Left: Optimized spring cup
Right: Original spring cup

CASE STUDY

Topology Optimized Spring Cup for Rail Vehicles

An award-winning research project of topology optimization enhancement with sand 3D printing for a lighter and longer lasting spring cup for rail vehicles that reduced CO_2 emissions and energy cost in its production, carried out by the Austrian Maschinenfabrik Liezen und Gießerei (MFL), the Austrian Foundry Institute (ÖGI), ExOne, and other project partners.

MFL ÖGI ExOne™

About MFL

Maschinenfabrik Liezen und Gießerei Ges.m.b.H. (MFL) is an Austrian company with two business units: Mechanical engineering and steel foundry. The company's mechanical engineering unit provides manufacturing consulting / engineering, individual and serial production of components up to 50 t weight and 35 m length, mechanical and plant engineering, as well as assembly and commissioning. Whereas the steel foundry unit uses a shell mold casting process to supply high-precision, serial production steel castings along with engineering and consulting services for its customers. It produces molds in max. 1,020 x 660 mm with a weight of 0.5 – 180 kg. MFL has around 700 employees, 220,000 m^2 company area, and 66,000 m2 hall space in one location. The company is part of the powerful MFL Group, which is represented by distributors or sales offices in over 50 countries worldwide, offering customers numerous synergies.

About ÖGI

Österreichisches Gießerei-Institut (ÖGI), or The Austrian Foundry Institute, is an association of practical foundry research which focuses on applications of castings in transport applications (automotive, rail, aerospace). ÖGI was established in 1954 and is a member of Austrian Cooperative Research (ACR), Austria's technology network and second largest non-university research organization.

CUSTOMER
Maschinenfabrik Liezen
und Gießerei Ges.m.b.H (MFL)

HEADQUARTERS
Liezen, Austria

INDUSTRY / PRODUCTS
Mechanical engineering & steel foundry
Casting consulting & engineering
High-precision steel castings

WEBSITE
www.mfl.at

RESEARCH PARTNER
Österreichisches Gießerei-Institut (ÖGI)

HEADQUARTERS
Leoben, Austria

RESEARCH SPECTRUM
Practical foundry research

WEBSITE
www.ogi.at

SOLUTION
ExOne S-Max® Pro

MATERIALS
Sand: Silica sand, Binder: Furan

The Challenges

Maschinenfabrik Liezen und Gießerei Ges.m.b.H. (MFL) stands for sustainability and is part of the UN Vision 2045. MFL aims to minimize the carbon footprint and the resource consumption for its products, taking the whole product lifecycle into consideration, from the production to the use and recycling. MFL tries its best to reduce environmental impacts caused by its productions. As an expert in casting, it also designs innovative products which help create a greener future.[6,7]

MFL also aims to be a powerful and reliable partner to the industry for decades to come. One of the fields it serves is railway traffic technology, which includes safety castings, safety welded assembly groups, and rail vehicles. Its strength lies in precision serial production.[6,7]

Railroads are increasingly confronted with the demand for lighter components, a challenging undertaking in view of the high risk potential, especially for safety components. While the international rail industry tends to act conservatively, an Austrian research project led by MFL has set the course for dramatic energy savings in the environmentally friendly mode of transport. Since 2019, the company and its research partners have been investigating how resources can be saved in the production and use of castings.[8]

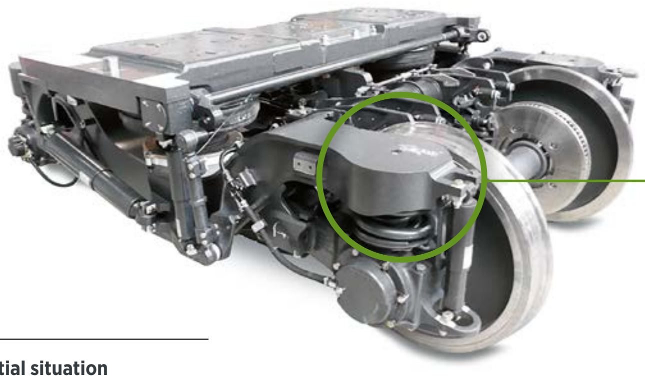
The research project, called "Inno-Up", is an open and collaborative project involving 22 organizations or project partners: MFL, ÖGI (The Austrian Foundry Institute), ExOne (the market leader in 3D sand printing solutions), and other foundries, component suppliers, casting users, and research institutes.[3,9]

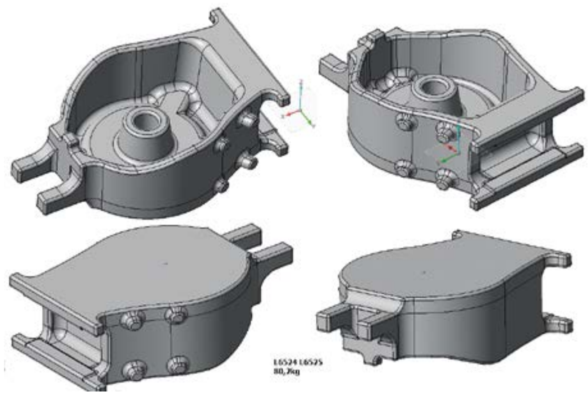
*"**Usually, customers come to MFL with their own design**, ready-made geometry, in their own perception of the component. We took a step back and asked the customers if they really know **what the component must be able to do.**"*

Markus Schmid, MFL

The Inno-Up project's goal was to test the use and networking of digital techniques for application-optimized dimensions and process-reliable production of cast components, as well as the use of the free design possibilities in casting with the targeted influencing of local material properties.[9] Moreover, it also aimed to increase both the innovation potential and the willingness of foundries (80 % of which are SMEs) to innovate with regard to the application-optimized dimensions and the reliable production of cast components.[8]

The project team decided to optimize the design of the spring cup, one of the high security components in railway vehicles (see the image below). Four spring cups made of steel G20Mn5+N weigh 62 Kg each and are assembled in one bogie frame of a train.[2,9]





Initial situation
Left image:
Example of a spring cup installed inside a bogie frame of a rail vehicle

Right image:
The spring cup was made of G20Mn5+N with a weight of 62 kg

The spring cup project had several goals:[2]

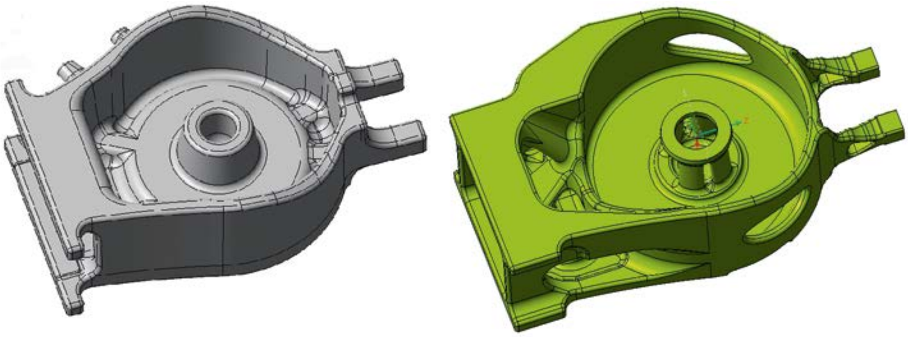
- To demonstrate the potential for weight optimization of a real component
- To develop an optimized design concept of the spring cup
- To design the concept according to power flow
- To minimize the weight of the spring cup up to 20 % while maintaining the same mechanical properties

One main challenge for MFL throughout the project was applying its engineering knowledge to rethink design focused around the actual function of a casting. "Usually, customers come to MFL with their own design, ready-made geometry, in their own perception of the component. We took a step back and asked the customers if they really know what the component must be able to do. We know approximately the constructed space where the geometry may be on. And we ended up only using or installing these materials, which are required for the force transmission," said Markus Schmid of MFL.[1]

The Optimization Steps

Topology optimization

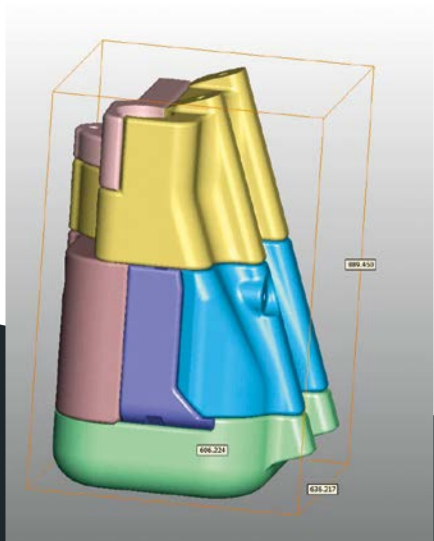
The research project involved a number of phases and steps. To maximize the performance of the spring cup, the project started with a topology optimization[1], including analysis of the original construction, determination of design space and design variables, and calculation of the optimized structure.[9] The project aimed to develop an optimized concept design of a cast component (raw part – without machining) based on the available design space. The concept should be force-flow compatible and thus have a minimum weight with the same strength, function, manufacturing process (casting) and material compared to the existing component.[9]



Topology optimization

Design of the casting system and core packages

The project team collaborated with a local company to create an optimized design concept of the casting system and 3D printed core packages for the spring cup based on the topology optimization. As the project's foundry, MFL had to assure its castability and geometry.[9] The re-engineered design indicated that topology optimization for the spring cup is possible to achieve and can lead to lower material consumption with comparable strength.[2]



Design of the core package

[1] Topology optimization (TO) refers to "an optimization approach with a goal of maximizing the performance of the geometry (e.g., stiffness and strain) by iteratively determining the optimal layout of material in a part within a design space for a given set of loads, boundary conditions and constraints. TO is based on finite element method (FEM), by which a design space is discretized into finite elements."[12]

S-MAX® PRO
The S-Max Pro is ExOne's fastest large 3D printer for core and mold production with any binder for flexible manufacturing capacity:

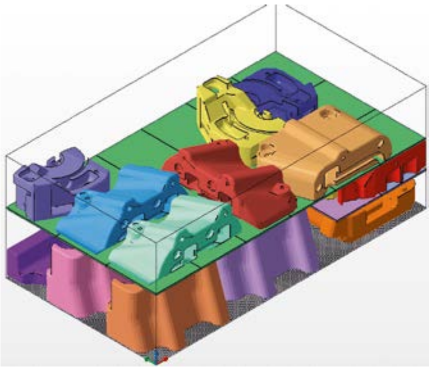
- Prototyping
- Rapid product development
- Short-run production
- Continuous 24/7 production
- Serial production

APPLICATION
Binders for standard job box: Furan, CHP
Binders for box-on-box: Furan, CHP, HHP, Inorganic

TECHNICAL DATA
Job box*: L 1,800 × W 1,000 × H 700 mm
Build volume: 720 l (25 ft³) / 1,260 l (44 ft³)
Build rate**: up to 145 l/h
Layer height***: 0.2 to 0.5 mm (200 to 500 µm)
Dimensional accuracy****: +/– 0.5 mm (500 µm)

* Available with 400 mm height with box-in-box or 700 mm height with standard job box
** Depending on layer height
*** Depending on material
**** Depending on part size and geometry (0.1 % of part size)

3D printing of core package and assembly
To cast the spring cup, forms and a core package consisting of several complex cores were required. As ExOne is the pioneer and leader in sand 3D printing solutions, the company was assigned the task binder jetting the core package, consisting of eight parts, on the S-Max® Pro 3D printer using silica sand with furan binder.



During the core assembly process, cooling chills were attached in the core packages and water-based zirconium coating was sprayed onto the cores. Venting, installation of exothermic risers, and screwing of the cores with threaded rods were a part of the assembly process as well.[11]

Casting in 3D printed sand molds and cores, unpacking, and fettling
In the project, MFL was also responsible for the practical implementation of the topology optimization to the real casting.[9] Through topology optimization and the use of 3D printing technology, energy and resources can be massively saved in the production and use of castings, thus contributing to the achievement of climate targets.[8]

The innovation core of the research is the stress or fatigue analyses and the topology optimizations based on the process and requirements data provided by MFL. In other words, "Together with our project partners, we were able to determine the ideal shape

*“Together with our project partners, **we were able to determine the ideal shape** of the components based on a computer-aided calculation process. **We converted this design into a ready-to-use geometry** – and finally cast it in a 3D-printed sand mold.”*

Peter Fuchs, MFL project initiator and foundry manager

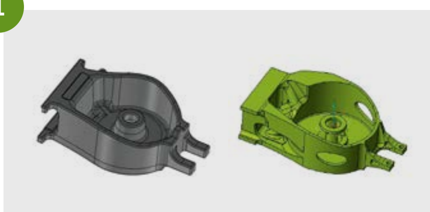
of the components based on a computer-aided calculation process. We converted this design into a ready-to-use geometry – and finally cast it in a 3D-printed sand mold,” said MFL project initiator and foundry manager, Peter Fuchs. He emphasized: “The optimization of these safety-relevant components requires the highest interdisciplinary precision. The constellation of mechanical engineering, materials, and casting technology expertise is unique in this form.”[8]

The cast component

“With this and other projects, MFL is further expanding its status as a competent partner for highly innovative engineering solutions for steel casting applications on the international market,” added Fuchs.[8]

The project phases and steps of the spring cup can be summarized as follows:

1



- Optimisation
- Calculation
- Construction

2

Design of the casting system and core packages

3

3D printing of core package and assembly

4

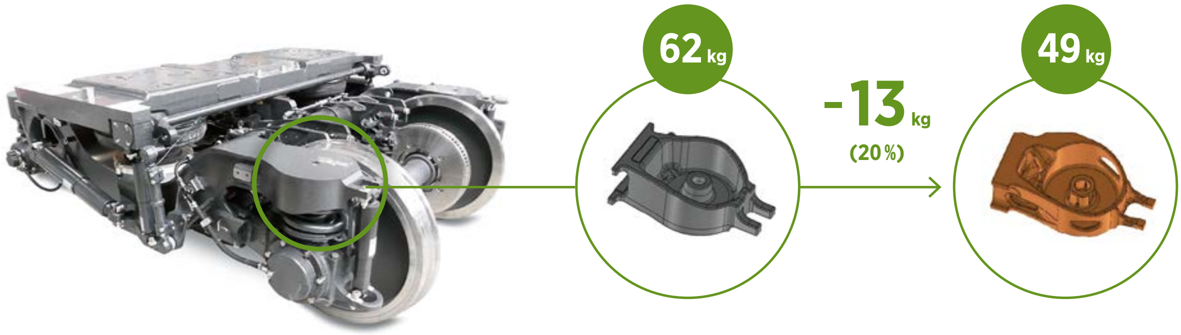
Casting, unpacking and fettling

The Project Achievement

Several analyses and tests were conducted by accredited organizations to examine the quality of the new spring cups in comparison to the original ones. The results were groundbreaking.

Weight Reduction

The weight of the spring cups, which were examined as test components and installed in bogies of high-speed trains, could be reduced by 21 percent (from 62 to 49 kilograms) – with proven unchanged strength and identical function.[2,8,11] The freedom or flexibility of design in 3D printing enables new complex shapes of the spring cup core packages – contributing to weight reduction.



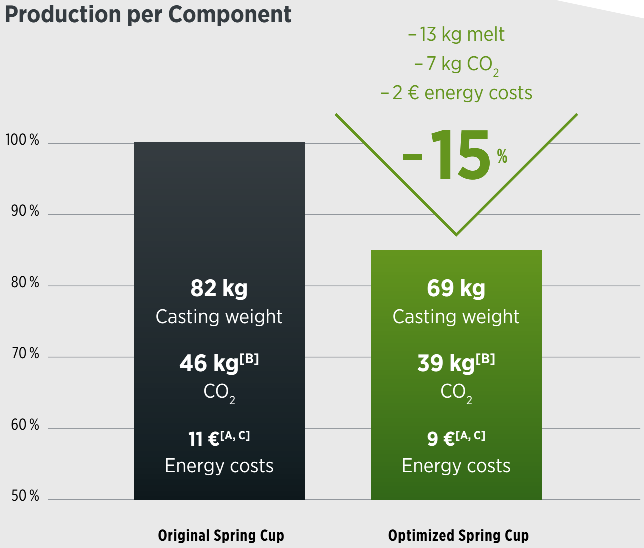
Reduction of CO_2 Emissions, Raw Material Used, and Energy Cost

Analyses were carried out to compare the original and optimized construction per component in terms of [2]:

- Casting weight
- CO_2 consumed
- Energy cost

The lightweight construction not only saves the emissions associated with the ongoing operation but also contributes to a reduction of CO_2 emissions, raw materials, and the required energy in its entirety to 15% even during the manufacturing process.[2,8]

Production per Component



Comparison of the original and optimized construction per component [2]

[A] Sturm, J.; Energie- und Rohstoffeinsparung durch konsequente Nutzung der Gießprozesssimulation, Giesserei 06/2011
[B] Franke, S.; Taschenbuch der Gießerei Praxis; Schiele & Schön; Berlin, 2019
[C] https://de.statista.com/statistik/daten/studie/287849/umfrage/strompreise-fuer-industrielle-verbraucher-in-oesterreich

“We can use the example of the spring cup to show how we are using ***digital technologies to achieve our ambitious climate targets.*** *The knowledge generated in the project will be made available to all SMEs.”* [4]

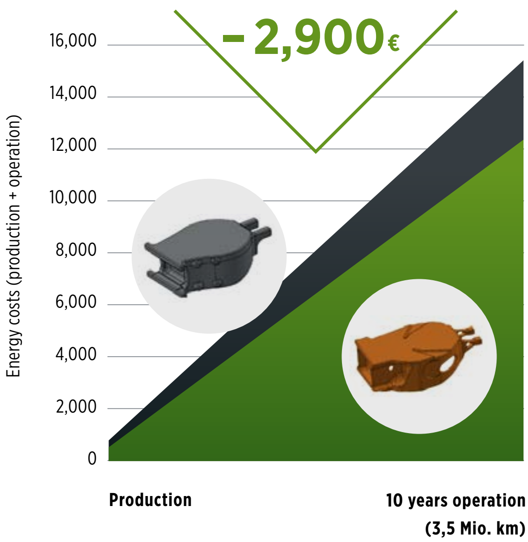
Eduard Koppensteiner, head of iron casting department ÖGI

Total Energy Cost per Train Reduction and Longer Operation

Moreover, the project team also calculated the total energy costs of the production and operation of 72 spring cups required by a train with nine wagons. With the optimized spring cups, the total energy costs per train are 2,900 € less than with the original spring cups.[2]

And a critical achievement: The reduced weight also leads to less material wear on the rails and less noise. It will be able to continuously support the train operation, which is set by regulation to 10 years and 3.5 Million km.[2]

Total energy demand per train (production + operation, 72 pieces spring cups)



Total energy cost per train [2]

“Due to this achievement, the research makes a significant contribution to environmental protection and resource conservation throughout the entire product life cycle. The results are not only a confirmation of the consortium’s innovative approach, but also an important step toward climate-neutral processes and mobility in rail transport technology,” emphasized MFL Managing Director, Herbert Decker.[8]

Eduard Koppensteiner, the head of the iron casting department at ÖGI, is also proud of the outstanding achievement of the research project: “We can use the example of the spring cup to show how we are using digital technologies to achieve our ambitious climate targets. The knowledge generated in the project will be made available to all SMEs.” [4]

Innovation Award

The spring cup project received an Innovation Award in 2021 from the Austrian Federal Ministry for Digital and Economic Affairs as well as from the Austrian Cooperative Research (ACR), the network of private and non-profit research institutes. The Innovation Award is a prestigious award as it is given by a high-profile jury for the most exceptional results in research projects.[1,8]

“We are proud to be able to make a contribution here that goes far beyond the legal requirements – and to position ourselves once again as an environmentally-conscious eco-innovation partner. The award is to the credit of our highly innovative employees,” said Decker, MFL Managing Director. [8]

According to ACR, the project team successfully turned the innovation process around and designed cast components with digital support so that it could use less material, produce lighter components, and therefore consume less energy while maintaining safety and functionality.[1]

Key Takeaways of the Project

The optimization of the spring cup project has several key takeaways as outlined below:[2]

- Topology optimization is possible and leads to lower material consumption with comparable strength
- 3D sand printing enhances the benefits of topology optimization of steel castings in terms of cost, resources, and emission reduction
- The combination of sand 3D printing and foundry technology creates a new alternative to other additive manufacturing processes
- Sand 3D printing enables new complex shapes and new casting concepts

Foundries, which are mostly SMEs, will also benefit from the entire project. The jointly acquired knowledge has been widely published and provides foundries with access to new casting possibilities.

Next Step: Move to Production
The development of the optimized spring cup, which received significant support from the Austrian Research Promotion Agency (FFG) as part of the ÖGI “Inno Up” project, is to be transferred directly to a real production as quickly as possible. To this end, a continuing project has been launched together with the same project partners.
“This innovation will make a significant contribution to securing Austria as a production location,” said Decker.[8]

The project’s findings are also applicable to other vehicle components and are a significant contribution to the competitiveness of Austrian mechanical engineering.[4]

"We are proud to be able to ***make a contribution here that goes far beyond the legal requirements*** *– and to position ourselves once again as an environmentally-conscious eco-innovation partner. The award is to the credit of our highly innovative employees."* [8]

Herbert Decker, MFL Managing Director

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