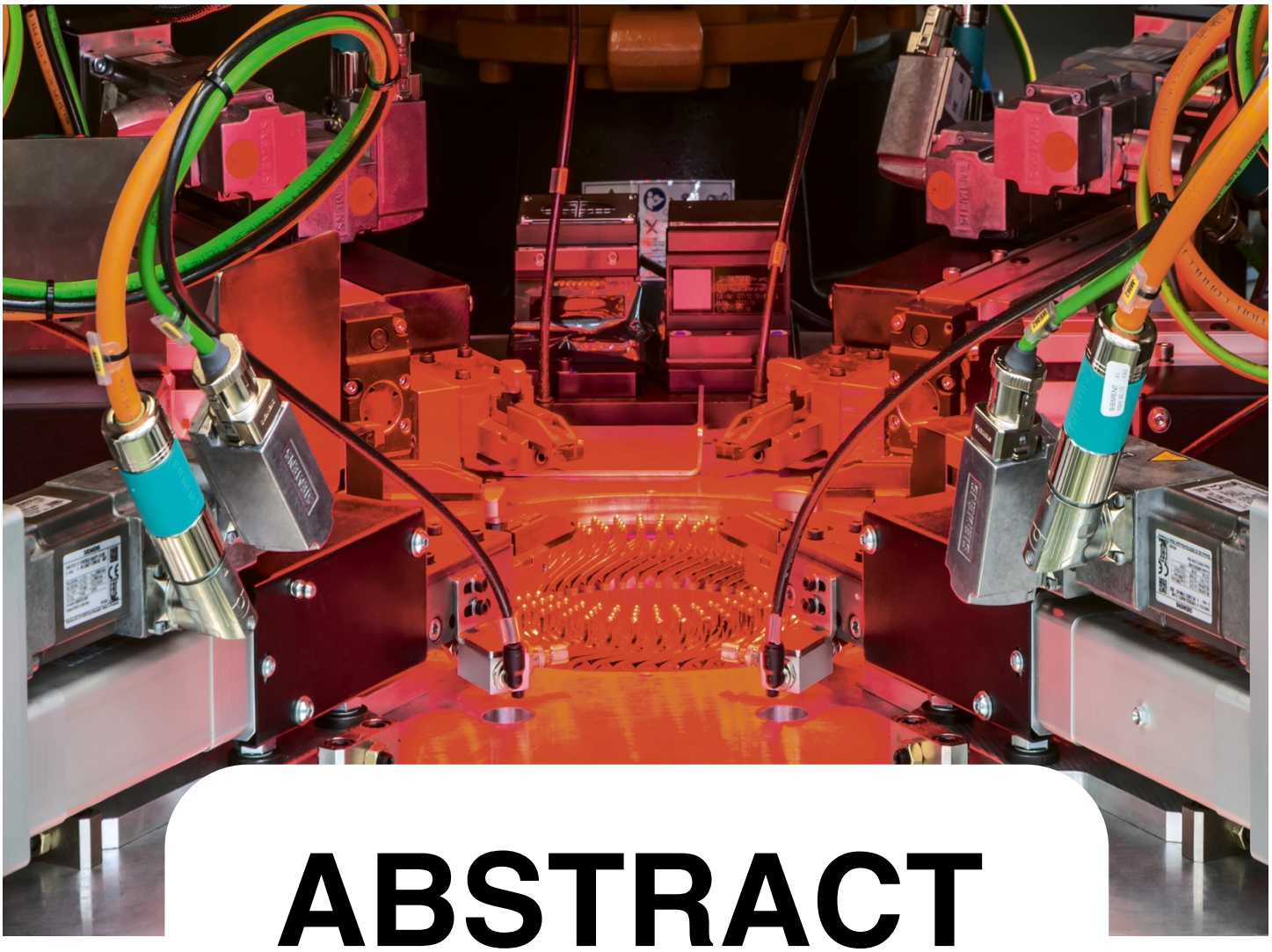
2023 LaserEMobility Workshop

SEZIONE LASER EMOBILITY
www.aitem.org/laseremobility-workshop

I March 13 – 14, 2023 I
I Politecnico di Milano I
I Milan I Italy I



ABSTRACT BOOK

2023

SEZIONE LASER E MOBILITY

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Introduction

LaserEMobility Section of AITeM – Italian Manufacturing Association is pleased to present its 2023 Workshop. Following the success of the 2022 edition, the LaserEMobility Workshop 2023 continues to be a place of discussion for an international audience from industry and academia working on laser-based processing in electric vehicle manufacturing.

As the next decade will see an increased use of electric vehicles, laser-based manufacturing methods will be the key for an efficient and high-quality electric vehicle production. To facilitate the collaboration in this field, Politecnico di Milano hosts the in-person two-day event with participants from research, laser component manufacturing, system integration, and application communities. The Workshop proposes a unique combination of industrial and academic presentations to an international audience, with technical presentations encompassing the latest technological trends. The presenting companies and universities represent over 10 different nationalities providing a broader vision.

This Abstract Book collects the abstracts of 37 oral and 10 poster contributions on the laser-based manufacturing applications in the electric vehicle manufacturing presented at LaserEMobility Workshop 2023. The works cover application-oriented topics over the whole field of laser material processing for electromobility, including:

- Battery cell and system manufacturing
- Processing of new battery materials and technologies
- Electric drivetrain manufacturing
- Fuel cell manufacturing
- Lightweight construction
- Process monitoring and control
- Digitalization and data-driven process optimization
- Sustainable electric vehicle manufacturing.

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2023 LaserEMobility Workshop

SEZIONE LASER E MOBILITY
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DAY 1
Mar 13th, 2023

Registration desk opens at 8:00

9:00 | 9:30		Welcome speeches	Carassa Dadda Hall
9:30 | 10:30	Industrial session	Advanced beam control and system design for E-mobility	Carassa Dadda Hall
10:30 | 11:10		Coffee break	Carassa Dadda Hall
11:10 | 12:50	Industrial session	Advanced beam control and system design for E-mobility	Carassa Dadda Hall
12:50 | 14:00		Lunch	Carassa Dadda Hall
14:00 | 15:40	Industrial session	Advanced beam control and system design for E-mobility	Carassa Dadda Hall
15:40 | 16:20		Coffee break	Carassa Dadda Hall
16:20 | 17:40	Academic session	Advanced joining solutions	Carassa Dadda Hall
		Sustainability and design	Room BL28.1.3
From 18:00		Department of Mechanical Engineering Lab Tour and *Happy Hour*	Via La Masa, 1 Building B23

DAY 2
Mar 14th, 2023

Registration desk opens at 8:00

9:00 | 9:10		Welcome speeches	Carassa Dadda Hall
9:10 | 10:50	Industrial session	Advanced beam control and system design for E-mobility	Carassa Dadda Hall
10:50 | 11:30		Coffee break	Carassa Dadda Hall
11:30 | 12:30	Industrial session	Roundtable discussion	Carassa Dadda Hall
12:30 | 14:00		Lunch	Carassa Dadda Hall
14:00 | 15:20	Academic session	Process monitoring and data analysis	Carassa Dadda Hall
		Novel and functional materials	Room BL28.1.3
15:20 | 16:00		Coffee break	Carassa Dadda Hall
16:00 | 17:20	Industrial session	Advanced beam control and system design for E-mobility	Carassa Dadda Hall

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XC ENGINEERING The best solutions for numerical simulations

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2023 LaserEMobility Workshop

DAY 1
Mar 13th, 2023

Politecnico di Milano
Building BL28
Via Lambruschini, 4
20156 Milan Italy

Registration desk opens at 8:00

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9:00 | Welcome speeches — Carassa Dadda Hall

Industrial - Advanced beam control and system design for E-mobility — Carassa Dadda Hall

9:30 | Thomas Hofmeister
Coherent
Laser Process Optimization and Monitoring for EV Production

9:50 | Matthias Beranek
Trumpf
Laser Technology Landscape for E-mobility Manufacturing

10:10 | Stefano Cattaneo
IPG Photonics
Integrated Solution for Battery Modules Production

10:30 | Coffee break — Carassa Dadda Hall

Industrial - Advanced beam control and system design for E-mobility — Carassa Dadda Hall

11:10 | Christian Dini
Civan
Dynamic Beam Lasers Offer New Parameters for E-mobility Joining Challenges

11:30 | Stefano Zarini
Optoprim
From Process Design Requirements to the Product: A Flexible, Modular Scanning System to Design Remote Laser Applications

11:50 | Jan Habedank
Raylase
Battery and Fuel Cell Production – the Eldorado for High-End Scanning Solutions

12:10 | Antonio Raspa
Luxinar
Tailored Laser Solutions for E-mobility

12:30 | Marcello Bianchi
Lumentum
Industrial Laser Processing of EV Battery Electrodes

12:50 | Lunch — Carassa Dadda Hall

Industrial - Advanced beam control and system design for E-mobility — Carassa Dadda Hall

14:00 | Markus Kogel-Hollacher
Precitec
Laser Welding for Electric Vehicles – Sensors With Sophisticated Data Models Enable Higher Manufactu-ring Quality

14:20 | Leonardo Daniele Scintilla
Fontana Group
Body in White Evolution in Luxury & Sports Cars Sector: Trends in Shapes and Laser Technology Applications

14:40 | Luca Schmerbeck
Sonplast
Quality Improvements and Sustainability in Li-ion Battery Cell Production

15:00 | Andrea Gariano
Pomini
Laser Surface Texturing of Rolls With Pomini Digital Texturing™ for High Quality Sheet Metal in Support of Automotive

15:20 | Giuliano Ellena
Podium Tech
Maximizing Performance, Manufacturability and Quality in Laser-Welded Battery Connections

15:40 | Coffee break — Carassa Dadda Hall

Academic - Advanced joining solutions — Carassa Dadda Hall

16:20 | Joerg Volpp
Luleå University of Technology
Laser Beam Welding of Chassis Elements of Electric Vehicles

16:40 | Murat Reis
Bursa Uludağ University
Investigation of the Effect of Angular Positioning Errors in E-mobility Micro Laser Spot Welding Applications

17:00 | Danijela Rostohar
Coventry University
Quasi-Continuous Wave Pulsed Laser Welding for Electric Vehicle Battery Joining

17:20 | Lukas Mayr
Technical University of Munich
Investigation on the Welding of Dissimilar Materials in Terms of Nanosecond Laser Pulses

Academic - Sustainability and design — Room BL28.1.3

16:20 | Max Biegler
Fraunhofer IPK
Concept Development for an All-Steel EV Battery Enclosure Enabled by Joining Technology

16:40 | Avelino Zapata
Technical University of Munich
Toward the Rapid Manufacturing of Lightweight Parts by Laser Directed Energy Deposition

17:00 | Caterina Angeloni
University of Bologna
Laser Welding in E-mobility: Process Characterization and Monitoring

17:20 | Carlo Biffi
CNR ICMATE Unit of Lecco
CuCrZr Alloy Manufactured by LPBF Process: Correlation Among Microstructure, Mechanical and Thermal Properties

18:00 | Department of Mechanical Engineering Lab Tour and *Happy Hour* — Via La Masa, 1 - Building B23

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9:00 | Welcome speeches — Carassa Dadda Hall

Industrial - Advanced beam control and system design for E-mobility — Carassa Dadda Hall

9:10 | Felix Roeckel
Manz
Laser-Based Manufacturing in E-mobility

9:30 | Davide Chesi
IMA Automation Atop
Improving Energy Storage Solutions by Means of Laser-Based Manufacturing Processes: High Performance Batteries and Fuel Cells

9:50 | Eric Punzel
BBW
Challenges of Al-Cu-Joints for E-mobility Applications

10:10 | Daniele Colombo
ADIGE SpA – BLM GROUP
Robotic Laser Welding and Beam Shaping in Service of E-mobility Applications

10:30 | Valentin Schmid
Grob
Challenges of Laser Material Processing in the Production of E-drives – Artificial Intelligence for Process-Safe Laser-Based Contacting of Hairpin Stators

10:50 | Coffee break — Carassa Dadda Hall

11:30 | Roundtable discussion — Carassa Dadda Hall

12:30 | Lunch — Carassa Dadda Hall

Academic – Process monitoring and data analysis — Carassa Dadda Hall

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Politecnico di Milano
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14:20 | Florian Kaufmann
Bayerisches Laserzentrum
Towards an Understanding of the Challenges in Laser Beam Welding of Copper – Observation of the Laser-Matter Interaction Zone in Laser Beam Welding of Copper and Steel Using in Situ Synchrotron X-Ray Imaging

14:40 | Eyitayo Olatunde Olakanmi
Botswana International University of Science & Technology
Machine Learning (ML) Driven Optimisation of Laser Materials Processing (LMP) Technologies for E-mobility: Challenges and Opportunities for Attaining Zero-Material Waste and Zero-Defect

15:00 | Pasquale Franciosa
University of Warwick
Utilising Laser Beam Shaping to Improve Weld Quality in High-Volume Manufacturing for E-mobility: Current Applications and Future Perspectives

Academic – Novel and functional materials — Room BL28.1.3

14:00 | Max-Jonathan Kleefoot
Aalen University
Microstructural Adaptation of Electrodes for Li-Ion Batteries by Laser Processing – Effects of Structuring on Performance and Process Understanding

14:20 | Lucas Hille
Technical University of Munich
Picosecond Laser Structuring of Graphite Anodes: Ablation Characteristics and Process Scaling

14:40 | Ahmad Zafari
University of Twente
Toward Next Generation 3D Printed Porous Materials for Energy Technologies

15:00 | Craig Milroy
The University of Texas at Austin
Electrochemical Characterization of Additively Manufactured Zinc for Rechargable Batteries

15:20 | Coffee break — Carassa Dadda Hall

Industrial – Advanced beam control and system design for E-mobility — Carassa Dadda Hall

16:00 | Ruben Hartwig
Primes
Maximizing Cost Efficiency and Production Uptime in Electric Vehicle Production Through Laser Beam Diagnostics

16:20 | Gwenn Pallier
Cailabs
Copper Laser Welding From 3 m/min to 35 m/min at 8 kW Thanks to Beam Shaping With Multi-Plane Light Conversion

16:40 | A. Kapxhiu, D. Buttaci
Marposs
Robotised Welding of Battery Module and Pack Frame and Connections

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LaserEMobility Workshop

Table of Contents

Industrial -
Advanced beam control and system design for e-mobility

Laser process optimization and monitoring for EV production

Thomas Hofmeister[1,*]
[1]Coherent, Inc;
*Corresponding author. E-mail address: Thomas.Hofmeister@coherent.com

Abstract: Real-time, in-line laser process monitoring is critical for any application which requires high-quality results, and product-to-product and batch-to-batch consistency. Furthermore, early detection of laser process variations provides the opportunity to stop or correct production before a bad part is assembled or – in a worst-case scenario – shipped to a customer. Coherent makes laser process monitoring easier and more accessible than ever with the introduction of SmartSense+. This accessory enables improved laser processing results and better reproducibility, and also provides traceability and documentation data. SmartSense+ is an opto-mechanical accessory which incorporates optical detectors for various wavelength-regions of the reflected process light and (optionally) acoustic sensors and includes all the required data acquisition and signal processing electronics and software. The presentation will show different process monitoring use cases for welding with single mode fiber and ARM lasers.

Keywords: Single mode fiber laser, ARM laser, optical sensor, acoustic sensor

Lasertechnology Landscape for E-Mobility Manufacturing

Matthias Beranek[1,*]
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*Corresponding author. E-mail address: Matthias.Beranek@trumpf.com

Abstract: For achieving high efficiencies and performances from electric drivetrains the single component assemblies impose high demands towards the manufacturing technologies. In laser joining, those demands are mainly based around the use case specifications for the weldjoints as well as in many cases high numbers of welds to be carried out at a single component. In order to fulfill increased and new requirements from the automotive industry, a broad spectrum of laser beam sources has evolved over the last years. In order to get a detailed overview and gain in depth knowledge about the applicability of the aforementioned, a classification along the laser wavelengths and waveguide designs will be presented. This covers fiber- and disc lasers emitting in the infrared and green wavelength regime in the multi-kilowatt class as well as differentiating between single spot and multi-spot beam shaping solutions for battery-, electric drive- and power electronics applications. A strong focus will be laid on copper and aluminium joining.

Keywords: Laserwelding, copper, aluminium, green laser, beam shaping, process sensors.

Integrated solution for battery module production

Stefano Cattaneo[1,*]
[1]IPG Photonics, Oxford, Massachusetts, United States
*Corresponding author. E-mail address: scattaneo@ipgphotonics.com

Abstract: Continuous and fast migration of the automotive industry to electrification is forcing production strategies towards higher and higher levels of automation and throughputs, of course, without accepting any compromise in terms of production quality.
This paper addresses the application of busbar welding for the interconnection of individual battery cells into modules. While the principles apply to any cell technology, the examples in this presentation will center around cylindrical cells as they represent the greatest precision and cycle time challenges for the manufacturer.
After summarizing the busbar welding requirements, the paper will review the selection of the principle hardware elements that include laser, beam delivery, vision and weld quality measurement system, and how each contributes to a high-yield, high speed manufacturing process. The paper will then focus on the integration of these components with a single dedicated system controller and software interface, and how this “Integrated Solution” greatly simplifies the implementation of a laser welding capability for the automation or line integration suppliers.

Keywords: E-mobility, battery, laser welding, hairpin, busbar, electrical vehicle.

Dynamic Beam Lasers Offer New Parameters for E-mobility Joining Challenges

Christian Dini[1,*]
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Abstract: E-mobility production challenges conventional laser materials processing with low-absorption materials such as copper and aluminum, low viscosity materials such as die-cast aluminum, and aluminum alloy and brass elements with low boiling temperatures. In addition, electric vehicles (EVs) require a whole new class of components that are larger in scale and have more complex geometries than internal combustion engine vehicle components. EV production also requires improved process efficiency and speed because certain components require hundreds of joints. From joining new metal alloy–based electric vehicle thermal management systems to fabricating bipolar plates used in fuel cells and welding die-cast aluminum, manufacturers need next-generation fiber laser technology to keep pace with increasing demands. The latest dynamic beam laser (DBL) developments include the ability to control not only beam shape but also sequence, shape frequency, and focal depth. These four parameters allow for unprecedented control to handle today's most challenging laser welding tasks and can be leveraged across a wide range of materials processing applications in e-mobility production. By changing one condition at a time, users can quickly and easily identify the ideal shape, frequency, and feed rate for the strongest weld, with minimal spatter and porosity. The presenters will discuss how DBL technology can increase feed rates while eliminating hot crack defects during the welding of aluminum cooling plates used in electric vehicle battery thermal management systems and demonstrate how beam steering and oscillation can reduce defects such as pores when welding die cast aluminum materials to achieve high-quality welds.

Keywords: Dynamic beam shaping, next-generation fiber laser, wobble welding technology.

From process design requirements to the product: a flexible, modular scanning system to design remote laser applications

Stefano Zarini[1,*]
[1]Optoprim Srl, Via Carlo Rota, 37, 20900 Monza, Italy
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Abstract: E-mobility sector has brought the need for a single end costumer to design hundreds of different remote laser applications: from welding to remote cutting. Starting from this considerations, at Optoprim Engineering, the division of Optoprim that design laser processes for large dimensions end costumers, with Photonic Tools (leader in beam delivery systems), identified the need of having a single flexible scanning system able to design each single process not focusing either on the optics or on the laser but rather considering them together. The need was identified in having a Modular Scanning Head (MSH) able to: have a variable magnification, host any type of monitoring system (from photodiode based to OCT), accommodate beam shaping from any laser source, to be able to host high NA laser (up to 0.2), work in a volume and not only in a single plane, have an integrate vision system, to be used up to 5 kW power and finally to be able to be selected to work either in IR or visible laser wavelengths. On top of that, all these variables should be changeable in the ms range. Using this approach, with a single remote optics, an high power beam shaping laser source and a single mode laser, it is possible to cover about 98% of all e-mobility applications being able to immediately select the optimal process parameters for the specific task and later to transfer those into production with a fixed configuration. Alternatively, for those that have low volume production but high number of different joints to be welded, it could be solution to their problem allowing them to work always in the optimal point of the process window. Results of the systems and of the approach are applied to remote cutting and hair-pin welding

Keywords: Beam shaping, Modular scanning head, Process development.

Battery and Fuel Cell Production – the Eldorado for High-End Scanning Solutions

Jan Bernd Habedank[1,*]

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*Corresponding author. E-mail address: j.habedank@raylase.de

Abstract: In a skyrocketing market for batteries and fuel cells, advanced laser beam deflection units (scanners) are playing an increasingly important role. Typical applications, such as laser cutting of electrodes, tab notching for 4680 cells, and welding of bipolar plates, impose very individual and in any case extreme demands on the beam deflection units used. For other processes still in the research stage, upscaling is an enormous hurdle. This presentation will provide a comprehensive overview of the opportunities and challenges for laser beam deflection, and also address the overlaying trend toward high-quality process monitoring.

Keywords: Laser beam deflection, Lithium-Ion batteries, bipolar plates, fuel cells, process monitoring.

Tailored laser solutions for e-mobility

Walter Gensabella[1], Antonio Raspa[1,*]
[1]Luxinar, Kingston upon Hull, United Kingdom
*Corresponding author. E-mail address: antonio.raspa@luxinar.com

Abstract: The need to reduce the carbon footprint of transportation is driving electrification. Estimates state that by 2040, half of the world's car fleet will be electric. New mobility and transport solutions are therefore under development, which, starting with cars, is expanding to all vehicles, from drones to trucks.

The laser excels as a flexible tool that performs welding, cutting, trimming, texturing, heat treatment and coating applications. In response to the rapid evolution of end products, it is increasingly important to evaluate and integrate laser processes from the earliest design stages to avoid replacing existing production processes.

Luxinar will present some application examples based on CO_2 lasers (at the different wavelengths of 9.3µm, 10.25µm and 10.6µm) and ultrashort pulse (USP) lasers operating at 1030nm or 515nm, demonstrating how important it is to develop reliable process windows for industrial applications.

Keywords: CO2 laser, USP laser.

Industrial Laser Processing of EV Battery Electrodes

Marcello Bianchi[1,*], Philippe Leopold[1,*]
[1]Lumentum Operations LLC, 1001 Ridder Park Dr, San Jose, California, 95131, United States
*Corresponding author. E-mail address: Philippe.Leopold@Lumentum.com

Abstract: The manufacturing of EV battery electrodes follows a complex process made of multiple sequential steps. The reject rates at each individual stage can dramatically influence the overall manufacturing yield and represent a major challenge to Gigafactories, specifically for capacity planning and throughput. Unlike mechanical solutions, laser manufacturing is a contactless process used for battery electrode slitting, cutting and notching. This presentation will review how high power Ultrashort Pulsed Lasers enable higher manufacturing quality of Anode and Cathode by minimizing burr, reducing heat affected zone and decreasing particule contamination. It will also present how Flexburst™ can address with flexibility the future electrode manufacturing requirements despite the wide variety of chemistry involved.

Keywords: laser processing, EV battery electrode, ultrashort pulsed lasers.

Laser Welding for Electric Vehicles - Sensors with Sophisticated Data Models Enable Higher Manufacturing Quality

Markus Kogel-Hollacher[1,*]
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*Corresponding author. E-mail address: m.kogel-hollacher@precitec.de

Abstract: It is already known that there are commercial sensor systems for monitoring or controlling laser processes. Most of them are based on camera or photodiode technology. It is also known that the introduction of real in-process measuring systems in laser material processing like OCT has significantly increased the safety of both defect detection and process control.

The focus of this contribution, however, relates to the use of artificial intelligence algorithms to "See New Things". We will discuss how classified, physical properties can be derived from already reliable process information - "seeing the unseen", so to speak Instead of defining complex rules for algorithms, the use of DataScience and Machine Learning methods reveals hidden structures in noisy unstructured data and make it possible to find the relationships of the data to the physical measurement.

Keywords:

Body in White evolution in Luxury & Sports Cars sector: trends in shapes and laser technology applications

Leonardo Daniele Scintilla[1,*]
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*Corresponding author. E-mail address: corporate.rdquality@fontana-group

Abstract: Fontana Group has more than 65 years as aluminum tailors and is the world leader for engineering, die construction, metal parts stamping (including Fontana BLOW technology), laser cutting and assembly in automotive sector. Fontana Group is a strategic partner for exceptional OEMs, including Ferrari, Rolls Royce, Lamborghini, Maserati, Aston Martin, Alfa Romeo, Jaguar Land Rover, Daimler, Ford, Audi, BMW and Volkswagen. Body-in-White (BiW) refers to the stage in automobile manufacturing where a car's frame is put together to create the vehicle's basic structure.

Design standards trends in automotive is more evident and some year ahead in the Luxury Cars and spots cars field where Fontana Group is largely involved. Two main aspects drive the change: the first is the design trends: a luxury car has to amaze. These trends implies obtaining complex shapes due to Style and severe aerodynamics and the demand for class A panels cosmetic requirements. The second driver is represented by lightweight need because of reduction of CO_2 emissions, the increasingly massive diffusion of E-mobility, performance increasing and sustainable product development. The result is the exponential growing of aluminum alloys usage in the automotive.

Industrial case of laser application in Fontana Group includes laser cutting as alternative to cutting dies, laser welding and repairing, laser hardening. It can be concluded that laser technology is fundamental to satisfy customers' requests and to meet the trends abovementioned that will increasingly support the product and processes development for mid-sized/volume cars in luxury and sports car sector.

Keywords: Body in white, automotive, laser cutting, laser welidng, laser hardening, aluminum alloys.

Quality Improvements and Sustainability in Li-Ion Battery Cell Production through Laser Notching and Separation

Luca Schmerbeck[1,*]
[1]Sonplas GmbH, Sachsenring 57, 94315 Straubing, Germany
*Corresponding author. E-mail address: l.schmerbeck@sonplas.de

Abstract: Lithium-ion batteries have become a vital part of our everyday lives, powering everything from mobile devices to electric vehicles. However, the processes along the value chain have significant environmental impacts which must be tackled by a more sustainable production and a product of highest quality.

In this presentation, the laser process as one core process of the Lithium-ion battery cell assembly will be presented as the alternative to traditional die-cutting machines. Its flexibility in the range of electrode formats as well as the process stability during acceleration and deceleration of the electrode web are compared. Here, a mark-on-the-fly strategy is pursued in laser cutting, which also offers an advantage in the critical phases of the web handling.

However, the most decisive factor in influencing cut edge quality is the choice of laser as well as the operating strategy. Comparisons between continuous wave and pulsed lasers in different power classes were made to determine the best suitability for various anode and cathode materials. Subsequently, the effects on the electrode material were evaluated and different defect classes were identified which are consistent with a literature review.

Finally, insight is provided into an operating strategy that reduces the most critical negative impacts on the material, thus reducing scrap in production and ensuring longevity in the finalized cell.

Keywords: Laser cutting, effects of defects, lithium-ion batteries, production strategies.

Laser Surface Texturing of Rolls with Pomini Digital Texturing™ for High Quality Sheet Metal in support of Automotive Manufacturing

Andrea Gariano[1,*]
[1]Pomini Tenova, Via Gerenzano, 58 - 21053 Castellanza, Italy
*Corresponding author. E-mail address: andrea.gariano@tenova.com

Abstract: Roll Texturing process is a post-process requirement on ground rolls for CRM production, for high quality ferrous and not ferrous rolled flat products, for high-end applications like Automotive production and White Goods domestic appliances.

Pomini Digital Texturing™ (PDT™) was introduced in the industrial production in 2016, and rapidly demonstrated quality and consistency of process results, together with substantial enhancements in safety, process flexibility, energy consumption, simplicity of operation and maintenance.

An optimized combination of roughness and peak count, as well as optimal waviness and craters distribution and overlaps are some of the peculiar benefits offered by PDT™.

Keywords: Laser surface texturing, body-in-white, roll texturing.

Maximizing Performance, Manufacturability and Quality in Laser-Welded Battery Connections

Giuliano Ellena[1,*]
[1]Podium Advanced Technology, Podium Engineering S.r.l. Viale Carlo Viola, 65, 11026 Pont-Saint-Martin AO
*Corresponding author. E-mail address: giuliano.ellena@podium-tech.com

Abstract: A battery system performance is closely bound to the quality of the connections between cells and tabs. Optimizing performance, manufacturability, and quality of laser-welded battery connections is essential to ensure the reliability and safety of battery packs for electric vehicle and energy storage applications. A comprehensive battery design, proper optimization of laser parameters, streamlined manufacturing processes, rigorous testing, and a focus on battery specifics are keys to the creation of high-quality, high-performance battery connections that can handle the demands of automotive e-traction applications.

Keywords: Battery design, process development, manufacturing, testing.

Laser-based manufacturing in E-Mobility

Felix Röckel[1], Dmitrij Walter[1,*]
[1]Manz AG, Reutlingen, Germany
*Corresponding author. E-mail address: dwalter@manz.com

Abstract: When it comes to compliance with environmental standards (emission regulations), E-Mobility is one of the most promising technologies and at the same time one of the biggest challenges of the present.
The rising demand for battery cells, power electronics, and electric motors in the automotive industry requires innovative and flexible manufacturing processes. Highly efficient laser processes are already essential for the entire process chain, and the share of laser technology in manufacturing will continue to increase.
In the field of E-Mobility, Manz AG has developed laser processes for cutting, scribing or welding of different materials, ablation of layers, and thermal activation of adhesive elements. The automotive industry applies these processes in the manufacturing of battery cells, battery modules, and inverter systems. To meet the high demand in the field of laser welding, Manz AG has designed a laser platform that allows the use of different laser beam sources and optical setups. To determine which laser process is most suitable for a required material combination Manz offers companies the testing of 4 different laser welding processes in its Laser Application Center in Reutlingen.

Keywords: Laser welding, serial production machines, singlemode laser, multimode laser, process monitoring.

Improving Energy Storage solutions by means of Laser based manufacturing processes: High performance batteries and Fuel cells

Davide Chesi[1,*], Simone Bigalli[1], Daniele Nocciolini[1], Rubino Corbinelli[1]
[1]IMA Automation ATOP,
*Corresponding author. E-mail address: davidechesi@atop.it

Abstract: In recent years the demand for electric vehicles has remarkably increased. A battery pack for use in electric vehicle consists of many cells that are structurally held and electrically connected. With the continuous development of electric vehicle manufacturing, new challenges are arising within joining processes, which affects the durability of batteries, the capability to storage energy and the electrical and mechanical performances of batteries for electric vehicles.

Ensuring the precision and repeatability of component assembly in the production of the electric vehicle battery modules and fuel cells, has become crucial to guarantee high production volumes and high efficiency. In this way laser welding is a promising technique, due to its intrinsic characteristics such as the capability of joining small parts, contain the heat affected zone, having a good repeatability and a high process speed. In addition, similar and dissimilar joints of a wide array of materials can be achieved through laser welding, including high strength steels, high conductive and reflective materials, such as Copper, Aluminum and nickel-based alloys.

Several characteristics are considered when comparing weld quality such as the surface finish, the reproducibility and the mechanical stability. There are different types of lasers, ranging from the visible to the infrared wavelengths. Choosing the right device for the task can be challenging. The present study shows an in-depth analysis on the relevance of laser welding in batteries for electric vehicle and fuel cells manufacturing applications, pointing out the advantages in using laser welding and describing the hardware characteristics to be considered.

Keywords: Batteries, Electric Vehicle, Fuel Cell, Laser welding, Energy storage.

Challenges of laser welded Al-Cu-joints for e-mobility applications

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Abstract: The automobile electrical system has been making advancements in recent years. Copper is well-known for its high electric conductivity, allowing the usage of high electrical currents, yet is being replaced by aluminum in order to reduce both weight and costs. Due to contact erosion issues, it is not possible to completely substitute copper, so mixed joints have become a more viable option. The challenge of laser welding Al-Cu-joints (aluminum and copper) is that the metals have different melting temperatures, making them difficult to weld. Additionally, their different thermal expansion coefficients can cause cracking in the weld after cooling. The investigation of different welding strategies using laser beam shaping, enabling stable joints with less intermetallic phases, is conducted and presented in this contribution.

Keywords: Laser welding, al-cu, dissimilar joint, beam shaping.

Robotic laser welding and beam shaping in service of e-mobility applications

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Abstract: Laser welding has demonstrated its capacity to generate high quality seams with high productivity in the automotive field. The rise of the demand for the electric vehicles requires an increased amount of welded joints. The new vehicles are made of a large variety of material mixtures, thicknesses, and weld configurations. The use of fast configurable and flexible laser welding tools will be essential for confronting the rising demand. The increased availability of robotic systems, high power fiber lasers, fast scanning optics, and monitoring systems open up new possibilities for the next generation flexible welding systems. This work presents flexible robotic welding cells configured for purpose in service of electric vehicle production. The systems are configured with 6 axis anthropomorphic manipulators with rotating tables along with additional axes as per requirement. The optical configurations are based on high brilliance fiber lasers with beam oscillation or in-source beam shaping capabilities along with wire feeding mechanisms. The variety of the beam configurations require benchmarking studies according to the weld joint type, thickness, and materials used. In particular, the welding of Al-alloy components produced by sheet metal bending will be demonstrated. The improved capacity of gap bridging in hard-to-reach areas with the aid of beam shaping will be discussed.

Keywords: Robotic welding, beam shaping, Al-alloy, gap-bridging.

Challenges of laser material processing in the production of E-Drives – Artificial intelligence for process-safe laser-based contacting of hairpin stators

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Abstract: Laser-based contacting of the hairpin ends plays a key role in hairpin stator production. In order to realize a stable laser welding process, all influencing variables within the laser welding process itself must be known on the one hand. On the other hand, the sometimes-significant interactions with upstream process steps must be considered, as deviations can have a detrimental effect on the welding result. Since hairpin stator production is therefore characterized by a superposition of numerous nonlinear effects, classical methods reach their limits when it comes to mapping the interactions. Furthermore, up to now there is no fast and inexpensive test method that can be used to monitor the quality of each welded joint, such as the size and number of pores, inline.

In this context, data-driven approaches that make use of artificial intelligence (AI) methods are coming into focus. The aim of the presented project is therefore to investigate the extent to which AI can be used to monitor the quality of welded joints based on existing material and process data as well as easily integrated sensor technology. The latter includes i.a. diode-based recording of process emissions, camera-based controlling of the stripping quality, in-process optical coherence tomography as well as measuring pin geometry pre- and post-process in 3D with a tandem sensor system.

Ultimately, the aspired AI solution should also make it possible to detect deviations in upstream process steps at an early stage and compensate for them. In this way, a significant contribution to increasing the efficiency in the production of electric drives for electric vehicles can be made.

Keywords: Laser welding; copper wire; electrical machines; hairpin technology, machine learning.

Maximizing cost Efficiency and Production Uptime in Electric Vehicle Production through Laser Beam Diagnostics

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Abstract: In electromobility, laser process windows are typically much narrower than in conventional "body-in- white" applications. Main applications for laser welding in electric vehicles are hairpin welds in stators and cell contacting in battery manufacturing. Laser beam diagnostics plays a crucial role in the production of stators and batteries. In addition, these components have many manufacturing steps, and the laser processes are often towards the end of production. These parts have a high value and errors during production lead to expensive rejects. In the worst case, even unnoticed defects can be introduced into the product.

These issues emphasize the importance of quality control measures to ensure the reliability and safety of the final product. One method introduced by the automotive industry to address this challenge is the use of sensors to check laser process parameters before parts are processed. The state of the art for many years has been in-line tracking of laser power. The typically small process windows in new processes call for more sophisticated solutions. These solutions allow early detection of potential problems so manufacturers can correct deviations from desired parameters and prevent loss of parts during the production cycle. The inline monitoring of laser power, beam diameter, focus position and focus shift are important for documentation and quality control.

Overall, the introduction of laser diagnostics in electric vehicle production has proven to be a critical step in ensuring the quality and reliability of these vehicles. It has also led to greater efficiency and cost effectiveness in the manufacturing process. The use of specialized measurement equipment, has further improved the accuracy and reliability of these diagnostic methods, making them an integral part of the EV production process.

Keywords: Laser diagnostics, quality control, in-line tracking, process windows, cost efficiency, production uptime.

Copper laser welding from 3m/min to 35m/min at 8kW thanks to beam shaping with Multi-Plane Light Conversion

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Abstract: Copper is a widely used material in the electric vehicle industry due to its excellent electrical conductivity and high thermal conductivity. However, welding copper can be challenging due to the high thermal conductivity and low absorptivity at 1μm. We discuss a new method of copper laser welding that utilizes beam shaping based on Multi-Plane Light Conversion (MPLC) technology to stabilize the melt pool for a broad range of speed and power.
The welding performance of different shapes based on MPLC technology is discussed including the penetration depth from 4 to 8kW and from 3 to 15m/min welding. In addition, live X-ray analysis has been performed as well as post-processing X-ray showing that no pores were inside the welds. The X-ray analysis including pores counting and capillary length for different welding parameters is described. The developed system allows for deep penetration welding up to 2.8mm at 8kW and 3m/min, which may be applied to busbars welding. On the other side, deep penetration welding up to 35m/min at 8kW has been possible too, paving the way for applications such as hair pins welding.
The welding performance of the MPLC technology based system versus a beam shaping based on double fiber laser technology system in similar conditions as well as versus no beam-shaping is shown. It includes the process window comparison with the welding penetration depth analysis and pores analysis. It demonstrates that the MPLC system enables lower speed as well as higher speed high quality welding.

Keywords: Laser beam welding, beam shaping, copper, X-Ray, process window.

Robotised welding of battery module and pack frame and connections

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Abstract: Presenting its own robotised welding machine for processing modules and packs, MARPOSS Elettrosystem will focus the explanation on the module/pack centring prior the process and the tab/busbar pressing while the process is being performed.

Being the positioning of the module/pack preparatory to an effective work - for either frame or electric connection welding- and the clamping of the tab/busbar fundamental for a good final result of the process, MARPOSS Elettrosystem will describe its core mechanical concept implemented in its machines.

Keywords: Module/pack centring, tab/busbar clamping.

Academic -
Advanced joining solutions

Laser beam welding of chassis elements of electric vehicles

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Abstract: Electric vehicles require lightweight designs of the chassis to increase their efficiency. At the same time, safety aspects need to be fulfilled. Therefore, the partners in the RFCS-funded project SteelS4EV developed manufacturing processes to join chassis elements with low distortion and high-performance using DP-steels. Using the laser beam offers the possibility of tailored energy input, where needed. The comparably low energy input promises low distortion during welding multiple joints of the chassis. However, the small laser beam dimensions lead to challenges. Even small distortions or variations during clamping of the joining partners can lead to gaps that a typical laser beam process cannot bridge. Beam shaping promises higher gap bridgability. In this work, static beam shaping using up to four spots with adjustable intensities was used to increase the gap bridgability. In opening-gap tests, about four times wider gaps were possible to bridge. Due to the beam spots melting the joining partners separately, it was possible to guide the melt towards the other joining partner during the process to close and maintain the connection. Additional laser heat treatment of the welded joint lead to high strength and hardness. The new vehicle designs were validated in simulation crash tests.

Keywords: Laser beam welding, beam shaping, gap bridging, electric vehicles.

Investigation of the Effect of Angular Positioning Errors in E-mobility Micro Laser Spot Welding Applications

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Abstract: It is a very sensitive process to determine the welding parameters for joining thin materials. Because it is desired that the welding process must be sensitive enough to not have mechanical or visual defects, on the other hand, the connection is expected to be strong enough to last for the life of the device. This study investigated the effect of angular positioning errors on welding quality in micro laser spot welding applications in the production of electric vehicles and battery systems. Experiments show that the most common operator error in manual spot welding is the angular positioning error between the laser beam and the plate surface. To show the effect of the welding angle, welding parameters such as laser signal intensity and duration were kept constant, welding samples were prepared with various laser beam angles, and the maximum loads each welding spot could carry were measured by tensile tests. Experiments show that heat-induced traces or micro-deformations occur on the visible face of the thin material at angles steeper than the critical weld angle. It was determined that a sufficiently wide weld area could not be formed on the thin stainless sheet at more oblique angles from the critical welding angle. The optimum torch angle range was determined using experimental results for the available laser welding parameters. The results show that in visual micro laser welding applications, the laser beam angle can be welded accurately in an angle range too narrow for the operator to adjust with the eye. Based on these results, a device equipped with an angular position sensor was developed, which helps the manual laser welding operator to weld in the correct angular position.

Keywords: thin metal, micro-laser, manual, welding, automotive, battery welding.

Quasi-continuous wave pulsed laser welding for electric vehicle battery joining

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Abstract: Electric vehicle (EV) battery joining using laser welding is very challenging owed to the typical materials used for the assembly of EV batteries. Copper has a high thermal conductivity, large laser reflectivity and the use of dissimilar materials (copper and aluminium) gives rise to intermetallic compounds (IMCs), lowering the strength of the weld and increasing the resistivity of the weld. This presentation will demonstrate how spatial beam oscillation, using an IPG Photonics fibre laser (YLR 150/1500 QCW), can be used to increase the quality of welds in copper-copper and copper-aluminium welding configurations. Consideration will be given to defects arising from the laser welding process in addition to how laser oscillation parameters can impact on the dimensions and quality of the welds. Peel strength, tensile strength, fatigue strength, surface topography parameters and resistivity of the welds will be reported to define the quality of the laser welds conducted.

Keywords: Laser welding, spatial beam oscillation, weld quality, weld defects, weld surface topography.

Investigation on the Welding of Dissimilar Materials in Terms of Nanosecond Laser Pulses

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Abstract: Pulsed beam sources have seen significant developments in recent years, opening up new fields of applications. Laser beam pulses in the millisecond and nanosecond range are widely used to weld dissimilar materials or thermally sensitive components. Especially copper and aluminum alloys, which can be found in electro-chemical power storages, are challenging in terms of welding with wavelengths in the near-infrared range because of the high reflectivity and thermal conductivity of both materials. The utilization of nanosecond laser pulses with peak powers of multiple kilowatt has been increasingly researched since these challenges can thereby be addressed. However, the influence of the process parameters on the resulting surface of the weld seam and the spatter behavior has not been investigated in detail. Due to the complexity, the tracking of spatters was analyzed using a machine learning model based on neural networks. The results show that an increase in the average laser power and reduction in the feed rate leads to rougher surfaces and increased spatter occurrence. Additionally, this study also provides an overview of the change in the process behavior of nanosecond pulse laser beam welding when the laser parameters are adjusted.

Keywords: Laser beam welding, nanosecond laser pulses, machine learning.

Academic -
Sustainability and design

Concept development for an all-steel EV battery enclosure enabled by joining technology

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Abstract: The stated goal of many automakers is to develop an environmentally friendly vehicle and achieve climate-neutral production throughout the supply chain.

Based on the benchmark of existing battery enclosures, this paper presents a concept for a battery enclosure made exclusively of high-strength steel and its production.

Very high demands are placed on a battery enclosure in terms of crash safety, leak tightness and installation space. The massive energy storage units of electric vehicles (EVs), are integrated within a battery housing in the underbody area of the vehicle structure, leading to comparatively high corrosion protection requirements due to direct environment exposure. In addition, very high demands are placed on the battery housing with regard to crash safety and the leak-tightness of the package volume. Above all, the high crash safety requirements can be met comparatively well with steel battery enclosure concepts by selecting high-strength steel grades in line with the requirements.

Different (laser) joining techniques and coating processes are evaluated on basic samples and on a demonstartor component. Based on the benchmark of existing battery housing concepts, typical joint geometries were derived. For this purpose, the joining process parameters were optimized, particularly with regard to sealing properties. The focus is on laser beam welding, laser brazing and resistance spot welding bonding. The investigations are accompanied by detailed leak testing.

A complete LCA analysis of the developed steel battery enclosure rounds off the holistic concept development.

Keywords: Battery enclosure, laser beam welding, LCA analysis, high-strength steel.

Toward the Rapid Manufacturing of Lightweight Parts by Laser Directed Energy Deposition

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Abstract: Despite the numerous benefits of battery electric vehicles, their relatively short maximal range compared to internal combustion engine vehicles limits their attractiveness for the consumer. Implementing lightweight structures is one solution to reduce the mass of the vehicle, which in turn lowers the energy consumption and thus extends the maximal range. With Laser Directed Energy Deposition (DED-LB), near net shaped parts of variable sizes and geometries can be additively manufactured. Therefore, in this study, DED-LB was assessed concerning its use for the rapid manufacturing or modification of lightweight parts. The additive process was performed on EN AW 6060 aluminum extrusion profiles commonly found in battery electric vehicles and using a S AL 4046 wire. Based on cross-sections, the influence of the process on the substrate was analyzed. The studies included temperature and microhardness measurements as well as microstructural analysis. Furthermore, the effect of the deposition rate on the geometric quality of the part was investigated. The results indicate that DED-LB can be performed on thin-walled structures to produce defect-free parts at relatively high deposition rates. However, the thermal impact of the process had a negative influence on the hardness of the substrate. Therefore, further studies on heat management are needed to optimize the process for the production of lightweight parts.

Keywords: Lightweight structures, resource-efficient production, annular laser spot, Laser Directed Energy Deposition, rapid manufacturing, lasers in manufacturing.

Laser welding in e-mobility: process characterization and monitoring

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Abstract: The global automotive industry is shifting to e-mobility, where the main challenge is addressed to battery's mass-production. To keep up with the market demand, high speed production rates have to be accomplished. However, high speeds can lead to faulty parts. To perform a defect-free process, real-time measurements of the parameters that provide joint's quality information have to be carried out with a closed-loop monitoring system that updates corrective and/or preventive actions in order to obtain a reliable, "zero waste" process. In this contribution, a Precitec system has been implemented as a possible economical and industrial-oriented solution: it is based on the feedback of three photodiodes which are intended to provide independent information about the process. Materials investigated are manly pure copper and aluminum, processed by means of different sources, wavelengths and scanning heads. Different welding configurations and lengths of the track were also tested. To date, monitoring systems do not allow real-time modifications of the parameters, they only state, at the end of the process, if any signal value exceeds the threshold without even telling the root cause of such defect. Thus, the objective of this paper is to find correlations between the data collected by the monitoring system with the typical process characteristics of laser welding.

Keywords: Quality control, photodiodes, monitoring system, laser welding, E-mobiity.

CuCrZr alloy manufactured by LPBF process: correlation among microstructure, mechanical and thermal properties

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Abstract: Copper based alloys are promising materials for electrical and thermal devices. In this respect, the use of laser powder bed fusion (LPBF) allows the realization of 3D complex structures, thus possibly enhancing their functional performances of such devices. On the other hand, LPBF also induces refined microstructures and build-up of residual stresses, due to the rapid solidifications and high cooling rate. Therefore, the selection of a suitable composition shall be carefully addressed to achieve a satisfactory processability of the alloy. In this work a CuCrZr alloy was manufactured using a MetalOne LPBF system (by Sharebot) for defining the feasibility of the alloy and evaluating the process influence on microstructure, mechanical and thermal properties. Moreover, different heat treatments, necessary to tune the CuCrZr microstructure, were implemented and their effect on the tensile and thermal properties was investigated as function of the building direction.

Keywords: LPBF process, additive manufacturing, Cu alloys, thermal properties, microstructure.

Academic -
Process monitoring and data analysis

High performance battery pack production via tempo-spatial beam shaping and inline monitoring in laser welding

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Abstract: Electric mobility requires the manufacturing of high strength, low electric resistance joints for a wide variety of components. Novel laser sources and beam steering equipment provide different temporal and spatial beam solutions such as dynamic oscillation or static modification of the emission profile providing larger interference widths of the joints. The beneficial effects in terms of process stability and of the mechanical and electrical properties of the connections are yet unclear. Moreover, from an industrial perspective major challenges still reside in the in-line identification of defects generated by variations of the processing conditions that can significantly affect the performance of the joints. In this work, a systematic investigation was conducted for the realization of busbar connections of a high performance battery pack of a racing e-motorbike. A modular experimental set-up was integrated featuring a 1 kW single mode fiber laser coupled to a high performance scanning device. The system was equipped with multi-purpose photodiode sensors both in coaxial and off-axis configurations filtered at different wavelengths alongside a spectroscope to characterize the process emission. Beam shaping capabilities of the system allowed to identify stable processing conditions for the realization of nickel plated steel to copper connections. Defect detection capabilities were implemented through the use of Machine Learning algorithms. Results show that even at single sensor level error detection accuracy above 85% could be achieved.

Keywords: Welding, beam shaping, monitoring, wobbling, machine learning.

Towards an understanding of the challenges in laser beam welding of copper – observation of the laser-matter interaction zone in laser beam welding of copper and steel using in situ synchrotron X-ray imaging

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Abstract: The increasing demand for contacting applications in electric components such as batteries, power electronics and electric drives is boosting the use of laser-based copper processing. Laser beam welding is a key for an efficient and high-quality electric vehicle production due to its local, non-contact energy input and high automation capability enabling reproducible weld quality. Nevertheless, a major challenge in process design is the combination of energy-efficiency and precise process guidance with regard to weld seam depth and defect prevention (i.e. spatter, melt ejections), partly caused by the high thermal conductivity of copper. High power lasers in the near infrared range and emerging visible laser beam sources with excellent beam quality can provide a suitable joining solution for this purpose. However, the defect formation mechanisms are only partially understood and a comparison of the material-specific features of welding copper compared to steel has not yet performed. In order to understand the influence of material properties and process parameters on the vapor capillary and melt pool geometry in laser welding, in situ synchrotron investigations on Cu-ETP and S235 using a 1030 nm laser source are conducted. The material phase contrast analysis was successfully used to distinguish keyhole and melt pool phase boundaries during the welding process with high spatial and temporal resolution up to 10 kHz. A significantly different keyhole morphology and sensitivity to parameter variation was found between the steel and copper material. In addition, the melt pool dynamics could be visualized and the formation of weld seam defects was observed.

Keywords: X-ray phase contrast observation, copper, keyhole welding, electromobility, process observation.

Machine learning (ML) driven optimisation of laser materials processing (LMP) technologies for e-mobility: Challenges and opportunities for attaining zero-material waste and zero-defect

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Abstract: Optimisation of laser materials processing (LMP) technologies via machine learning (ML) approaches is transforming the field of materials design via the attainment of zero-material waste and zero-defect during the fabrication of components for e-mobility application. In this study, application of ML techniques to identified LMP technologies for fabricating selected materials for manufacturing e-mobility components are reviewed. Best practices for implementing diverse ML techniques when optimising LMP process/materials parameters for manufacturing e-mobility components were highlighted. Approaches for elucidating key steps in applying ML techniques towards optimising LMP technologies for manufacturing e-mobility components have been formulated. This study identifies challenges and opportunities while applying ML techniques to optimise LMP technologies for designing materials for manufacturing highly performing e-mobility components at low cost and reduced lead time.

Keywords: Laser material processing (LMP), machine learning (ML), E-mobility, optimisation, digitisation.

Utilising laser beam shaping to improve weld quality in high-volume manufacturing for E-mobility: current applications and future perspectives

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Abstract: We will review current challenges and opportunities in utilising laser beam shaping to improve weld quality in high-volume manufacturing for E-mobility. Research has already confirmed a positive effect of laser beam shaping on controlling weld profiles and keyhole stabilisation, with suppressions of spatters and significant reduction of porosity in weldments. However, only few attempts with scattered results have studied the impact of laser beam shaping on intermetallic formation.

This talk will start from a technological review of existing laser beam shaping solutions, and then move on to current applications in welding high reflective materials (copper), crack-sensitive alloys (high strength 6xxx series aluminium) and dissimilar materials (steel to aluminium). Discussions on the impact of laser beam shaping on microstructure refinement, intermetallic and phase transformation will be provided in both similar and dissimilar materials, using advanced metallographic techniques and process modelling via multi-physical CFD simulation. Finally, case studies will be drawn from manufacturing of battery packs (cell-to-tab welding, busbar welding, battery enclosure manufacturing) and e-motors (hairpin welding) which require strict electrical and structural joints to comply with OEM requirements.

Keywords: Laser beam shaping, laser welding, intermetallic and hot cracking, battery pack manufacturing, multi-physical CFD simulation.

Academic -
Novel and functional materials

Microstructural Adaptation of Electrodes for Li-Ion Batteries by Laser Processing - Effects of Structuring on Performance and Process Understanding

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Abstract: In recent years, battery technology has become a key technology in the automotive sector. Factors such as energy density and fast-charging capability, but also costs, are important in ongoing electrode development. Thus, silicon-containing anodes and new cell designs are also currently being investigated in greater detail. Another approach is the adaptation of microstructure by means of suitable processes. Laser surface structuring is one of these methods, in which a selective surface ablation is achieved by means of short-pulse lasers. Another method is the geometrical defined structuring of the electrode by ultrashort laser pulses. Enhanced properties through these processes include improved fast charging capability, improved electrolyte wetting properties or an improved lifetime compared to similar electrodes without laser processing. All these positive effects can be varied depending on the type and settings of the structuring for the needs in subsequent use in a battery. In our presentation, we will compare various processes and show the resulting different effects on the electrode properties. For example, a surface ablation can be highly advantageous for the wetting properties. Structuring with a defined ablation depth, on the other hand, is highly advantageous in terms of fast-charging and lifetime. To bring such processes into industrial production, it is necessary to understand the process mechanisms. For this purpose, we have investigated the processes by using a high-speed infrared detector to measure temperature curves on the surface during pulse impact to make observations about the prevailing ablation mechanisms.

Keywords: Electrode laser structuring, ultrashort pulse, infrared measurement, process understanding.

Picosecond Laser Structuring of Graphite Anodes: Ablation Characteristics and Process Scaling

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Abstract: Three-dimensionally structured electrode architectures, resulting in substantial performance increases of lithium-ion batteries, have seen widespread research attention in the last years. Pulsed laser radiation is a versatile tool for electrode structuring allowing the creation of drill patterns with micrometer precision. However, for the industrialization of laser electrode structuring, a deeper understanding of process product correlations as well as an increased process speed are necessary. In the talk, results from a comprehensive process study in which graphite anodes were structured using picosecond-pulsed laser radiation are presented. The influence of laser processing parameters, such as the wavelength, pulse energy, pulse repetition rate, and number of pulses per drilling, on the resulting structure geometries is discussed. Suitable parameter combinations with respect to product characteristics, i.e., a high aspect ratio of the created drillings, and the process productivity are identified. Further, throughput scaling by parallel processing is investigated, using beam splitting with diffractive optical elements. The influence of the areal energy input on geometric, mechanical, and electrochemical electrode properties as well as its control by suitable processing strategies are assessed. The presented results contribute to a transfer of laser electrode structuring from the laboratory to an industrial scale.

Keywords: Laser structuring, electrode structuring, lithium-ion batteries, battery production, electrode production.

Toward next generation 3D printed porous materials for energy technologies

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Abstract: Laser powder bed fusion (LPBF) is one of the most commonly used additive manufacturing (AM) techniques capable of 3D printing near-end-use metallic products. Thanks to the high resolution of this technique and manipulation of laser parameters, geometrically defined (cellular structures) and undefined porous materials can be produced. Although such porous structures have vastly been used for biomedical applications, there are very limited works focusing on their electrochemical applications, specifically for space applications. This can be attributed to the limitation of LPBF in producing some of the structures crucial for such applications, namely fine feature sizes of 50-100 μm or lower and ultrafine/nano pores all in porous materials as thin as < 200-500 μm. The present work takes on this challenge by combining the design and LPBF of geometrically defined and undefined porous materials and electrochemical deposition. Thin porous structure of 100-500 μm in thickness with pore sizes ranging from a few microns to larger ones of the order of 100 μm was built. A wide range of laser parameters were used and to achieve even finer pores than those produced by LPBF (ultrafine). Then, thin layers of Ni were deposited on the 3D printed porous materials to create bimodal pore size distributions. A variety of properties, such as pore structures and electrochemical performance, were also assessed. These results obtained were promising and indicated a great potential of LPBF, and AM in general, for fabrication of porous electrodes in which the formation and structure of pores can be fully controlled.

Keywords: Laser Powder Bed Fusion, porous structure, energy technologies.

Electrochemical Characterization of Additively Manufactured Zinc for Rechargable Batteries

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Abstract: The excellent gravimetric and volumetric energy-storage capacity of zinc (820 mAh g^{-1} and 5855 mAh cm^{-3}) and its relative abundance and low price (~ \$2.2 kg^{-1}) make zinc batteries an attractive alternative to lithium-ion (Li-ion). Zinc metal is used as an anode in commercial alkaline batteries (*i.e.* Zn-MnO_2), as well as other primary systems that exhibit specific energies that are comparable to (or higher than) Li-ion, such as Zn-Ag (150 W h kg^{-1}), Zn-Ni (372 W h kg^{-1}), and Zn-air (up to 400 W h kg^{-1}), but which lack sufficient rechargeability to compete with Li-ion. Commercial zinc anodes are either zinc foil, which has high electronic conductivity but very low surface area, or powder (*i.e.*, powder composites or pastes) which has high surface area but poor inter-particle conductivity and long-range electrode connectivity; unfortunately, both of these form-factors significantly hinder zinc anode performance. To address these shortcomings, we present a method of fabricating pure zinc electrodes with Laser Powder Bed Fusion (LPBF), which creates direct metallic connections between individual metal particles, without the need for solvents or non-conductive binders/surfactants. Furthermore, LPBF provides exquisite control over electrode form factor with high precision and resolution. We present an electrochemical analysis of these pure zinc samples, and demonstrate their viability and rechargeability in both alkaline electrolyte and at neutral pH in a representative *in vitro* environment (phosphate buffered saline electrolyte) to evaluate the use biodegradable and environmentally friednly energy storage applications.

Keywords: Laser Powder Bed Fusion (LPBF), additive manufacturing (AM), zinc, batteries, energy storage.

Poster Session

Effect of Novel Beam Shapes during Laser Welding of Copper Hairpins

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Abstract: Hairpins are copper components in stators of electric motors which substituted electric cables. They must be coupled and the welding procedure is delicate because of several reasons: copper is a hard-to-weld metal, a stator contains a large number of hairpins to be welded, the process should avoid contamination of the near components by spatters and the product must resist to vibrations with a large lifetime and reliability. Laser assures a high production rate, but the copper low absorption of fiber laser complicates the process. This study is oriented in defining if different beam shapes can reduce the spatter and the porosity of the welds, according to keep a high production rate. The setup is composed by a 5 kW fiber laser source with in-source beam shaping capability (nLIGHT Corona CFX-5000) and a scanner head with a zoom module able to set the magnification of the spot and its position over the focal axis (Laser Processing Head MSH, Optoprim-Photonic Tools). Preliminary bead-on-plate research has been used to determine the general effect of beam shapes on copper, the most interesting configurations have been applied directly to the couples of hairpins. The results are examined in terms of stability of process, porosity of metallographic cross-sections, heat affected zone, electrical resistance, mechanical resistance and high-speed videos to detect the spattering effect.

Keywords: Laser welding, beam shaping, hairpin welding, copper welding.

Critical temperature identification and process adaptation for zero-defect laser cutting of structural and functional components for the next generation of e-vehicles

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Abstract: Laser cutting stands out as a versatile and well-established technique capable of processing a wide variety of alloys in the metal-working industry. The laser beam, as a digital tool, enables the flexible manufacturing of tailored blanks with complex and intricate geometries for the automotive industry. This technology can play a fundamental role in the transition to the next generation of electric vehicle enabling the redesign of structural and functional components in the shape of both tubular and sheet formats.

Although the laser cutting technology exhibits a significant potential as a flexible manufacturing route, challenges reside in obtaining zero-defect production especially during the cutting of intricate components with elevated degrees of complexity. Due to the thermal nature of the laser-material interaction, the cut quality can degrade beyond limits of acceptability especially in terms of the cut profile roughness eventually leading to loss of cut or critical dross formation conditions. It thus stands out as a scientifically and industrially relevant question the identification of the critical temperature beyond which the cutting process degrades and the study of mitigating strategies to avoid the formation of defects.

In the present investigation, the degradation of the cut quality is investigated through a methodological framework to relate it to the workpiece temperature, thus identifying critical conditions for the cutting of a structural steel. A high-speed thermal camera enabled the in-situ monitoring of the workpiece temperature whilst controlled pre-heating of the material could be achieved by using a defocused laser beam. The cut quality, in terms of surface roughness, was correlated to the workpiece temperature characterizing the degradation behaviour. Finally, different mitigating strategies are presented to re-establish acceptable cut quality and compensate defect formation mechanisms.

Keywords: Laser cutting, heat accumulation, process development, process monitoring.

Laser Induced Reverse/Forward Transfer for Microelectronics

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Abstract: The presence of electronics in the mobility industry is growing fast and the miniaturization of electronic devices is the key for saving space for larger batteries and improving signal integrity and operating speeds. Ultrashort pulsed lasers represent a valid technology thanks to the ablation-based interaction guaranteeing very high resolution, accurate control of energy input and flexibility often used for material removal. In a different configuration, the irradiated material, called “donor material”, is ejected in the form of sub-micrometric droplets that can be stacked in order to achieve freestanding 3D components or 2D printed circuits in the micrometric scale. The transferring mechanism involves the presence of a transparent substrate through which the laser propagates and it may act as donor carrier or receiver, according to the transfer direction with respect to the laser emission. In this work, a UV femtosecond laser is used to perform both Laser Induced Forward and Reverse Transfer (LIFT and LIRT respectively) of solid-state metals in a flexible manner. The system architecture and the process development were carried out as a collaboration between Technoprobe and Politecnico di Milano. The experimental activity involves an initial understanding of the process mechanism followed by the fabrication of micrometric objects. LIFT deposition mode of PVD-sputtered pure Ti allows to create 3D structures.

Keywords: Micro additive manufacturing, multimaterial additive manufacturing, microelectronics, ultrafast laser.

Laser Powder Bed Fusion (LPBF) with Novel Beam Shapes for E-Mobility Applications

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Abstract: Laser Powder Bed Fusion (LPBF) is a type of additive manufacturing technology that uses a laser beam to create parts layer-by-layer. LPBF has shown promise for e-mobility applications by enabling the creation of functional and topologically optimized shapes that can improve the performance of electric machine components. High performance e-mobility materials are designed to match demanding functional requirements. However, their processability with common fiber laser sources integrated into industrial LPBF architectures remains challenging. New generation laser sources with in-source beam shaping capabilities have been developed, which could enhance LPBF flexibility by enabling the manipulation of irradiance characteristics. In this study, a multi-core fiber laser source was integrated into an industrial LPBF system, and three representative materials, namely AlSi7Mg0.6, FeSi2.9, and pure Cu, were chosen for their numerous e-mobility applications. First, the available beam profiles were reconstructed, and rigorous shape-encoding parameters were introduced to unveil their structure. Then, large experimental plans were designed to understand how non-Gaussian beam profiles could be employed in a reproducible manner. Initial results showed that by correctly tuning average power and beam profiles, the mechanical properties of AlSi7Mg0.6 alloy could be improved while guaranteeing an adequate densification. The combination of ring irradiance profiles with high energy density allowed to manipulate the microstructure properties, i.e. grain size and crystallographic texture, of FeSi2.9 parts. Moroever, the use of combined beam shapes can be beneficial to the densification behaviour of pure Cu.

Keywords: Beam shaping, irradiance profile, Laser Powder Bed Fusion, E-mobility.

Real-time dross attachment estimation and closed loop control for productivity optimization in laser cutting

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Abstract: Laser cutting has become one of the reference manufacturing technology for metal sheets and tubes due to its elevated flexibility and quality in comparison to conventional technologies. Given the fast and on-going transition of the automotive sector to e-vehicle production, digital techniques enabling the redesign and production of complex metal components with different geometries is required. Although the technology has shown its benefits, failures or significant losses of quality are not rare due to many uncontrollable factors. Moreover, when process parameters are developed for the laser cutting technology, in order to ensure the desired quality, a conservative approach is typically applied which is however penalizing for the process productivity. This implies that the cut is generally performed at speed levels lower than the maximum compatible with the needed quality levels. Hence, an opportunity arises to optimize the process productivity by finding the optimal trade-off between quality and cutting speed.

The current investigation presents the approach developed to obtain a real-time estimate of the dross attachment and the controller architecture designed to regulate the cutting during the laser fusion cutting of stainless steel. An industrial camera positioned coaxially to the laser beam allowed to collect process images which were successively employed to extract significant geometrical features of the laser irradiated zone. These features are then mapped via an artificial neural network to estimate online the dross attachment. Once the dynamical system was identified, the control scheme was implemented to minimize or impose a desired value of dross attachment whilst maximizing the cutting velocity.

Keywords: Laser cutting, process monitoring, camera monitoring, dross attachment, real-time estimation.

Record in high-speed nanostructuring of electrodes for the increased active area and battery performance

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Abstract: Fabrication of (3D) electrode architectures leads to a better electrochemical performance and operational lifetime in comparison to conventional 2D ones, due to an increased active surface area, reduced mechanical tensions during electrochemical cycling, and an overall reduced cell impedance. It can be utilized in many applications, including electric vehicles or stand-alone electric energy storage devices. Here laser structuring processes have great potential as a flexible tool able to fabricate details in the sub-micrometer range. However, despite the great potential of 3D electrode fabrication and demonstrated capabilities of lasers to produce them, the speed of laser micro and nanostructuring of electrodes is still low with respect to many industry standards. In this work, we introduce unique technologies combining high-energy pulsed ultrashort laser system HiLASE PERLA with beamshaping and multi-beam micro and nanostructuring technologies able to utilize different beam shapes or produce more than 40,000 beamlets to reach record speeds in nanostructuring of electrodes reaching productivity over 1900 cm^2/min with structure detail below 750 nm. In the following pilot test, the fabricated nanostructure improved the performance of the oxygen evolution electrode in the means of stability compared to the catalyst, better adhesion of the catalyst on the surface, and improved the removal of oxygen bubbles.

Keywords: 3D electrodes, nanostructuring, multi-beam, beamshaping.

Boosting Electric Motor Productivity with Digital Twins

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Abstract: Multi-loop closed manufacturing systems are widely used in the e-mobility industry for producing critical components of electric motors, yet their operation and control have been scarcely studied in the literature. Digital twin technology provides a solution by allowing for effective analysis of MCMS. By creating a digital model of the production system, it enables the identification of ways to enhance system performance and prevent production stoppages resulting from deadlocks. Practical specifications and managerial insights for enhancing MCMS design and management can be derived from the experimental results.

Keywords: Electric Motor, digital twins, production automation, multi-loop closed manufacturing systems.

Current trends in remote laser cutting of Li-ion battery electrodes

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Abstract: Anode, cathode, separator, and ion-conducting electrolyte are the basic elements in lithium-ion batteries. Regarding the manufacturing of lithium-ion batteries, slitting the electrodes is one of the production processes of batteries. Shear cutting is the conventional method for the cutting of anode and cathode. Tools for shear cutting wear out after some time and reduces the quality of the cut. Remote laser cutting can be a promising method for the cutting of electrodes because of the non-contact nature of laser processing. This work presents a short state-of-the-art about the usage of remote laser cutting of lithium-ion batteries. Besides, the recent publication concerning the solid-state battery has been analyzed. While the process is of great industrial interes, only a total of 34 published papers have been found concerning the remote laser cutting of electrodes. The number of research groups worked on the electrode cutting of laser is very limited. Several laser solutions concerning different wavelenths, emission modes and power levels have been employed. The main issue remains the reduction of the cutting defects namely dross and clearance, along with the need to increase the productivity rates. The literature is expected to grow in a faster pace as the solid state battery concepts grow.

Keywords: Laser cutting, slitting, remote processing, pulsed wave lasers.

Zwobbel®-technology for laser processing

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Abstract: This poster reports on the recent development of the Zwobbel-technology inspired by laser process requirements. First, we will outline the integration of the technology into a standard processing head. Second, we report on its stroke capability and show the measured focus accuracy of ±100μm as needed for laser applications. Third, we will discuss the Zwobbel-dynamics that reflect in controlled oscillation frequencies up to 900 Hz for cutting and welding applications. The developed predictive-controller allows for full step responses around 2 Millisecond to be used in high-speed applications such as 3D structuring. Based on our actual controller capabilities, we discuss Zwobbel®-applications in cutting, welding and 3D laser processing. The functionality descriptions are companied by laser process investigations.

Keywords: advanced beam control, dynamic beam shaping, system design.

In-source Beam Shaping and Wobbling During Laser Welding of Al-Alloys for Lightweight Construction in Automotive

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Abstract: Owing to its high strength-to-weight ratio, corrosion resistance, ease of manufacturability and recyclability, aluminum alloys are highly desired in aerospace, automotive and marine industries. As more and more aluminum alloys are being used in these industries, the requirement for sound joining techniques also increases. Among these joining techniques, laser welding takes the attentions due to its speed, its ability to provide deep and narrow welds and its compatibility with automation. Nonetheless, with its hot crack affinity, porosity formation due to vaporization of alloying elements, reflectivity and high molten material viscosity comes a small operation window of laser welding of aluminum alloys. In this context, this study elaborates on novel methods to extend the operation window for laser welding of aluminum alloys by comparing and assessing two commonly used beam shaping methods, namely, in-source beam shaping and wobbling are compared.

Keywords: Laser welding, beam shaping, wobble, In-source, EN AW 5082.