data.

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Comparing Johnson Cook and Barlat material models for 316L stainless steel

by Yiğit Gürler[1], İbrahim Şimşek[1], Müge Savaştaer[1], Ayberk Karakuş[1], and Prof. Alper Taşdemirci[2]
1. Bosch Thermotechnology Manisa R&D Department
2. Department of Mechanical Engineering, Izmir Institute of Technology

Uniaxial and hydraulic tensile tests are alternative ways of deciding the stress-strain hardening curve for sheet metal materials. The hydraulic bulge test allows a higher amount of deformation than the uniaxial test, thus providing consistent results on material characterization.

The mechanical modelling parameters are the most important factor for the accuracy of numerical results. The uniaxial tensile test is one of the standard methods in sheet metal characterization. Furthermore, numerical solutions are an alternative in the sheet metal forming process for time and cost efficiency. When additional data is needed in addition to tensile test data, hydraulic bulge tests can be performed and used for different hardening models. This test method allows a higher plastic stress value. Fault modelling is performed to avoid geometric instabilities.

LS-DYNA is a convenient tool for investigating the material behaviour with different material cards because it has an extensive library of material models. In this study, two different material models are described, namely *MAT133_BARLAT_YLD2000 and *MAT093_SIMPLIFIED_JOHNSON_COOK. The Johnson Cook material is the industry's preferred model for simulations because the parameters are easily obtained.

Material characterization

Material parameters are essential for the accuracy of the models. Tests were performed at Atılım University and obtained the material parameters used (see Figs. 1 and 2). 316L steel sheets were modelled with *MAT133_BARLAT_YLD2000 and *MAT093_SIMPLIFIED_JOHNSON_COOK to compare the effectiveness of the material models.

Tensile test

The geometry of the tensile test specimen is designed according to DIN-EN-10002. One end of the specimen is clamped and tested with a strain ratio of 10^{-3}.

Bulge test

A thin-sheet specimen is placed in the lower die with a cavity in its centre. Then, the sheet metal specimen is clamped between the upper die and the lower die. Fig. 1 shows a two-dimensional diagram of a typical bulge test configuration. Unlike tensile tests, there are no standards for hydraulic bulge tests. In the literature, one finds different configurations of test equipment, with varying die cavity diameters and compressive load capacities.

Numeric model

Tensile test

A model of the tensile test was established using a quadratic mesh. The specimen is designed according to DIN-EN-10002 using a fully-integrated mesh element formulation 16.

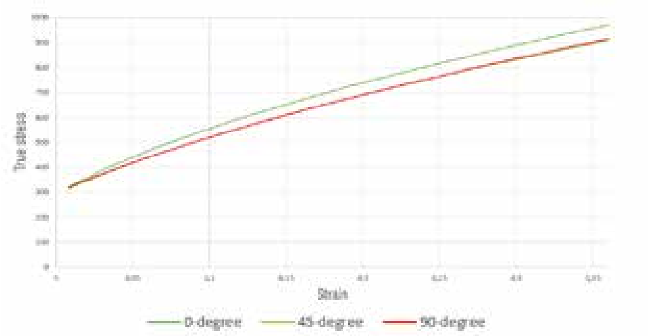

Fig. 1. Tensile test results for roll directions of 0/45/90 degrees.

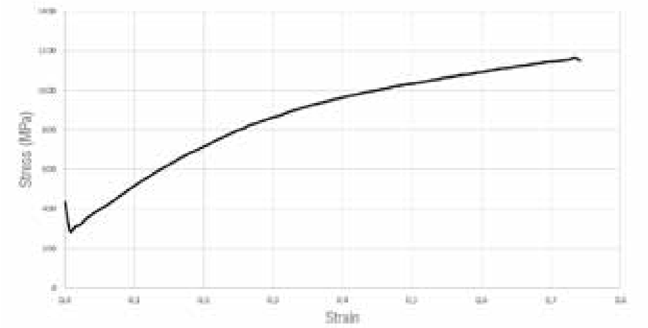

Fig. 2. Result of hydraulic bulge test.

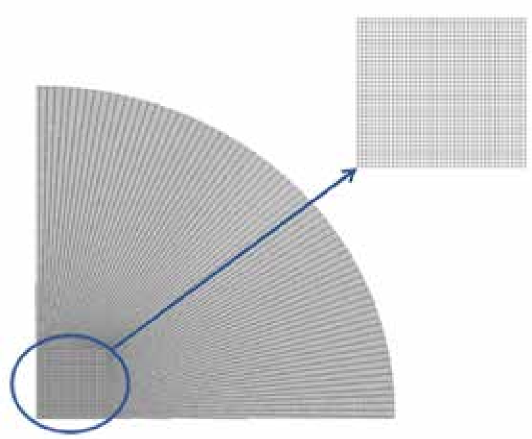

Fig. 3. Finite element mesh for hydraulic bulge test focusing on the central region of the specimen.

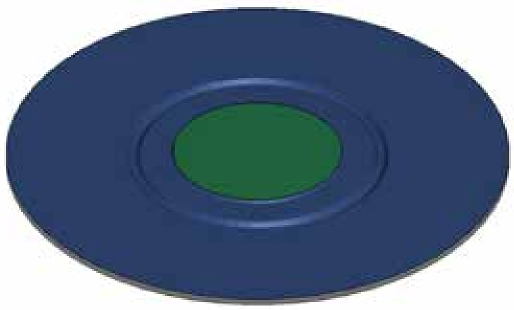

Fig. 4. Numerical model of the hydraulic bulge test.

Bulge Test

A full model of a bulge test was constructed using quadratic mesh elements for the specimen and dies. The hydraulic bulge test specimen has a diameter of 220 mm. In the finite element model, 64441 nodes and 64060 elements are used for the upper die, blank, and lower die. A fully-integrated mesh element formulation 16 was used for the blank sheet,

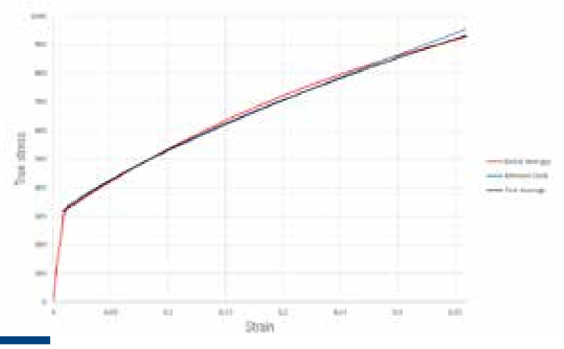

Fig.5. Comparison of stress-strain results of numerical and experimental tensile tests.

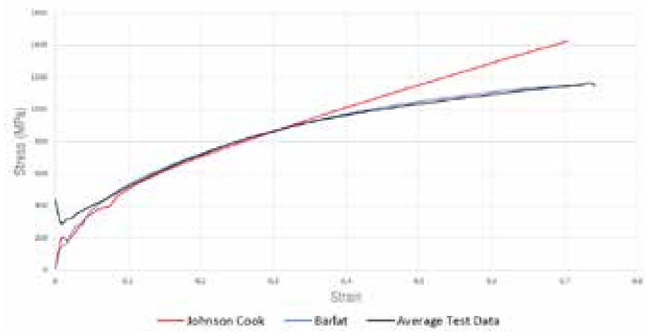

Fig. 6. Comparison of stress-strain results of numerical and experimental hydraulic bulge tests.

and element formulation 2 with the Belytschko-Tsay formulation was used for the upper and lower dies. The dies were modelled with a rigid material and had a fillet radius of 3.65 mm; AUTOMATIC_SURFACE_TO_SURFACE contact was used between the blank and die. The mesh of the hydraulic bulge test specimen (blank) is shown in Fig. 3. The size of the mesh increases with the distance from the centre.

Results

The results of the finite element analysis for Barlat_YLD2000 and the simplified Johnson Cook material model are shown in the graphs in Figs.5-6.

Conclusion

As a result of this study, it is clear that the material models *MAT133_BARLAT_YLD2000 and *MAT093_SIMPLIFIED_JOHNSON_COOK have a very similar behaviour in the tensile test. However, the hydraulic bulge test results of the FEA analysis have a very different behaviour after a strain of ~0.35. Differences between the results after ~0.35 strain affect the results for certain forming cases, such as deep drawing, etc.

Therefore, using the Barlat material model provides more accurate results than Johnson Cook and for this reason its use is when dealing with sheet metal forming simulations which can reach high strain level.

Acknowledgement

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Simulation of the blast furnace process using the Rocky-DEM API

by Lee Sung-Je
Tae Sung S&E, INC

Inside a blast furnace, iron ore and coke particles exhibit complex behaviour as a result of chemical reactions with hot gases. In this issue, we use Rocky-DEM's API (application programming interface) to evaluate the nonlinear behaviour of the particles based on the blast furnace's internal processes.

Granular materials serve as the primary materials various industrial processes, including those for chemicals, materials, pharmaceuticals, agriculture, and steel. To increase the efficiency of these processes, it is essential to predict the behaviour of particles that change continuously and interdependently. One of the processes in which particle behaviour has a dominant influence on process efficiency is the blast furnace. A blast furnace is a cylindrical tower furnace used for smelting metals. Its general shape and processes are shown in Fig.1.

Layers of iron ore particles and coke particles are alternately charged from the top of the blast furnace, and hot air is blown from the bottom. The coke at the bottom of the blast furnace is burnt by the hot air, and the heat generated by its combustion is used to smelt the iron ore and discharged it from the bottom. In terms of particle behaviour, the coke particles become smaller in the region where they are burnt by the hot air and eventually disappear, while overall, their general behavioural characteristic

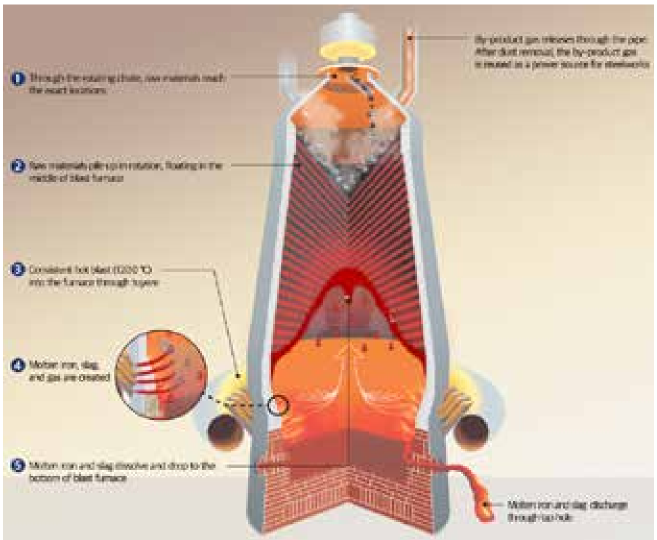

Fig. 1. Blast Furnace. [Courtesy of POSCO Newsroom]

is to continuously move downwards. In the process of smelting the iron ore by the heat of coke combustion, the particle size decreases, moves downward and finally disappears. The discrete element method (DEM), a special method of analysing particle behaviour, is required to simulate the complex behaviour of the particles and assess their structural impact on the blast furnace. This article discusses the simulation of the complex behaviour of the particles inside a blast furnace using Rocky-DEM.

Initial conditions of the blast furnace process

Inside the blast furnace, layers of coke particles and iron ore particles are introduced alternately from above while the products of the coke combustion sink and pile up to form an inverted triangle at the bottom of the blast furnace known as a 'Deadman'.

Simulating the initial state of the blast furnace by stacking the particle layers one by one in an empty blast furnace requires substantial analysis time. To make the analysis more efficient, the initial particle state was simulated using Rocky-DEM's Volume Fill feature which enables the defined space to be filled in a single step.

As shown in Fig. 2, when the Continuous Injection method is used, it is necessary to perform an analysis that creates the particle layers individually; Volume Fill on the other hand, enables the defined shape and space to be filled with all the particle layers in a single step, allowing the analysis to begin much more quickly. Therefore, analysis time can be significantly reduced for large-capacity equipment such as blast furnaces. Furthermore, Rocky-DEM's Volume Fill capability can be used effectively even if the initial shape of the particle distribution is clear.

After modelling the layers of coke and iron ore particles and the Deadman in 3D, we used the volume fill function to define the initial state of the particles in each region. To further improve the efficiency of the analysis, the model was cut vertically with a width

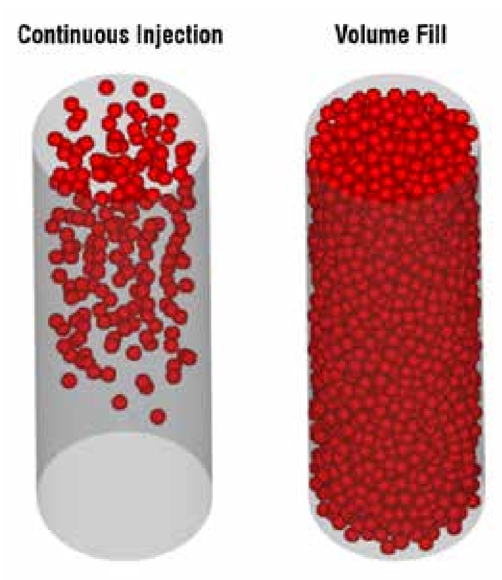

Fig. 2. Particle input method.

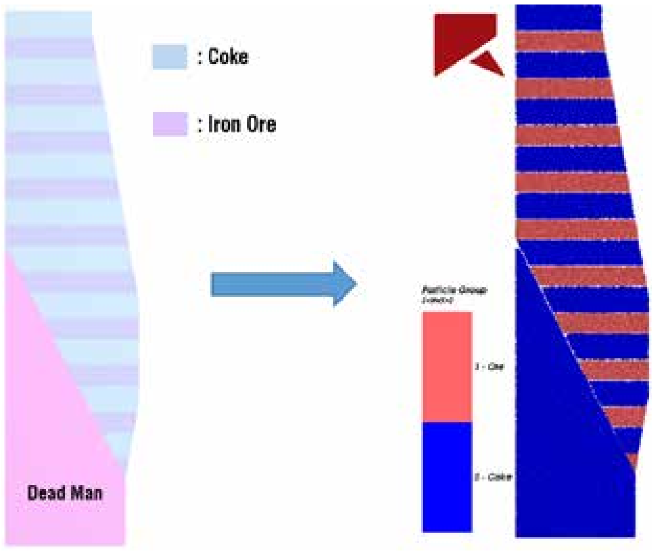

Fig. 3. Initial particle layer placement.

corresponding to 10°. Since the cut model is symmetrical, the analysis was only performed for half the width. A symmetrical boundary condition was applied to the cut plane.

Simulation of chemical reactions using the API

Pig iron is produced through a chemical reaction in which coke is burnt by the hot air flowing from the bottom of the blast furnace and the heat of its combustion smelts the iron ore. In analysis using CFD (computational fluid dynamics) such as Ansys Fluent, the process inside the blast furnace is modelled as four separate phases: gas, liquid, bulk solid, and powder to analyse the reactions, etc. Its main objective is to assess calorific value, temperature distribution, and oxide formation occurring during chemical reactions. Since the entire area of interest is modelled as a continuum, there are limitations to the evaluation of the influence of the behaviour of the individual particles. In DEM analysis instead, the influence of particle behaviour can be accurately assessed because the material in the blast furnace is modelled as individual particles. However, according to its basic theory, in DEM analysis particle size decreases with the chemical reaction, and it is not possible to simulate a phase change such as melting from a solid to a liquid. Further functions must be added to define the behaviour of the particles due to the chemical action inside the blast furnace.

Rocky-DEM provides an API to define customized functions in addition to the built-in numerical models. Three user-defined functions are required to simulate the nonlinear behaviour of particles within the blast furnace process. The first of these relates to particle size reduction due to chemical reactions: coke is burnt with hot air, and iron ore is smelted by the heat of this combustion. The particle size gradually decreases during this process. The gradual reduction of the particle size by the chemical reaction is defined by the following equation:

$$\frac{dD}{dt} = -\frac{R_r}{S}$$

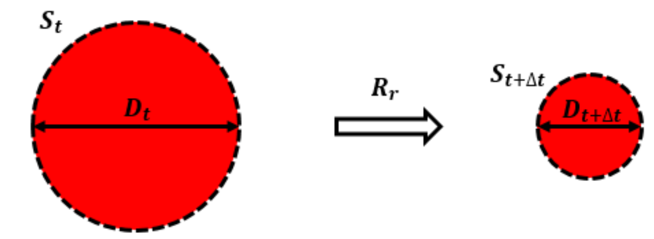

Fig. 4. Particle reduction mechanism.

where D is the particle size, R_r is the rate of particle size reduction per unit of time, and S is the particle surface area. In this example, the particle size reduction rate is defined linearly, but a non-linear reduction rate can also be applied.

Since the coke is burnt in the vicinity of the channel (raceway) where the hot air is injected, the particles flowing into the raceway are defined as decreasing in size. The cohesive zone is the region where the iron ore is smelted. It was defined so that the iron ore particles decreased in that zone only. The size reduction ratios of the coke and iron ore particles were defined separately.

The second user-defined function simulates the complete combustion of the coke particles into ash in the raceway. It was assumed that any material remaining after the coke particles were completely burnt was removed from the blast furnace. If the coke particle in the raceway was smaller than a certain size, it was assumed to have completely burnt up and was therefore removed from the analysis.

The third user-defined function simulates the total combustion of the iron ore in the cohesive zone. The iron ore is completely burnt up in that area. To simulate this process, an iron ore particle is removed from the analysis once it passes through the defined cohesive zone.

To accurately simulate the behaviour of the particles within the full blast furnace process, the analysis must be performed by applying the three user-defined functions simultaneously.

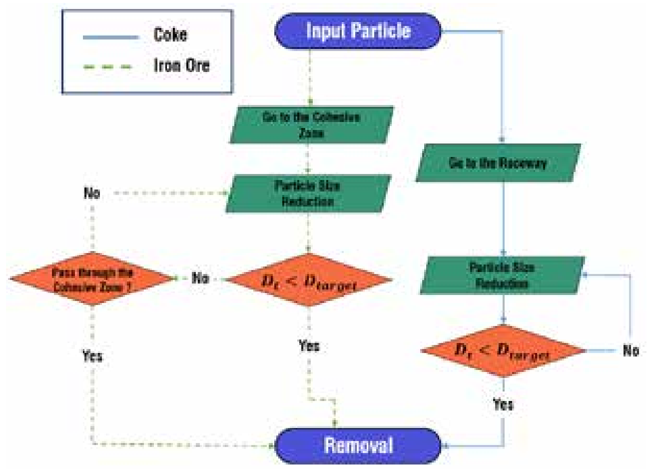

Fig. 5. Flowchart of particle behaviour.

For the continuity of the process, the blast furnace must be stacked with coke and iron ore above a certain level. Since the weight of the upper particles acts as a load on the lower particles and structures, the quantity of particles added alternately from the top is equal to the number of particles that are removed through the combustion and smelting processes.

Fig. 5 shows the flow chart of the particle behaviour inside the blast furnace, where D_t is the particle size, and D_{target} is the particle size to be removed.

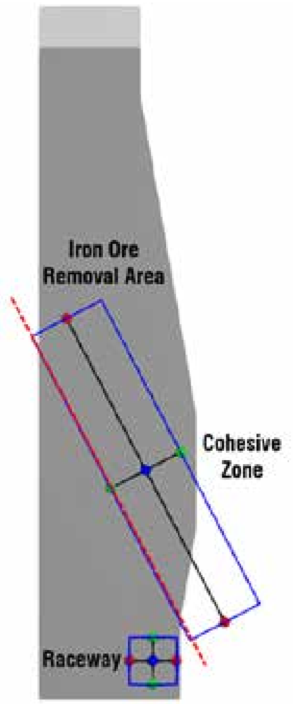

Fig. 6. Blast furnace analysis conditions.

Particle behaviour inside the blast furnace

The Rocky-DEM API was prepared according to the flow chart presented in Fig. 5 and applied to the analysis of the particle behaviour inside the blast furnace. The content of the three major APIs applied to the analysis, is:

1. Reduce particle size in defined areas
2. Remove particles when they become smaller than the defined size
3. Remove particles when passing through a defined area

The API was created using C++ and reference was made to the source code provided by ESSS, a Rocky-DEM developer. We reviewed the behaviour of the particles based on the chemical reaction inside the blast furnace which had been implemented using the API. Analysis conditions were defined as shown in Fig. 6.

Fig. 7 shows the particle behaviour according to the chemical reaction, while Fig. 8 shows the particles' path of movement.

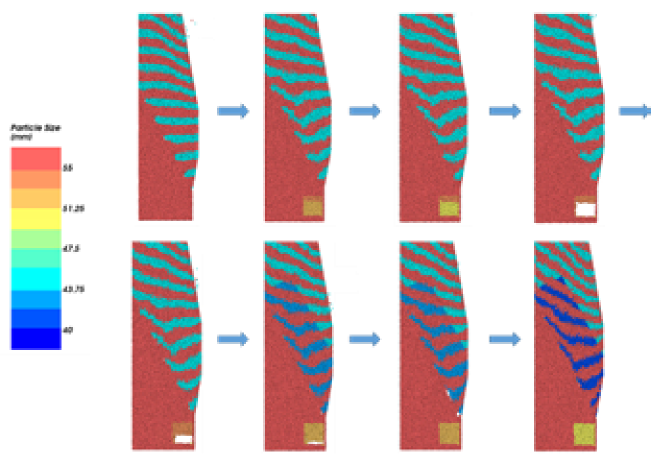

Fig. 7. Particle behaviour inside the blast furnace.

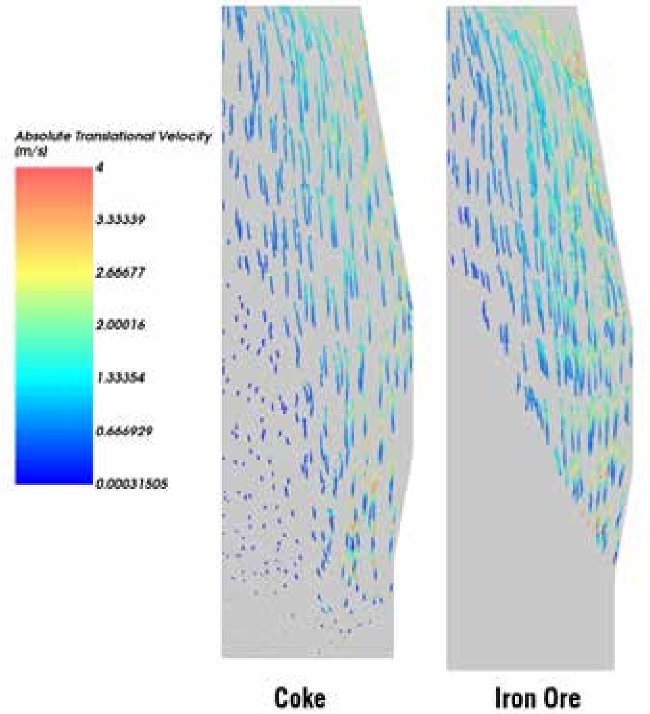

Fig. 8. Particle movement trajectory.

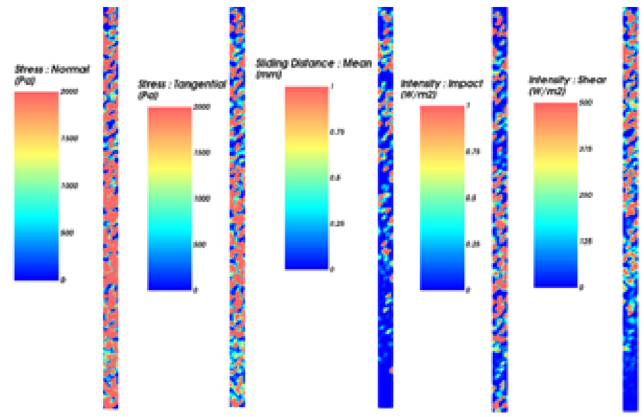

Fig. 9. Example of the structural effect on the blast furnace.

About TSNE

Since its establishment in 1988, TSNE has specialized in CAE, providing engineering programs and services to Korean customers. Tae Sung S&E (TSNE) aims to be the "One Stop Total CAE Solution Provider" (OSTS) both in domestic and global markets. The company leverages its large base of business capabilities and its team of CAE experts to provide services to customers in various industries (aerospace, automotive, civil engineering, biomedical, shipbuilding, electrical and electronics, energy, defense, chemical industries, etc.) and is expanding its business scope to research innovative technologies and apply them in the field.

It strives to become a global engineering company and increase its potential as a sustainable engineering company. Tae Sung S&E is partner to all engineers who endeavour to solve challenges. Tae Sung S&E will work with you to achieve "NO PROBLEM, BE HAPPY".

Various types of loads and physical quantities generated by the contact between the particles and the blast furnace, including normal forces that can cause deformation of the blast furnace, and shear forces and sliding distance that cause wear, can be evaluated as shown in Fig. 9.

Conclusion

This article explores the use of the Rocky-DEM API to analyse particle behaviour based on the chemical reaction inside a blast furnace. However, basic DEM analysis theory does not allow for the simulation of phenomena such as particles becoming smaller and disappearing due to chemical reactions. In order to simulate such nonlinear particle behaviour inside the blast furnace, an API that can be coded to allow user-defined functions to be applied to the analysis was used.

Although the chemical reaction occurring inside the blast furnace was not implemented directly using the API, the particle behaviour characteristics arising from the chemical reaction were implemented with the API and applied to the evaluation. The scope of the application is expected to expand as the API becomes available in areas that have been difficult to access in existing, traditional DEM analysis, such as the case of particle behaviour inside a blast furnace. The accuracy of the analysis should also improve using user-defined numerical models.

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New developments in HPDC foundry digitalization focused on process control and ZDM

by N. Gramegna[1], A. Salata[2]
1. EnginSoft - 2. RDS Moulding Technology

The development of sustainable production systems focuses on minimizing production costs, increasing productivity, and improving product quality. It is universally acknowledged that digital transformation is one of the central themes of Smart Manufacturing and a necessary condition by which companies can differentiate themselves from competitors in low-cost countries. Moreover, highly flexible digital systems maintain production efficiency despite extreme variability in demand, and simultaneously enable a reduction in scrap and energy consumption. With this in mind, it is necessary to develop integrated methodologies, technologies, and tools for process control, improved maintenance, intelligent quality management, and production logistics.Against this background the new data-driven digital twin architecture of a multi-stage production system such as high pressure die casting (HPDC) interconnects all stages and their peripherals. The aim is to improve product quality towards zero defect manufacturing (ZDM) by monitoring a plant and its sub-areas to increase reliability at reduced production and maintenance costs.

Recent applications in die casting foundries highlight the expected impacts with feedback from months of production line data acquisition and management. Key elements are the flexible management of alarms and alerts as well as real-time processing of KPIs related to overall equipment effectiveness (OEE) and production costs. The project realized at RDS Moulding Technology underlines that digitalization in the foundry is an enabler for small and large companies. This article describes the design of a new sensorized mould for the production of Siemens gearmotor housings and the implementation of an intelligent monitoring system supported by a predictive quality model created through instructive sampling.

The results refer to the PreMANI project ‘PREDICTIVE MANUFACTURING: design, development and implementation of Digital Manufacturing solutions for Quality prediction and Intelligent Maintenance’, supported by the Veneto Region with the POR FESR 2014-2020 programme, coordinated in collaboration by the innovative regional networks IMPROVENET and SINFONET that combine industrial Internet of things (IIoT) and cyber physical system (CPS) expertise with process management and quality control along the foundry production chain.

The Smart factory and the digital twin

The Smart Manufacturing Operations Planning and Control Programme develops and implements advances in measurement science that enable standards for performance, quality, interoperability, wireless and cybersecurity in real-time prognostics and health monitoring, the control, and optimization of smart manufacturing systems (source: NIST). A Smart Factory is a complex manufacturing ecosystem where the convergence of ICT and operational technologies and skills drive digital transformation. Two challenges are emerging: the convergence of IT and operational technology systems and the broadening of the range of competencies and skills needed to drive the transformation, including cross-functional competencies, soft skills, and digital talent. The next frontier is production system efficiency rather than labour productivity. Secure data, real-time interactions, and connections between the physical and virtual worlds will make the difference: enter the digital twin (DT).

To unlock the full potential of the smart factory, organizations must design and implement a strong governance program and develop a culture of data-driven processes to make better decisions based on available, reliable, and meaningful data.

Advanced digital solutions and key enabling technologies must be constantly focused on solving the problems of the manufacturing sector, which can only return to competitiveness through:

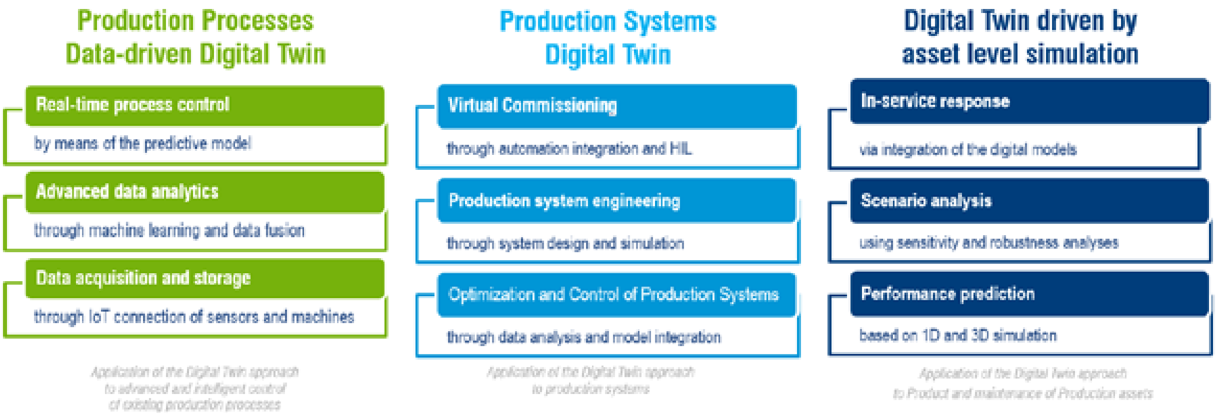

Fig. 1. The Digital Twin: (1) data-driven, (2) system modelling, and (3) simulation-powered.

- increasing efficiency,
- reducing time-to-market,
- minimizing costs, and
- increasing quality of products and services.

A data-driven digital twin of the production line

OEM specifications or supplier quality requirements partially drive product production, missing the opportunity to monitor the process and quality of any component at any stage and to react appropriately at the next stage to minimize scrap and time-to-market, while also reducing the cost of the final product. In complex production processes human input still plays a key role, mainly in supervising production KPIs and making improvement decisions. This could change as soon as effective applications of artificial intelligence enable truly automatic reconfiguration of the production system.

There are three levels of digital twin (DT): (1) data-driven, (2) system modelling, and (3) simulation-powered. This paper focuses on the first category (Fig. 1). All of them consider the three elements of real and virtual connections and human interaction.

The data-driven digital twin (DD-DT) has the macro-objective of continuously combining production efficiency (and stability) and better quality, to be achieved through digitalized production process monitoring, the interconnection of quality control and all associated data along the production chain, and the implementation of intelligent algorithms for quality prediction when total quality inspection is not sustainable. Often the two goals of production efficiency and better quality are at odds because intensive and rapid utilization of equipment can generate more breakdowns and production stoppages while better quality is only achieved with an optimized setup at each stage of the production line. The identification of the optimal setting is no guarantee of stable quality because the actual production environment (e.g. raw materials, machine, workpieces, equipment, etc.) experiences deviations in performance and time due to the dynamic behaviour of the production line. Degradation of equipment and/or machines and devices, as well as seasonal variations in the environment and environmental effects, generate instabilities in real production performance leading to stoppages and breakdowns.

More specifically, the DD-DT of the production line is based on three key elements: the monitoring platform, the data pool, and the cognitive system (Fig.2).

The monitoring platform is based on the information provided directly by the production process and its component devices, but also by advanced sensors applied to the process itself, which primarily enable the continuous monitoring of the recording of the evolution of all variables during each production cycle in order to identify all deviations from the optimal setting. Process stability means quality stability in production. At the same time, the cost estimate of the design and industrialization phases can be confirmed reliably and with process stability. Cost-benefit analysis is improved by introducing the cost model and linking it to the most relevant production parameters to verify the cost of the part number in real time.

The application of a control and cognitive system in complex production lines is not new in the factory [3-5]. The first applications

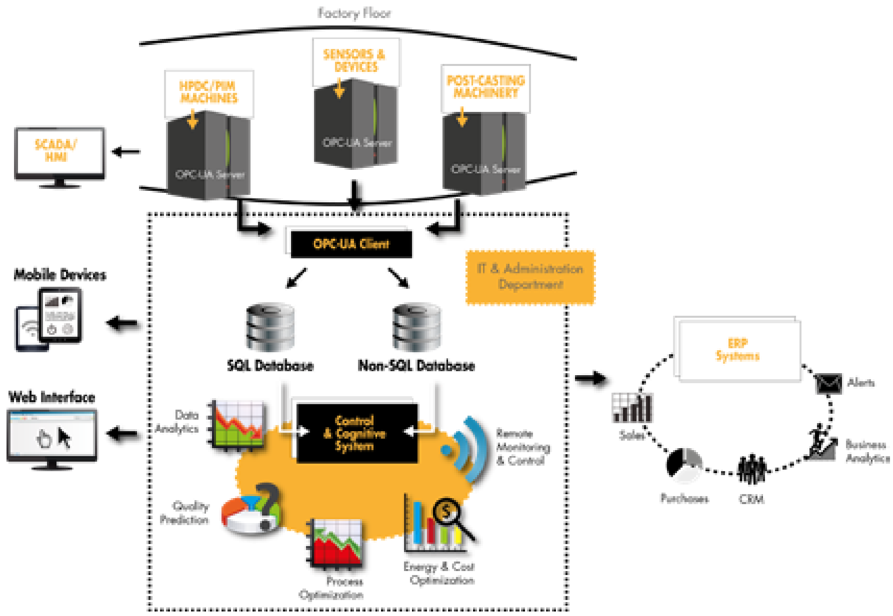

Fig. 2. Process monitoring and real-time data processing.

were in foundry and plastic injection moulding. Today, interoperability, flexibility and scalability are key elements driving innovation in the DD-DT starting from the ICT architecture. From the factory floor to the DT, the new ICT architecture activates connectivity between each manufacturer or end-user to collect data describing every stop of the production process along the production chain. Data collection is based on the OPC unified architecture (OPC-UA) protocol at the level of PLCs (programmable logic controllers) on the factory floor. The new solution is inspired by the Reference Architecture Model for Industrie 4.0 (RAMI) architecture with reference to the assets, integration, communication, information, functional, organizational and business processes.

The challenge of bringing production to zero defects requires the ability to manage the complexity of the process: identify key process variables, understand the variable-defect (cause-effect) relationship, implement sensors that can capture variables in real time, and in-depth process analysis and knowledge. Integrated virtual tools are the building blocks of the new control and cognitive platform. The rapid reconfiguration of the process for zero-defect production is supported by a deeper understanding of cause and effect based on a large and extensive amount of data from virtual and real process exploration.

High pressure die casting sector

In the smart factory scenario high pressure die casting (HPDC) of light alloys, a strategic industry for the EU, is one of the most representative large-scale production lines in the manufacturing sector in which it is possible to monitor production events with adequate precision. The process is executed by a special machine that manages a multitude of process parameters (cycle time, piston speed, mould and melt temperature, etc.). HPDC process production is one of the most 'defect-generating' and 'energy consuming' processes in EU industry. This sustainability issue requires machines and peripheral devices to be able to efficiently and ecologically support production with higher quality, faster delivery times, and shorter lead times between successive generations of products.

Lack of quality significantly affects the cost of transformation, and defects are often detected long after production, without taking real-time, corrective actions based on a continuous learning model that links process data input to potential defects. The real limitations on the HPDC industry are the continuously increasing costs that reduce efficiency and minimize the impact of innovations and development. Furthermore, standard products such as gearboxes and motor blocks will soon be replaced by large thin parts required for electro-mobility. These parts are extremely difficult to produce reliably with high quality and represent a challenge for the HPDC industry.

The new DD-DT platform covers the full HPDC production chain from material processing to the final product. The major limitation is the acquisition of data from each stage, as well as the corresponding digitalization and classification of defects.
HPDC is a typical production process that suffers greatly from the problem of low yields. It generates defects of various kinds and types with an average rejection level of 10%. These defects are classified in CEN TR 16749 [2], considering a three-level approach. A survey of EU HPDC foundries found that most foundries quantify defects by considering gas/air porosity (70.9%) or shrinkage (56.4%) using X-ray inspection (in the range of 70-80% of cases). However, in certain situations these types of defects in castings can be accepted if they fall within a previously identified threshold (in this case, and according to the EN 12258-1 definition, they are considered 'imperfections' instead of 'defects').

The foundry use case

A gearmotor housing was selected as a use case in which to apply all the advanced and innovative solutions for optimizing and monitoring the HPDC process. The housing is produced from a net-shaped geometry with one part per die and assembled into an electric motor for various applications such as escalators (Fig. 3).
The die and related process parameters was optimized using the casting simulation tool (MAGMAsoft). It was necessary to first optimize the mould, modifying the gait and overflow systems to improve the fluid dynamics in the cavity and to redesign the thermoregulation and lubrication systems in the cycle to improve the thermal performance of the equipment. At this stage, automatic optimization techniques were applied to define the best configurations.

This activity was also preparatory to defining the positioning for the thermal and pressure sensors on the printing parts. Subsequent to the mould redesign and using virtual simulation it was possible to identify the macro areas on which to apply the sensors and to define which of these areas would be more sensitive to process variations. The purpose here was to define the most important areas from which to capture process instability data to be correlated with the quality of the components produced.

The position of the sensors was chosen by analysing virtual DOEs (design of experiments), where the process parameter variables include:

- injection curve (first phase speed, second phase speed, and switching point)

Fig. 3. High pressure die casting product: a gearmotor housing.

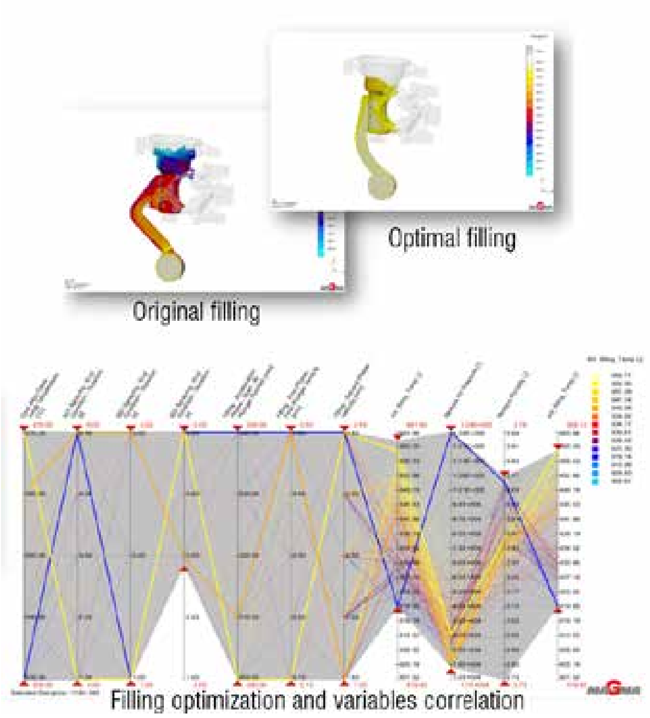

Fig. 4. Optimization of filling and correlation of variables with defects.

- lubrication time and blowing time
- temperature and flow of the temperature control units
- alloy temperature

The variations in these variables is observed and correlated with both the values emitted by the sensors and the previously presented component quality criteria by means of appropriate processing tools (Fig. 4).

New revised castings were studied to improve castability and quality: from a fluid dynamics point of view, changes to the geometry and optimal parameter configurations are suggested.
Fig. 5 shows how porosity was significantly reduced and die life was extended by changing the thermoregulation and lubrication configurations (see Table 1).

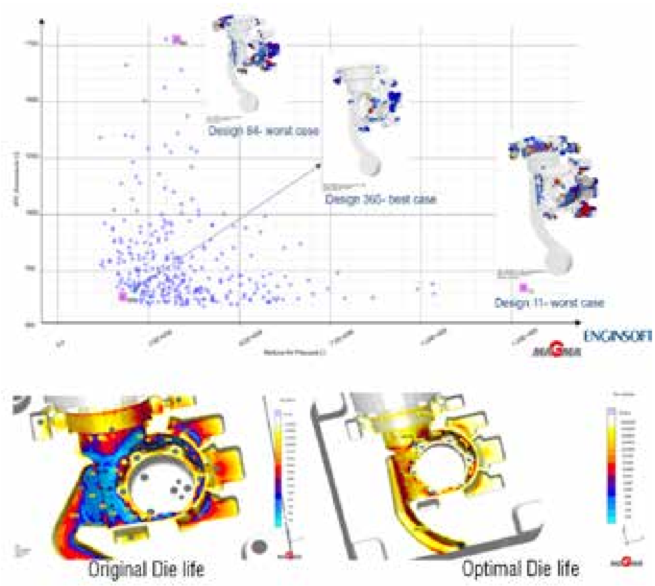

Fig. 5. Optimization for solidification defects and prediction of die life.

Original HPDC parameters	Optimal HPDC parameters
Oil at 180 °C for mobile die thermoregulation	Oil at 130 °C for mobile thermoregulation + H2O at 20 °C in central die-core
Oil at 250 °C for fixed thermoregulation	Oil at 130 °C for fixed die thermoregulation
Die lubrication for 15 sec with an average local time of 2 sec	Die lubrication in three steps Step 1: 3 sec; step 2: 2 sec; step 3: 5 sec

Table 1. Thermoregulation and lubrication configuration

Process monitoring and alerts

After the design phase, the monitoring platform was implemented by integrating the process and equipment data collected from an intricate network of existing and innovative sensors that had been applied to all key units in the manufacturing production line. The platform performs real-time data mining and triggers alerts when a deviation is outside the optimal range.

With regard to monitoring, data was acquired from the measurement system (supplied by Electronics GmbH) connected to a 560-ton press (Table 2).

HPDC PHASE	SENSOR SIGNAL	RDS APPLICATION
Injection	Biscuit thickness Length of injection phases Injection force First stage pressure Injection pressure Exhaust pressure Specific pressure Piston position	Piston position Injection pressure Exhaust pressure
Solidification	Contact temperature Contact pressure	Contact temperature Contact pressure
Cycle preparation	Oven temperature Room temperature Lubricant quantity	Oven temperature Room temperature Lubricant quantity

Table 2. Data acquisition from the measurement system

Predictive quality model

Standardized quality classification and investigation methods [1], and the traceability of parts, are crucial for training the predictive quality model that guides the minimization of the indices affecting rejection rates. All process parameters (both virtual and physical) that can influence the quality of a given product were considered in the DOE used to train metamodel by correlating the process input variables and sensor data with the quality indices for the areas of interest.

Full factorial and Sobol algorithms were applied to the DOE of the housing which is produced in 344 shots considering statistical repeatability and thermal steady state. The correlation of the input signal and quality indices highlights the most significant variables and deviations affecting the quality in the specific stage of casting, e.g. the die pressure signal correlates well with porosity and cold shot in the central areas of the body.

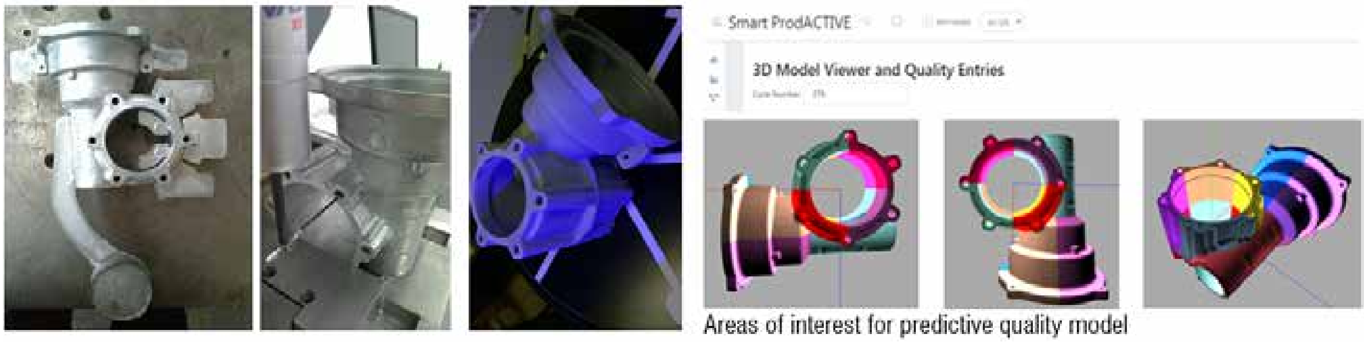

Fig. 6. Quality control and casting area of interest.

Quality mapping is based on NDT (non-destructive testing) using visual inspection, X-ray, and metrology tools. Defect classification and digitalization is required for all the different areas of interest (Fig. 6) with particular reference to joint or cold shot, internal porosity, and lamination.

The quality prediction model correlates process variables with quality indices to supervise and optimize process parameters to result in zero defects. The cognitive system works with advanced machine learning algorithms to support the reactive decision-making in real time to improve product quality by catching potential defects as early as possible during key process steps. A wizard guides the user during the training phase. The system also offers a set of ready-to-use machine learning (ML) algorithms, automatically processes all data sources to obtain the optimal approximation, and displays the processing results. The algorithms are used together with enhancement techniques based on: (a) decision trees, (b) nearest neighbours, (c) random forest, (d) support vector machines, and e) neural networks or customized algorithms.

Users do not need analyse the data or manually find the model or algorithms for their production scenario. A simple interface guides them in acquiring, interpreting, and classifying the production signal in the dataset to train the metamodel, and in verifying the correlation, accuracy and error metrics. After automatically training the metamodel via grid search (cross validation), a single model was generated for each area and different defect. An example of error is 9.6% for porosity in the central body in contact with mobile die. The algorithms and models are automatically improved and retrained during production using the results of the new quality inspections.

DD-DT-assisted production and predictive quality modelling

Production normally starts using the best process configuration. The stability and repeatability of the best cycle is monitored with real-time comparisons to the previously selected reference curve and using instantaneous verification of the thresholds to meet the predicted quality. The waste or good parts predicted by quality models are displayed on a PC, table or smart phone connected to the system via the web. The decision support system (DSS) supports the selection of the best setting for the reconfiguration of the process parameters by suggesting the correct adjustment. It sends a message to the operator containing the identified defects and a proposed new configuration. The GUI displays the deviation recovery, process stability, and good quality forecast. At the same time, it updates costs and production KPIs in the OEE (Figs. 7-8). The basic dashboard includes some predefined KPIs, such as quality, availability, and target cycle time. The user can define new KPIs (e.g. material volume, energy savings, and cost).

The results widget (Fig. 8) assists the quality prediction system: when the defect index values for a casting are all below the relevant thresholds set, the part is considered 'good'; if even one value is over the threshold, the part is considered a 'waste'.

The monitoring system controls the quality of the production process from an abnormal operating state that generates waste (i.e. during the heating phase), to the expected operating state that produces good parts.

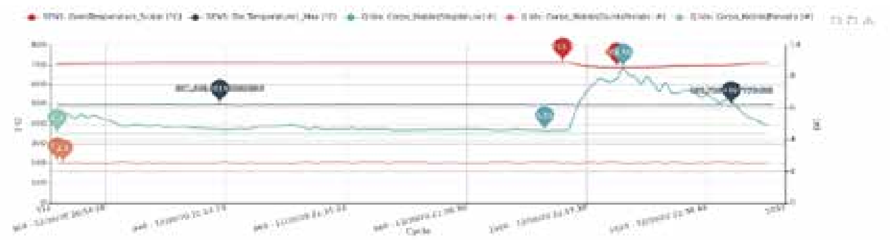

Fig. 7. Example of KPI display during production.

Fig. 8. Identification of good/waste castings (left) and list of defect levels in the corresponding areas (right).

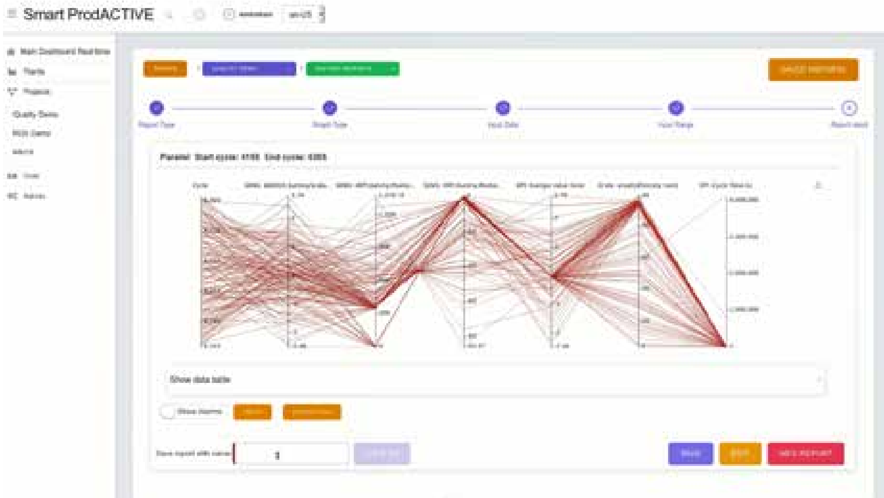

Fig. 9. Identification of good/waste castings (left) and list of defect levels in the corresponding areas.

In the end, the monitored data also contributes significantly to the real-time costing of each part. The cost model is based on the production and organization phases and the assigned cost categories (e.g. materials, manhours, maintenance, etc.) and cost items (e.g. raw material, scrap, operator, etc.). The cost KPI is evaluated after each shot in real time and the historical database shows the trend by correlating it with the process parameters and quality levels. The report wizard guides the user in selecting the chart type, data, and the cycle interval to be displayed. The periodic reports that can be printed and automatically shared with managers can include any graph or table (Fig. 9).
The repository of reports and data tables sits in the cloud and the MES (manufacturing execution system) connection was tested.

Conclusions

This paper discusses a significant improvement to sustainable production when there are limitations to non-destructive inspections in-line (e.g. in casting) by means of an improved inspection system that enables a 'right first time' production process. Newly developed methodologies and tools prevent defects from being generated at the component level and propagated to the system level. A digital twin substantially improves and virtualizes manufacturing and engineering processes to save resources by avoiding testing and mock-ups.

The data-driven digital twin has proven to be essential in smart factories (e.g. Foundry4.0).

The new, distributed architecture and extension of the interoperable, flexible digital platform along the production chain:

- facilitates remote process control supported by alarm management to accelerate rapid identification of defects up to full zero-defect production,
- reduces the cost of non-quality, and
- enhances the ability of agile production to restart with corrected configurations based on digital know-how.

The pilot line of this new development in foundry digitalization demonstrates a significant reduction in defects with a 50% reduction in HPDC waste and a 60% increase in die life. The simulation of the foundry process supports the design of highly sensitive sensor network to detect process instability and capture defects in real time. Production supervision alerts the user in case of deviations and suggests the appropriate action based on the predictive quality model.

This validation in the foundry environment is also a reference for other complex manufacturing processes where the same approach can be successfully applied. The web platform has been designed to support multi-site production line monitoring (e.g. material supply, casting, heat treatment, and machining in the case of a foundry).

The cloud becomes the final repository of the reports and data tables and the MES connection was tested.

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The digital twin is enhanced by real-time monitoring, data collection, and artificial intelligence to train the predictive model that is implemented from the machine level up to production chain level. This represents a significant step forward towards the most complete of digital transformations enriched by advanced ICT and human decision-making systems based on data, simulations, and representative process and product KPIs.

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face to face with Marco Baroero

VP of Engineering Systems and Configuration Management

Leonard Aircraft Division: Implementing model-based system engineering in a single platform for competitive edge

by Roberto Gonella, EnginSoft

At this point in the evolution of simulation, the intention is to realize the guidelines of the model-based system engineering (MBSE) method; in short, to manage the 'outputs' of the different areas of design within a single virtual platform, and EnginSoft is collaborating with a number of companies to realize this project. The Leonardo aircraft division has begun collaborating with EnginSoft in the embryonic stages of defining and implementing such a platform.

Engineer Marco Baroero, Vice President of Engineering Systems and Configuration Management at Leonardo's Aircraft Division, is the strategist and architect of this new engineering structure and is drawing on EnginSoft's expertise, which is complementary to Leonardo's deep-rooted and historical aeronautical knowledge, to outline the roadmap of this challenging and progressive company project.

> "The goal of CAE virtualization is to integrate all simulations and disciplinary analyses into a multidisciplinary Virtual Engineering environment that combines the modelling of operational scenarios with the consolidation, refinement, and integration of experimental data and operational data.

Q. What role does (and should) innovation play in the industrial world?

A. The constant evolution of economic and political scenarios and contexts has required and continues to require continuous innovation from aeronautical companies' development models in terms of drastically reducing both time-to-market and the cost of the complete product by leveraging new technologies and using innovative approaches to project management.

As such, innovation is both fundamental and essential to remain competitive. However, in innovating, you should avoid 'posing' as an innovator because it is mandatory, but you should rather be rigorous in your approach and in applying the results: the industrial world needs - and must - bring innovation 'into production'. To achieve this, industry has to develop and focus on the high but expensive TRLs (Technology Readiness Levels) on one hand, while working in cooperation and 'system' with research, universities, and start-ups on the lower and intermediate TRLs on the other.

Q. What are the strategies for being innovative and which valuations drive innovation?

A. In order to be innovative in the industrial world, you must first and foremost have clear industrial reference objectives along with a path/roadmap to achieving them, while also being ready to modify and update them in response to changes in the context and reference scenarios.

During implementation, you then need to be 'open-minded', ready to capture both obvious and unexpressed requirements, and willing to experiment with contamination across technological domains, in other words not only delving vertically into a single discipline/field, but also understanding what can be transferred horizontally from different and apparently distant technological areas.

Q. What role do CAE and virtual prototyping tools have to play in this respect?

A. Design is currently completely done using both hardware and software. In the late 1980s and early 1990s, design already involved 3D CAD modelling. Similarly, specific in-house or commercial (COTS) CAE analysis and simulation tools were used for functional verification and preliminary validation.

Today, the goal of CAE virtualization is to integrate all simulations and disciplinary analyses into a multidisciplinary Virtual Engineering environment that combines the modelling of operational scenarios with the consolidation, refinement, and integration of experimental data (physical verification) and operational data (product in service). This will allow the entire project, or any of its local modifications, to be evaluated from the very beginning of the development process, enabling any criticalities or the need to intervene to be identified early on in the project, thereby reducing modifications (with the associated high time and costs) during the implementation phases.

With the assistance of new artificial intelligence techniques and the computing power of supercomputers, we intend to implement 'Digital Twin' approaches to create complete models in which not only all the aircraft components, but also the interactions between them, can be validated and assessed. By creating these Virtual Engineering and Digital Twin environments, together with the ongoing maturation and extension of the new project management processes (MBSE, Agile and CMMI), we should significantly reduce the time-to-market of the full product.
Our ultimate goal is to achieve virtual product certification by minimizing, if not eliminating, physical testing activities, which will significantly reduce costs and time requirements. This last objective, however, cannot be achieved by industry alone but will require the concurrence and contribution of the aviation and certification authorities.

Q. How have users' needs changed in recent years?

A. The users of our products have immediately 'adapted' to new technologies and, accustomed as they are to increasingly effective and advanced 'generalist' software (telephone apps, and office automation software) on their personal devices, they expect comparable interfaces and ease of use from both data and operations. The most successful CAE products are those that offer ease and continuity of use, similar to everyday tools and applications.

In particular, as both end users of the aeronautical product (customers) and as aeronautical companies, we need to collaborate and exchange data in a massive, structured, and continuous manner between different 'platforms'. This requires open systems and standard interaction protocols to avoid the considerable costs of migration or of establishing data exchange systems. Unfortunately, this does not always coincide with the policies of CAD/CAE suppliers.

Q. In your professional experience, how has your approach to design changed?

A. At first, CAE tools were 'personal': they were used individually by specialists who essentially owned and managed the data and results. Now that integration, verification, and multidisciplinary preliminary validation are necessary and essential for efficient and effective design, engineering platforms' collaborative functionalities for information control and configuration management have also become essential for CAE tools.

Q. What has EnginSoft's contribution been and how has it been able to enhance the quality, potential and capacity of your industry?

A. In the same way that all our competitors' innovative projects are doing, in developing new models and operational scenarios we need partners that are experts in new methodologies and technologies to support our aeronautical experts who must continue to focus primarily on the development and updating of our products.

EnginSoft combines significant skills and experience in multidisciplinary simulation, Virtual Engineering, and Digital Twin applications, with knowledge of the processes, peculiarities, and problems of the aeronautical world (an important feature in our sector). The company is therefore able to give a highly valid contribution to our new development path.

Projects with EnginSoft in a multidisciplinary field oriented towards Virtual Engineering have been completed with results that exceeded expectations, both in terms of operational use and of the satisfaction of our technicians.

Moving forwards, we intend to proceed along this path with additional projects for the further multidisciplinary extension of the projects already developed, and in the application of AI algorithms for the validation of experimental data.

Q. What prospects do you see for numerical simulation software in relation to the challenges posed by the future?
A. One of the main requirements is the ability to design / develop collaboratively in parallel with competitors in extended / virtual enterprise scenarios, in which the possibility of working together, while also segregating proprietary competitive information, is of vital importance. This scenario is complicated by disparate national regulations regarding information and cyber security that further complicates the creation of integrated collaborative environments.

Q. What projects, objectives and new goals do you intend to pursue thanks to the use of these tools?
A. Companies that optimize the management and use of these new technologies will have a significant competitive advantage. Our current attention is on using a Digital Twin within an Extended / Virtual Enterprise in order to achieve virtual certification of the product while minimizing or even completely eliminating physical testing. The entire Leonardo group's innovation projects are moving in this direction.

Q. What do you hope for from the world of scientific technology in its continual search for a balance between creativity and competitiveness?
A. The complexity of current products requires increasing investment in development that leads to, and requires, international collaboration involving increasingly complex supply chains. Technological feasibility frequently clashes with regulatory or legislative and intellectual property issues. Overcoming these problems - at least at European level - would certainly facilitate the ability to quickly and easily exploit new technologies.

> “In the same way that all our competitors' innovative projects are doing, in developing new models and operational scenarios we need partners that are experts in new methodologies and technologies to support our aeronautical experts who must continue to focus primarily on the development and updating of our products.

About MARCO BAROERO

Eng. Marco Baroero has always worked for Leonardo and has achieved several notable successes during his career; these include his role as chief engineer of the Eurofighter EF2000 programme in the early 2000s; and later becoming the manager of the Alenet platform, a complex, corporate, design management project. Today, he enthusiastically performs the role of aircraft certification manager in the prestigious position of Vice President of Engineering Systems and Configuration Management.

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Safety, health, and ergonomics of metalworkers engaged in manual grinding and finishing operations

Developing a prototype solution to reduce vibrations to their hands and arms

by G. Morandina[1], A. Trevisan[1], P. Pasqualotto[2], M. Chiodin[2], A. Trevisani[3], D. Richiedei[3], A. Ragazzon[4], A. Parolin[4]

1. EnginSoft - 2. SAFAS - 3. University of Padua - 4. BNP

The FORSAL (FOnderia Robotizzata per la SAlute dei Lavoratori [Foundry robotics for worker health]) project is part of the Veneto region's Smart Manufacturing framework, which makes use of the enabling technologies of micro/nano electronics (interactive robotic tooling management systems), advanced materials (high-performance light alloys for prototype production and custom-made tooling materials for the aforementioned processes), and advanced production systems (the introduction of robotic systems into foundries). Active ageing is the key driver for innovation here.

The project's key goals are to study inclusive and human-centred workspaces and organization, and to design innovative solutions for building machinery and equipment with safety, environmental protection, energy saving and efficiency in mind.

The FORSAL project (ID 10063706), which was approved by the Veneto Region in 2017 to support collaborative R&D activities for developing innovative sustainable technologies for new products and services (action 1.1.4), has successfully designed and prototyped a system that reduces the vibrations transmitted to operators by the grinders used for the finishing processes on foundry castings.

This article introduces the ergonomic issues related to grinding operations, and then focuses on the design and validation of a vibration reduction system that can also be used outside the foundry environment.

Fig. 1. Angle grinder used in foundries.

The material removing and finishing processes of foundry products involve specialized operators who use tools, such as angle and axial grinders, to manually perform quite complex movements to reach all areas of the metal parts to be finished. Since these operations cannot yet be delegated to traditional robots or to cobots (collaborative robots) due to the high levels of dexterity and dimensional precision required, and since no available exoskeletons fully meet the current efficiency and quality requirements, the FORSAL project focused on finding solutions to immediately improve working conditions, specifically in terms of safety, health and comfort. The project concentrated on the two main elements that cause operator fatigue: the vibrations and the weight of the instrument to be supported.

We analysed commercial grinders currently being used by the SAFAS Foundry. With the health of its workers at heart, SAFAS became a partner in the project to share its experience and facilities to support the analysis, design and validation of a vibration reduction system for commercial grinding and finishing tools.

A multi-thematic analysis (of the ergonomics, mechanical design, vibro-acoustic conditions, tool morphology and performance, tooling dimensions, and finished product quality requirements) was necessary to subsequently define the requirements for an innovative customized system for the specific tools. The materials, methodology and validation paths identified by the analysis can be applied to a wide range of grinding and finishing tools.

To objectively quantify the extent of vibrations transmitted to the operator's hand and arm during grinding operations, instrumentation from the University of Padua (UniPD) was utilized to take and process acceleration measurements for various types of tools used at the SAFAS foundry. The measurements revealed that the Fein type angle grinder, model MSfov852-1 (shown below), transmitted the greatest stresses to the operators. This grinder was therefore chosen as a test case for vibration reduction system.

Ergonomic study of the grinding and finishing process

To create the innovation and facilitate the operators' activities it was necessary to first study the ergonomics of the current situation and to identify objective criteria to measure the comfort of use so that these working conditions and, consequently, the quality of production could be improved.

BNP was the FORSAL project partner that studied the current situation in the steel foundry sector with specific reference to SAFAS with the purpose of identifying a starting point for developing a new solution as well as the requirements it had to meet.

The first task concerned behavioural observation and analysis in the field. In particular, BNP assessed the present state of grinding operations and identified the potential criticalities. Key aspects considered in the analysis were: correct posture, biomechanical risk, the different types of tool handles, their weights, and the length of time the operator had to maintain the positions.

Semi-structured interviews were conducted to obtain the operators' point of view and to focus on the key ergonomic design elements of the tools. Using videos, photos, pictures, and interviews, BNP also analysed body positioning as a function of the type of tool in use and its grip, as described in the table below. The same criteria were used to verify the improvements resulting from the prototype solution designed and created through this project.

Design of the vibration reduction system

A solution was designed using an integrated CAD (computer aided design) and CAE (computer aided engineering) system to attenuate the vibrations transmitted to an operator's hand and arm by the grinder shown in Fig. 1, which is used for surface finishing operations.

The design, developed synergically by all the FORSAL project partners, focused specifically on devising a vibration reduction system consisting of two fundamental elements: a front handle isolated from the grinder body by means of elastomeric anti-vibration mounts, and a device designed to partially decouple the grinder body from its rear handle, again using elastomeric anti-vibration mounts.

Body Position / Type of Tool	Tool Grip
Standing or linear / angular	Neutral / flexion
Leaning (supported) / linear	Neutral
Covering the tool / linear	Neutral / flexion
Covering the tool / angular	Neutral / extension
Inwards / linear	Neutral / flexion
Crouched / linear	Neutral / flexion
Crouched / angular	Neutral / flexion / extension
Force from above / linear	Neutral / flexion
Kneeling / linear	Neutral / flexion
Kneeling / angular	Neutral / extension / flexion

Table 1. Summary of machining postures and tool gripping modes.

Fig. 2. First prototype of the grinder with the vibration reduction system installed.

Fig. 3. FEM model of the grinder coupled to the vibration reduction system.

The geometry and a CAD model of the grinding machine were used to define the shape of the front handle, firstly identifying the potential coupling points between the tool and the new system. The anti-vibration mounts were inserted at these points. The mounts were selected by first identifying a general size using simplified dynamic models and then refining the choice through a numerical investigation based on the finite element model described below. A similar approach was taken to dimension the device that partially decouples the grinder's body from its rear handle. The end result was the prototype shown in Fig. 2.

The numerical study was based on a finite element model (Fig. 3) created to represent the grinder and the vibration reduction system coupled to it. The input data included the force values and acceleration fields obtained from experiments on the grinder during the machining phase and the forces produced by a suitably unbalanced disc-tool, as required by standard EN 60745-2-3:2011+A13:2015 for repeatable tests that reflect typical stress conditions.

The survey relied on three types of analysis:

- a static analysis to identify the stress and strain on the complete system;
- a modal analysis to identify the natural frequencies of the complete system and evaluate them with respect to the force frequencies; and finally
- a harmonic analysis of the amplitude of the vibrations induced on the front and rear handles of the device and then transmitted to the operator's hand and arm.

The results of the analyses (deformations, stresses, and accelerations) were subsequently processed to determine the body's mechanical resistance, its fatigue behaviour, and its efficiency in terms of ergonomic comfort.

Static Analysis

The static analysis was used to determine the stress and deformation on the components of the front and rear handles due to the weight of the grinder, as well as of the maximum force exerted by the operator during grinding activities (Fig. 4).

The static test enabled us to verify the adequate stiffness of the complete system for forces significantly higher than those proposed by the reference standard (45 N), up to a 'feed force' of 70 N verified by SAFAS during operations. Even at this level, the system continues to reduce vibrations by maintaining sufficient gaps between the vibration reduction system and the grinder so as to prevent direct contact between the surfaces of the components thereby attenuating the transmission of the vibrations.

Modal Analysis

The modal analysis was conducted to determine the modes of the system's vibrations (natural frequencies and modal shapes). To describe the human-machine interaction as accurately as possible, we defined the system's constraint conditions by simulating the operator's grip using lumped parameters (masses, springs, and dampers) to generate a representation of the operator's hand (Fig. 5), according to Annex B of standard EN 10068.

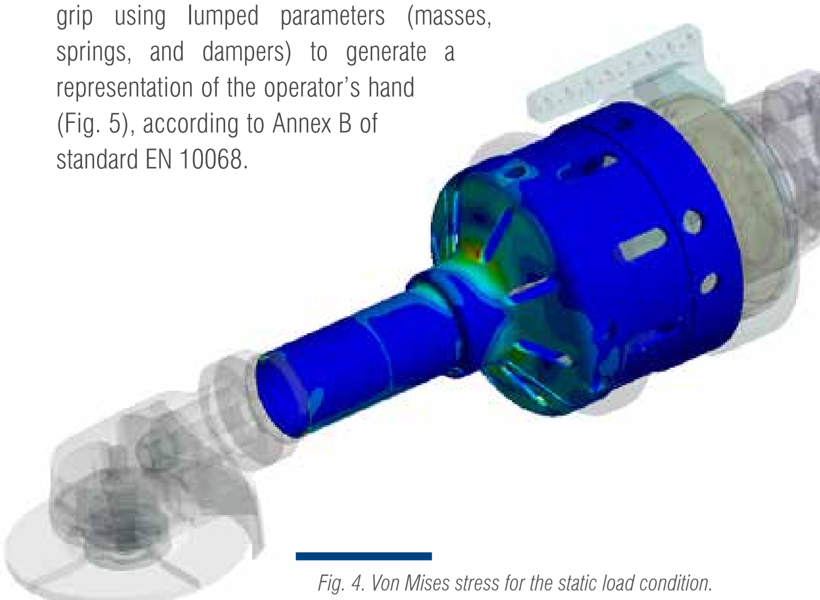

Fig. 4. Von Mises stress for the static load condition.

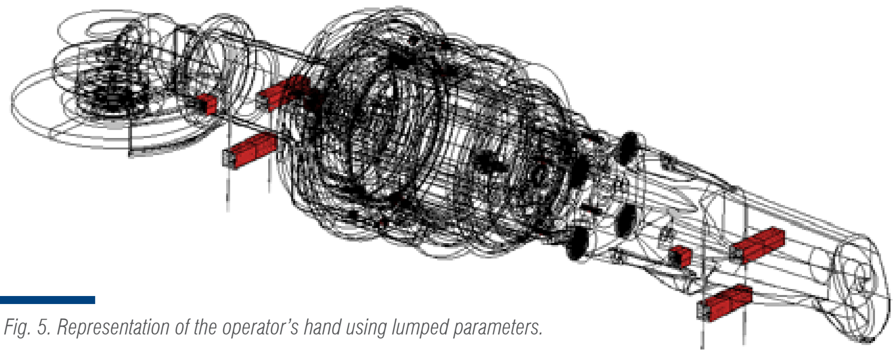

Fig. 5. Representation of the operator's hand using lumped parameters.

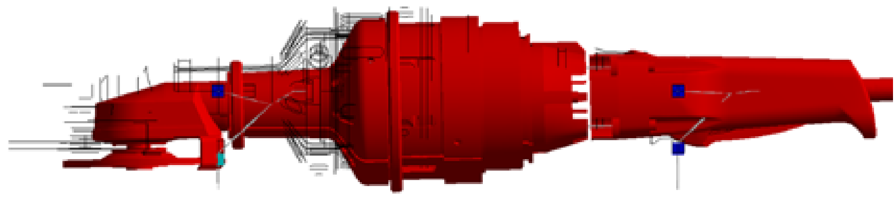

Fig. 6. Representation of the complete system's first vibration mode at a frequency of 1.51 Hz.

When used correctly, the representation of lumped parameters represents the frequency response of the hand in the different grip conditions.

Natural frequencies and modal shapes are the fundamental parameters for designing a structure and/or a component under dynamic load conditions. The minimum design objective required the complete system's natural frequencies to be sufficiently distant from the rotating tool's excitation frequencies to avoid excitations in the device's resonance.

To this end, the stiffness of off-the-shelf anti-vibration mounts was carefully selected, as well as the weight distribution in the front and rear handle components. For instance, Fig. 6 shows the first vibration mode of the complete system.

To effectively reduce the vibrations transmitted to the operator's hand and arm, however, the procedure for selecting the elastic parameters (attributable to the anti-vibration mounts) and the inertial parameters (attributable to the components added to the original grinder) had to be refined to obtain the lowest possible value in the frequency response modules (assuming as input the excitation force and as output the acceleration transmitted to the operators' hands) at the excitation frequency. The harmonic analyses described below enabled us to obtain this result.

Harmonic Analysis

Harmonic analyses are used to describe the behaviour of an object under dynamic load conditions. Resonances can often render critical the resistance of a component that was correctly sized for only static verifications. In the case studied, on the other hand, attention was placed on verifying the device's effectiveness in reducing the vibrations from the handles at the well-known and very slightly variable excitation frequency.

A comparative harmonic analysis was performed to evaluate the ability of the designed device to reduce the amplitude of vibrations transmitted to the handles. The results obtained from the numerical model of the original grinder were compared with the results obtained for the complete system including the vibration reduction devices. The amplitude of force used for the analyses was derived from the indications of standard EN 60745-2-3: for angle grinders with a 125 mm disc, the unbalance value is indicated as being 90 gmm. With the rotational speed of the disc at 8800 RPM, the amplitude of the harmonic excitation is 76.43 N.

These harmonic analyses enabled the absolute effectiveness of the vibration reduction system to be verified and also confirmed that, in conditions of maximum 'feed force', the amplitude of the vibrations is compatible with the residual gaps present between the grinder body and the attached vibration reduction system device.

Fatigue Analysis

Using the results obtained from the harmonic analyses, we reconstructed the time stress histories for the points of interest on the grinder body. These temporal histories were further broken down into histories of peaks and valleys that are useful for counting voltage cycles, for example through the rainflow method.

Noting the tension cycles (amplitude and repetitions) present in the time histories, we analysed the S / N curves to calculate the number of limit cycles and each of their contributions to wear and tear, which enabled us to evaluate the overall damage and relative fatigue life of the component. To calculate the latter, we evaluated the alternating Von Mises stresses acting on the anterior handle of the reduction system.

The fatigue analysis highlighted that the front handle is subject to low tension levels, both from the vibrations induced by the standard unbalance, and from the load of the operator's grip (70 N), which is cyclical in nature. In both cases, the amplitude of calculated voltage is below the fatigue limits prescribed by the Eurocode.

Experimental measurements

A first campaign of experimental measurements was conducted at the University of Padua's Department of Management and Engineering (Dipartimento di Tecnica e Gestione dei Sistemi Industriali). A grinder with a disc with an unbalance equal to that described in the standard was used. This made it possible to measure the vibrations transmitted to the grinder handles modified with the vibration reduction system (Fig. 7).

The results obtained showed dramatically different dynamic behaviour by the anti-vibration mounts, both in compression and in shear, from what was expected based

Vibration	Expected performance without the vibration reduction system	Expected performance with the vibration reduction system	Performance obtained with the vibration reduction system
Anterior Longitudinal	1.4 g	0.37 g	0.75 g
Rear Longitudinal	1.5 g	0.79 g	0.85 g
Anterior Transversal	4.2 g	0.81 g	1.1 g
Rear Transversal	3.3 g	0.27 g	0.12 g

Table 2. Average values of the amplitudes of vibrations on the front and rear handles of the grinder.

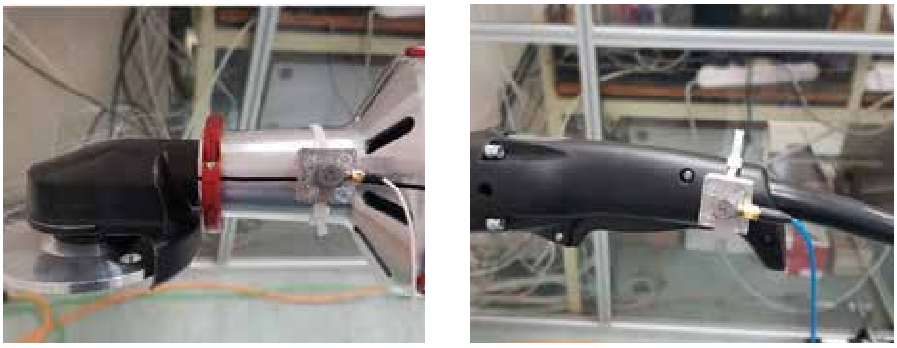

Fig. 7. Location of sensors placed on the handles of the modified grinder (front left and rear right).

on the technical documents provided by the suppliers. In particular, a viscoelastic behaviour emerged that is certainly dependent on the excitation frequency and the amplitude of the deformations. The relevance of the detected discrepancies has imposed a detailed analytical, numerical and experimental analysis which has allowed identifying equivalent stiffness values for the anti-vibration mounts, valid both for the grinder's usage range of frequencies and for the amplitudes of the expected deformations, which can properly describe the mounts altered dynamic behaviour.
Subsequent to appropriately recalibrating the numerical model, a second prototype of the newly modified grinder was created. This showed excellent performance and was also used in field tests in the foundry (see Fig. 8), achieving the results summarized in Table 2.

Conclusions

From an ergonomic point of view, it should be noted that after numerous operators had used the modified grinder for a period of time, they appreciated the reduction in the vibrations transmitted to their hands, while the system's ability to withstand static loads was also deemed adequate. Since the vibration reduction system significantly increases the weight of the grinder, it is intended to be used with a support system, to which operators have adapted easily overall. They have however highlighted critical issues that have led to its redesign by BNP.

Twenty-seven different processing tests were conducted using two distinct types of abrasive disc and placing the grinder in the various positions typically adopted: mainly horizontal or vertical (Fig. 8).

The prototype system that was designed and built satisfied the efficiency and quality requirements and improved working conditions in terms of safety, health, and comfort by eliminating the two main causes of operator fatigue: vibrations and weight to be supported.

The vibration reduction system and its support require further refinement before being industrialized and made available for a wide range of applications and for other application areas. It should be further noted that the grinder can also be connected to the mechanical interface of a collaborative robot by means of the special flange already present in the prototype to extend the benefits of its excellent vibration reduction ability to robotic systems, too.

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Fig. 8. Typical processing tests using the modified grinder.

Open innovation platform for material modelling in organic electronics

MUSICODE addresses the Horizon 2020 Call number DT-NMBP-11-2020 "Open Innovation Platform for Materials Modelling" with the aim of creating a comprehensive modelling environment for materials design and processing, and device optimization in the Organic Electronics application domain. The platform integrates: modelling workflows spanning the micro-, meso- and macro-scales; graphical user interface tools for workflow design; a data management and execution framework with ontology-based semantic interoperability and plug-ins to Materials Modelling Marketplaces, the Open Translation Environment, and HPC infrastructures.
Industry workflows for optimizing material properties and manufacturing will be demonstrated.

The challenge for modelling is to enable expeditious and accurate business decisions targeting high efficiency, performance and manufacturability while reducing errors, defects, resource waste, and performance variabilities.

But maintaining industrial competitiveness also requires efficient design, fast uptake of new materials, and smart adaptation of processing conditions.

This makes the challenge even more complex and ambitious given the sheer number of new candidate materials being discovered every year and the multitude of processing variations.

Nevertheless, this great challenge is also a great opportunity. Organic and Large Area Electronics (OLAE) do not share the same restrictions as their inorganic counterparts: candidate materials are unlimited; process changes are not prohibitively expensive; there are less cross-contamination issues when changing materials; there are few compatibility issues; there are no prior-investment issues. Multi-scale modelling

Project No: 953187, **Duration**: 2021-2024, **TRL**: 4 → 6
University of Ioannina (Coordinator)
Karlsruhe Institute of Technology
University of Surrey
Aristotle University of Thessaloniki
Czech Technical University in Prague
Fluxim AG
TinniT Technologies GmbH
Ansys
ESTECO SPA
Organic Electronic Technologies
AIXTRON

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Call DT-NMBP-11-2020.

website:
musicode.eu

can be a guide through this largely unexplored terrain and become a decisive tool in propelling the OLAE industry's design capacity and productivity towards world leading applications and products.

This is the vision and objective of MUSICODE: to create an Open Innovation Platform for Materials Modelling and unleash the potential of OLAE. The project objectives are:

1. Develop novel validated multiscale modelling workflows for OLAE materials, processing, and devices;
2. Develop an ontology-based integrated modelling platform for workflow design, execution, data management;
3. Cooperate with EU stakeholders (European Materials Modelling Council, Marketplaces and High Performance Computing centers) for a complete customer offer.
4. Implementation of modelling workflows to optimize the manufacturing of organic photovoltaics (OPV) and organic light emitting diodes (OLED).

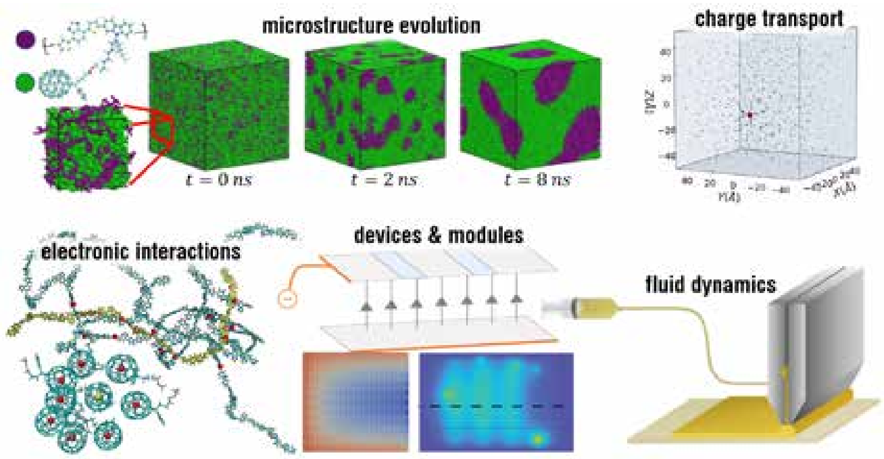
MUSICODE aims to create modelling workflows spanning the micro-to-macro (electronic-to-continuum) length scales and address specific problems related to the development and fabrication of OPV devices.

These include the effect of the material structure, photoactive blend composition, dopant concentration, and process parameters (e.g. nozzle shape, temperature, ink viscosity, printing speed, substrate treatment) on final material properties and device performance. The chosen physics models are run hierarchically with the output of one becoming the input for the next, returning results and key performance metrics back to the user.

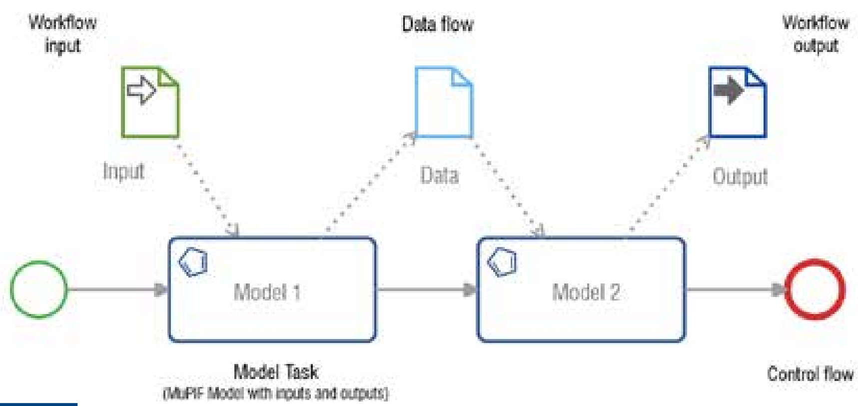
Modelling scales include electronic and atomistic (UoI), mesoscale (KIT), continuum (TinniT), and device (Fluxim). To compile the modelling workflows, a novel workflow editor will be developed based on the Business Process Model and Notation (BPMN 2.0) standard and ESTECO Cardanit tool.

OET's OPV installations in an agricultural green house

R2R pilot line to validate the modelling workflows



MUSICODE's multiscale modelling, from electrons to devices



ESTECO's novel workflow editor for multiscale modelling

The workflows will be delivered to a novel interoperability layer (CVUT:MuPIF) for execution and then to an innovative data management system (Ansys:MI) for data population and traceability.

Careful validation is key to the successful implementation of modelling. MUSICODE models will be tested with extensive experimental fabrication and the characterization of materials and devices (AUTh, USUR, Fluxim) and validated in real industrial pilot lines (OET, AIXTRON).

Our goal is for MUSICODE to become the central EU open innovation platform and repository for modelling, workflows, data, and metadata in Organic Electronics.

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FF4EuroHPC continues its mission to inspire SMEs to unleash their innovation potential with the help of innovative technologies

by Emanuele Della Volpe[1], Marisa Zanotti[2]
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High-performance computing (HPC) and related advanced technologies assist and enable organizations in a wide range of sectors to develop innovative products, optimize production cycles, shorten design cycles, use fewer resources or materials and, in particular, reduce production costs and time. FF4EuroHPC aids the competitiveness of European SMEs by funding business-oriented experiments and promoting the adoption of advanced HPC technologies and services. Two open calls were offered under the project, with a funding budget of €8-million dedicated to assist experiment partners.

Supporting **42 experiments and 118 experiment partners from 22 European countries**, the FF4EuroHPC project successfully continues Fortissimo's mission to connect business with innovative technologies thereby increasing the innovation potential of European industry. Each of the selected experiments targets a specific economic sector of end-users and is designed to accelerate innovation and create business value in that area. The manufacturing sector accounts for more than half of the experiments, followed by engineering consulting, and the medical and healthcare sector. The first tranche of the experiments will be concluded in the coming weeks and will produce success stories, presenting information on business benefits for participating SMEs and also for other supporting organizations. In addition, benefits for society and the environment will be highlighted through the results, as well as business advantages.

FF4EuroHPC presents an HPC-based navigation system for an autonomous marine litter hunting project

Protecting the seas and oceans from litter is becoming a global concern and around the world there is a growing need for more efficient, clean, and autonomous technologies to identify and collect marine litter, particularly plastic, in a systematic and repetitive manner.

About the experiment

Green Tech Solution is an innovative start-up working in the field of environmental protection and the blue growth economy. It

has developed ‘Litter Hunter’, a system consisting of an unmanned aerial vehicle (UAV) and an unmanned surface vehicle (USV) that work together through a ground control station to identify and retrieve solid waste floating at sea.
High-performance computers make it possible to tackle a computational problem that Green Tech Solution encountered during the plastic waste recovery service at sea: optimizing the plastic waste recovery strategy by predicting with adequate accuracy in space and time the position of hundreds of pieces of floating waste at sea.

Fig. 1. Neural network trained in object detection can classify objects with an average accuracy of more than 90% Copyright: Green Tech Solutions.

The proposed experiment, called ‘HPC-based Litter Hunter’, is crucial for taking the collaboration of unmanned systems to the next stage, as it requires more than 250.000 hours of deep learning, which is impossible with conventional computational systems.

The experiment was divided into the following interconnected tasks: design a data collection campaign dedicated to the acquisition of aerial footage tracking the movement of 20 objects for 120 minutes. At the same time, four Laser Drifts (biodegradable buoys used to map surface currents) were released from which further trajectories were derived, as well as important meteorological-oceanographic data. In addition, two days were dedicated to the acquisition of aerial footage of five classes of litter useful for training a neural network for object detection and classification.

The result was 10.000 marine litter tracers for 60 simulations in an area covering the entire Gulf of Naples. The data enabled the training and validation of the path prediction neural network, achieving the desired accuracy over a 100-minute forecast. Finally, an optimization strategy was developed using a genetic algorithm capable of determining interception trajectories with a multi-objective approach: minimizing the distance travelled by the catamaran and the recovery time, while maximizing waste recovery.

Key outcomes and results

At present, the experiment has produced a series of results to overcome the initial limitation by following four steps:

1. Aerial filming of a series of floating marine litter using a fleet of two or more drones.
2. Identifying and classifying marine litter in terms of size and materials (PET, PPT, biological) using a neural network trained to recognize five types of objects: hard plastics, soft plastics, plastic bottles, masks, and polystyrene.
3. Predicting the evolution of the trajectories of the classified waste, using a second neural network, over a sufficiently long period of time.
4. To look for the best trajectory to collect as much waste as possible while minimizing the distance travelled by the catamaran and the recovery time, respecting its structural and performance limits.

The future

This updated version of Litter Hunter will revolutionize the approach to monitoring and remediation of bodies of water. The pipeline from aerial observation by drone to data output for an automated mission that will be executed by the USV saves up to 80% of economic resources compared to current approaches. Green Tech Solution aims to expand the system's operations from the Italian coast to over 2.000 km of European coastline, reaching Spain, Greece and Norway.

FF4EuroHPC presents cloud-based CFD optimization of magnetic drive pumps

The experiment will investigate and optimize magnetic drive centrifugal pumps using cloud-based HPC with the aim of improving performance and developing new products. Mag-drive chemical process pumps eliminate the need for shaft sealing, increasing safety and reducing costs. Axial thrust balancing is critical to design: CFD (computational fluid dynamics) allows this to be predicted, but optimizing pumps

Fig. 2. Copyright: Green Tech Solutions.

Fig. 3. A magnetic drive centrifugal pump.

to maximize efficiency, minimize thrust, and avoid cavitation requires exceptionally large models. Therefore, an advanced HPC infrastructure and CFD engineering tools are essential.

Brief description of the experiment

CDR Pompe will provide the necessary specifications to build a model to study the operating conditions of its pumps, aiming to improve their performance and produce a product that best suits the market needs. As these objectives require an HPC infrastructure and engineering tools, the simulation will involve high-fidelity CFD transient analyses on Ansys software. The optimization process will be geometry-related and based on design of experiment (DoE) and response surface methodologies. In this regard, EnginSoft has committed to providing the engineering know-how in terms of CFD modelling, while CINECA will provide the necessary hardware and support to conduct CPU-intensive parallel calculations through the cloud.

Innovation

While a single pump impeller can be easily studied, simulated, and optimized, an entire machine is an entirely different undertaking. Modelling the entire performance curve to revamp the pump design to maximize efficiency and minimize thrust and cavitation requires a far more complex model. This is particularly challenging because any assumptions made to simplify periodicity fail when applied to the magnetic drive system in an operating scenario.

This innovative approach aims to operate and test the pumps in extreme and critical situations, such as off-design conditions at the cavitational or vibrational limits: the multi-domain parametric calculation will optimize the pump's performance and operating range, thereby increasing expected productivity and reducing required maintenance.

EnginSoft's role

EnginSoft will take advantage of its extensive experience in the rotating machinery market to provide engineering know-how in terms of fluid dynamic parameterization and CFD modelling. The company's technical contribution consists of selecting the best turbulence model and rotating frame algorithms to accurately predict the performance parameters of the pump, with a focus on axial thrust.

The parametric geometry will be created ensuring maximum robustness and meshing efficiency using geometric and automated meshing tools from Ansys. The CFD solution will be configured to be automated and repeatable for all project designs, with both qualitative and quantitative monitoring of key results. The automated process will run its hundreds of design points on CINECA's HPC system, collecting sufficient data to optimize the pumps using the response surface methodology.

The experiments "HPC based Litter Hunter" and "HPC4POP" have received funding from the European High-Performance Computing Joint Undertaking (JU) through the FF4EuroHPC project under grant agreement No. 951745. The JU receives support from the European Union's Horizon 2020 research and innovation programme and Germany, Italy, Slovenia, France, Spain.

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AGILE manufacturing for competitiveness and product innovation

by Nicola Gramegna
EnginSoft

The AGILE project stems from discussions held within the Veneto system of companies and research organizations in the post-emergency period to identify a strategic approach to achieve 'agile' reconversion of production systems by applying advanced solutions to product innovation. It is part of the Smart Manufacturing specialization strategy and is an 'industrial reaction' to the COVID-19 emergency, focusing on flexibility, reconversion, and resilience, which positions it within the broader competitiveness objectives for Industry 4.0-based businesses.

The AGILE approach is underpinned by several 'lessons learnt' during the Covid-19 pandemic, namely the importance of:

- Competitiveness: to enable rapid product innovation and adapt production systems accordingly;
- Emergency situation response: to ensure the ability to rely on a structured, integrated, easily reconfigurable system;
- Quality control in an agile production system: to implement innovative remote monitoring methodologies supported by artificial intelligence and certification;
- 'AGILE' reconfiguration: to compete with equal parity in the aspects of quality/functionality and work safety standards.

The AGILE Project operates within specific and representative types of production lines, namely:

- aluminium alloy and cast-iron foundry;
- profiling of aluminium alloys;
- assembly of welded components, in various materials

Project PARTNERS

The project partners are members of the Italian SINFONET and M3NET Regional Innovation Networks, namely: Zanardi Fonderie, Ecor International, SAEN, AM Teknostampi, Delka, Promotec LSMC, MBN, Unilab, EnginSoft, GOM Italia, NCR (National Research Council) ICMATE (Institute of Condensed Matter Chemistry and Energy Technologies), and the University of Padua's Department of Management and Engineering (Dipartimento di Tecnica e Gestione dei Sistemi Industriali, DTI) and Department of Industrial Engineering (DII).

Regione Veneto - POR FESR 20214-2020 azione 1.1.4.

About the AIM National Conference:

The AIM National Conference is the benchmark initiative for business technologists, researchers and academics working in metallurgy.

The 39th edition takes place from 21-23 September 2022. It is especially important because it comes after the two-year pandemic and because metallurgy is becoming increasingly pertinent in the context of the ecological transition, sustainable mobility, the circular economy, and the ever-higher performance required of any mechanical component. The centrality of metallurgy to these issues will take centre stage during the three-day conference, which will analyse materials, products, processes, and technologies.

SINFONET is one of the sponsors of the conference and three presentations will be dedicated to AGILE Project.

For more information, visit: aimnet.it/nazionaleaim

The enabling technologies of the project are:

- Advanced Manufacturing Systems (virtualization of the design phase; development and industrialization of advanced and rapid production technologies; rapid reconfiguration and optimization of design and production lines; and intelligent quality management);
- Advanced Materials (production of high-performance light alloys and cast irons; use of additively manufactured components; and use of innovative powders to optimize tool life);
- Nanotechnology (production of nanostructured powders for tools; and the nano-scale characterization of material surfaces).

The scope of the innovations targeted can be outlined by reference to AGILE's areas of activity:

- Virtualizing the design phase to manage and optimize the design chain: integrating and customizing systems in relation to the characteristics of the production cycles;
- Developing and industrializing advanced and rapid production technologies;
- Rapidly reconfiguring and optimizing the production lines to manage product and batch variations while introducing KPIs (key performance indicators) and OEEs (overall equipment effectiveness indicators) to ensure the flexibility of the entire production system;
- Intelligently managing quality by implementing monitoring and control systems that use predictive quality models for near real-time production interventions and by increasing product traceability for digital certification.

Several industrial cases and their demonstrators, which exploit the smart manufacturing approach and implement the innovative solutions mentioned above, will be presented during the upcoming AIM National Conference in Padua in September 2022.

Accurate pollutant prediction with Equivalent reactor networks

by Fabio Villa
EnginSoft

The simulation of reacting flows is critical for developing competitive products in diverse industries: transport, power generation, materials processing, the chemical industry, and many others. Improving designs for these cases is difficult because they often consist of systems with complex geometries, boundary conditions, and physics, including large networks of chemically reacting species, turbulence, and radiation.

Using the appropriate fuel model enables exploratory design particularly to predict:

- Ignition delay and fuel efficiency
- The effects of varying fuel composition
- Emissions, including soot particle number and size
- Undesired auto-ignition effects (such as knocking, reliability, noise, and operability limits)

The more accurate the fuel model, the more realistically the fuel performance of your design can be predicted. Ansys Chemkin couples Multiphysics simulations incorporating advanced physical models with an advanced chemical solver to provide full simulation capabilities for reacting flows. Many tools have recently been included in the Ansys CFD enterprise license.

Ansys Chemkin

Depending on the complexity and chemical detail of the combustor application, there are several reactive CFD methods to choose from:

- Direct integration
- Table look-up with CFD progress variables
- Equivalent reactor network

The first two methods use a classical (3D) CFD application solver (such as Ansys Fluent/CFX) and are better choices if geometric details are to be included in the simulation, but may be expensive in terms of CPU time if a detailed mechanism is included, or if an extensive design-of-experiments campaign is to be created.

In these cases, equivalent reactor networks (ERNs Fig. 1) which mimic flow but allow for fully detailed chemistry are a viable method that combines high-fidelity flow simulation with detailed kinetics (Fig. 2). Manually generated ERNs, which are linked 0-D models, have long been used to provide high fidelity.

Ansys Chemkin is a standard for solving complex chemical kinetics and surface chemical reaction problems used in the conceptual development of combustion systems. It has evolved since its inception as the Sandia National Laboratory combustion kinetic code (Chemkin II) and has been extensively validated over several decades and is frequently cited in peer-reviewed technical journals.
Engineers can quickly explore the impact of design variables on performance, pollutant emissions, and flame extinction by simulating real-world combustors, burners, and chemical reactors, permitting emissions to be predicted most efficiently with detailed chemistry in minutes.

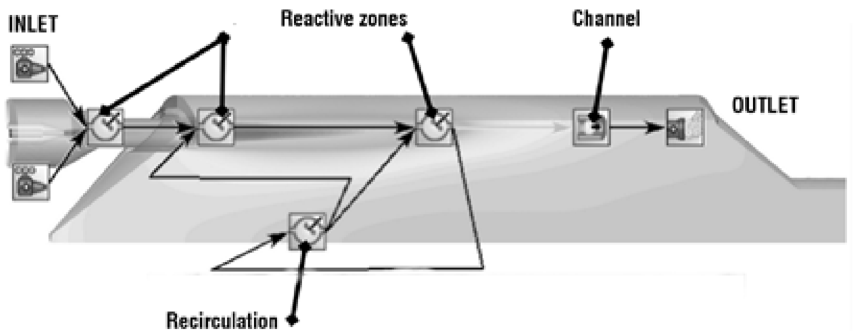

Fig. 1. Equivalent Reactor Networks.

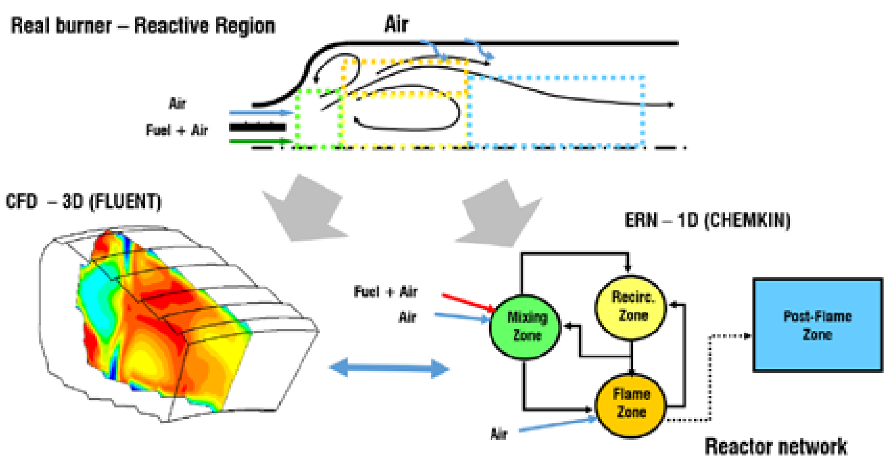

Fig. 2. Burner simulation to link detailed combustion chemistry and CFD.

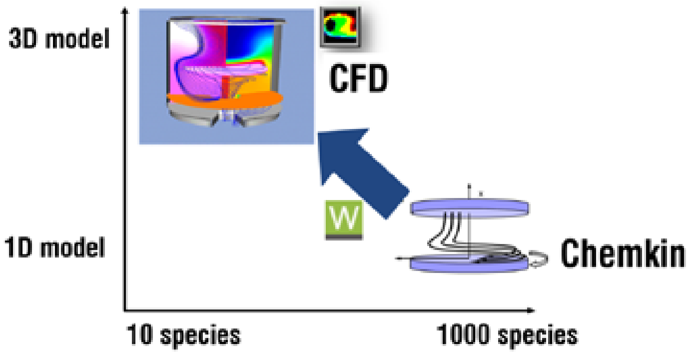

Fig. 3. Standard mechanism reduction process in Ansys CFD.

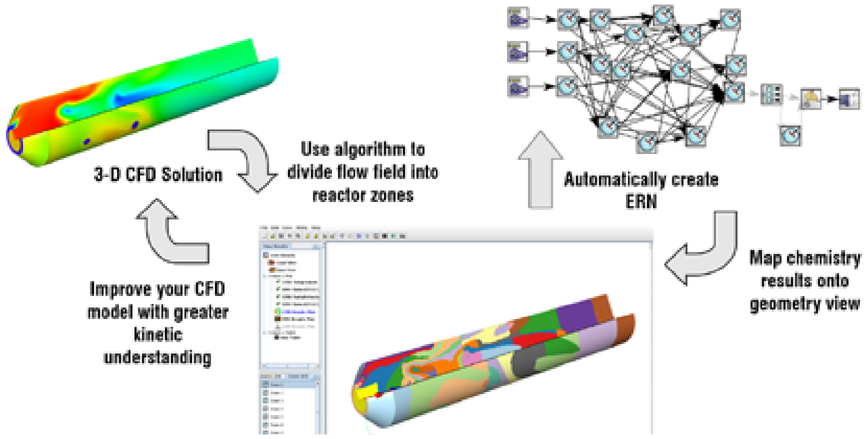

Fig. 4. Automatic generation of an ERN from 3D CFD results using Energico.

ERN simulations yield fast and accurate emissions and stability predictions, particularly for applications that may be challenging to conduct directly in CFD due to complicated flows. Another advantage over other combustion methods is that you can quickly explore operating conditions, fuel effects, and fuel load without having to run large CFD simulations every time, saving design time.

Ansys Model Fuel Library - CFD

A fuel model is defined by two components: its composition and its chemical kinetics or 'mechanism'. The Ansys Model Fuel Library (MFL) is a source of over 65 well-validated fuel mechanisms (H2 is included) and is the result of a ten-year collaboration with industry, academia, and national laboratories.

Compared to public data, it provides consistent rules for reaction rates and validated fuel-blending behaviour. Detailed soot kinetics have been validated from scratch, ensuring accuracy in predicting the multistage emission formation process.

The generation of a surrogate fuel from the MFL mechanism allows designers to accurately match fuel properties including chemical class, heating value, octane/cetane number, H/C ratio, boiling points, and soot threshold index. Using raw data from the public domain may not be as predictive.

Ansys Reaction Workbench

A master chemical mechanism, directly from the model fuel library, may be too complex to be used in a CFD simulation. However, a manual reduction of such a mechanism is not simple and may provide undesirable results.

One way to avoid oversimplification of the chemistry is through automated chemistry reduction, which converts the detailed fuel model to a smaller size suitable for calculation, while maintaining the accuracy required for specific engine or fuel conditions or key predictions of engine performance (Fig. 3). Ansys Chemkin-Pro Reaction Workbench for example automatically generates the smallest skeletal mechanism that meets selected specifications, such as target parameters and acceptable error tolerances.

Ansys Energico

Manually-generated equivalent reactor networks (ERNs) for a combustor are also commonly difficult and error-prone. Today's advanced specialized software tools allow designers to quickly explore ERN strategies and sensitivities, resulting in fast, accurate and predictive system models.

For example, Ansys Energico simulator accelerates combustion system design and allows detailed chemistry to be used even if you do not have an indepth understanding of complex kinetics (Fig. 4).

The resulting ERNs simplify design exploration easier such as setting up automated parameter studies for variations in important operating conditions. The method is appropriate for the design of furnaces, burners, gas turbines, boilers, and flares. It is a quick way to include better chemistry without compromising CFD quality.

Conclusion

The incorporation of detailed kinetics into CFD simulation is the baseline for any recent application in the combustion field. The correct combination of methodology described here, and technology enables you to predict important parameters such as fuel effects, ignition, combustion phase, and emissions.

Ansys simulation tools eliminate the traditional trade-off between accuracy and speed by using the right methods and the right chemistry for your specific application.

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Paste Extrusion Modelling (PEM) 3D printing using the PUR polycomponent process

The "Goliath" 3D printer prints large-format urban furniture and other objects from any granulate. Another future innovation is under water printing.

The newly developed "Goliath" manufacturing system from the German startup Teu2tec GmbH enables rapid 3D printing of large-format objects from any granulate using the paste extrusion modelling (PEM) process.

The system uses classic two-component polyurethane binders with fast curing times and granules with grain sizes of up to 2,00 mm. Due to the fast curing of the material (< 10 s), this process guarantees both economical production and almost unlimited freedom of design.

By adapting the binders and materials used, the product properties can also be flexibly adjusted. All products to be manufactured can thus be cured elastically or firmly.

Printing method

The special design of the print head enables the printing of highly viscous pastes. "Due to the very short pot life of less than 10 seconds, we can currently work with printing speeds of up to 300 mm/s with a mass flow of up to 100 g/s.
That, already, is very impressive!" states Jens Mikus, development engineer at Teu2tec.

The layer height can be adjusted from 3 mm to 12 mm, which not only enables fast printing processes, but also makes it possible to realise optically complex components due to the low layer height. The volume of 2200 x 2200 x 2000 mm is large enough for designing furniture or playground equipment in its entirety for urban development.

Discontinuous printing

In an initial series of tests, the Teu2tec team has already succeeded in setting down and repositioning the print head during the active printing process. With the process technology used, an interruption of the extrusion during the additive process is realised and repositioning is made possible without further printing paste escaping from the nozzle.

Underwater printing process

The first "under water" printing tests were concluded at the beginning of 2022. It is already becoming apparent that the process with appropriate binder systems enables components to be printed under water.

This significantly expands the field of application and classifies this printing process as a highly flexible and unique manufacturing process.

Currently the Teu2tec team is looking for partners to further develop the technology and to pilot the production process, as well as for investors.

About Teu2Tec Industries

Teu2tec was launched in 2018 to support innovation. As a service provider, the company actively supports the development and implementation of new ideas, products and processes. Teu2tec sees itself as an "agile archipelago" for its partners and provides them with freedom in many ways. Ideas need space. In addition to dynamism and flexibility, Teu2tec's core competencies include credibility, enthusiasm, and conflict management - skills that often make the decisive difference between success and defeat, especially in processes of change.

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Special vehicle manufacturer REFORM relies on additive manufacturing from 3D solution provider, Prirevo

REFORM develops and manufactures special vehicles for year-round use in mountain agriculture and in municipal areas. The company relies on additive manufacturing from 3D specialist, Prirevo, based in upper Austria, for flexible and innovative product development.

Developing modern, versatile, and economical special vehicles that can withstand continuous use in challenging conditions requires a high level of expertise and experience. Growing product portfolios and variations require greater flexibility in shorter time frames. For an innovative company like REFORM, additive manufacturing processes were a logical step for product development.

The 3D solution provider Prirevo quickly emerged as a suitable partner: a manufacturer-independent specialist that provides the best hardware for specific requirements and supports implementation with exceptional know-how.

From the digital model to the printed ABS interior.

3D-printed vehicle cabin on show in Prirevo's showroom.

Outstanding prototypes that reduced time and costs at the same time

Using 3D printing enabled REFORM to rapidly and flexibly create many vehicle parts during development, which reduced costs.
Today, the company manufactures complete interiors, trim parts, rooves, wings and bonnets. It optimizes the fittings ergonomically, quickly, and inexpensively. Larger pieces are glued, filled, and painted.

Increasing the applications of 3D printing thanks to a good partnership

Years of successful collaboration with Prirevo are reflected in REFORM's growing use of additive manufacturing processes. Currently, the company owns two 3DGENCE F340 printers and one 3DGENCE ONE 3D printer. At peak times, REFORM makes use of Prirevo's 3D printing services, taking advantage of its regional proximity.

"*Using additive manufacturing processes allows us to create excellent prototypes that save us both time and money. We have found an excellent and reliable partner in Prirevo for the implementation of our high standards,*" says Dominik Haas, design engineer at REFORM.

REFORM thus benefits from Prirevo's strict focus on quality, user benefits, and on-site service, attributes that many other satisfied customers have been relying on for years. Prirevo manufactured more than 8.000 components for these satisfied customers in 2021 alone.

About REFORM

REFORM develops and produces special vehicles for year-round use in mountainous agriculture and municipal technology. Successful REFORM products include the Muli and Boki transporters, Metrac and Mounty tool carriers, Motech single-axle mowers, and Boki cemetery excavators. REFORM is an innovative and customer-focused family business with an international outlook. The company group includes Reform-Werke in Wels (Austria), Agromont AG in Hünenberg (Switzerland), and Kiefer GmbH in Dorfen (Germany).

For more information, visit:
www.reform.at

About Prirevo

The 3D solution provider Prirevo offers a comprehensive range of manufacturer-independent additive technologies and services. Located in Ried im Traunkreis (Austria), it's premises house an innovation centre, a digital factory, and an impressive showroom.

For more information, visit:
www.prirevo.at or contact:
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2022

38th INTERNATIONAL CAE CONFERENCE

METAMORPHOSIS TO FULL DIGITAL MASTERY

Successful transition through artful technology deployment

16-17 NOVEMBER
ONLINE

Transferring technology know-how by studying industrial implementations

18 NOVEMBER
VENICE, PALAZZO LABIA, RAI VENETO

Inspirational thought leadership to guide/ support successful transition

The 38th edition of the International CAE Conference, the annual event that explores the evolution and new trends in numerical simulation, will be **transitional in nature**.

The event will be divided into two separate and complementary initiatives:

- **16-17 November** will be **dedicated to software technology producers**, each of whom will have a channel in which to host their own symposium, to be held in English and/or Italian (at the organizer's choice) and to present particularly significant experiences or case studies online;
- **18 November** will be held, by invitation only, in the prestigious Palazzo Labia in Venice, home of RAI Veneto, and will feature discussions by **leading representatives of industry and academia** to share visions and strategies for successful digital transition. This event, in Italian, can also be attended online.

In line with the changes sweeping across the world in the wake and waves of the Covid-19 pandemic, the 2022 edition seeks to bridge the established and respected traditions of past editions and the future versions of the event.

Anno di transizione quello che caratterizzerà la 38a edizione dell'International CAE Conference, l'annuale appuntamento che esplora l'evoluzione e le nuove tendenze della simulazione numerica.

L'evento si articolerà in due distinte iniziative, tra loro complementari:

- **le giornate del 16 e 17 novembre** saranno **dedicate ai produttori di tecnologie software**: ogni organizzatore avrà a disposizione un canale per proporre il proprio simposio, che consentirà di presentare esperienze particolarmente significative in modalità on-line. I contributi potranno essere, a scelta dell'organizzatore, in italiano e/o in inglese.
- **l'appuntamento del 18 Novembre**, nella prestigiosa sede della Rai Veneto, Palazzo Labia a Venezia, prevederà la partecipazione di **importanti rappresentanti del mondo industriale ed accademico**, che si incontreranno per condividere strategie e visioni per una transizione digitale di successo. All'evento, in lingua italiana, si potrà presenziare su invito, oppure assistere in modalità on-line.

L'evento del 2022 vuole essere un ponte tra la consolidata tradizione delle passate edizioni ed il futuro della manifestazione.


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