



# Forskning – motståndssvetsning Swerim

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# Gemensamma sätt att bedriva forskning

- Forskningskonsortiet – Fogningscentrum, CJS
- Nationellt finansierade projekt



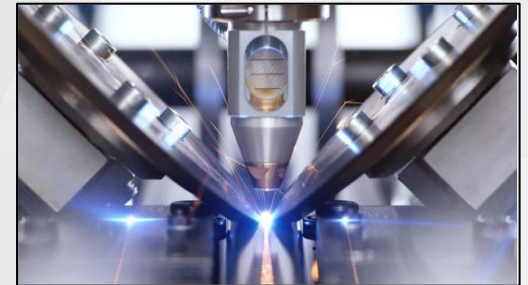
# Centre for Joining & Structures (CJS)

**CJS gathers companies from different sectors, for example, the automotive industry, material suppliers, heavy machinery, manufacturers of welding equipment and consumer products.**

- The project scope is prioritised by the participating companies with industrial relevance as the focus.
- CJS is divided into three main research areas:
  - Automotive - thinner materials, ex BiW, hang-on parts
  - Heavy - thicker materials, ex dumpers, bridges
  - Stainless - ex power generation, tubes & pipes

## **Participating companies:**

Volvo Cars, Scania, Gestamp, SSAB, Volvo Construction Equipment, HIAB, ESAB, Hydro, Outokumpu, Alleima, Valmet, Ålö, Permascand, Linde and Svetskommissionen



# Forskningsfrågor de senaste 2 åren inom CJS

Pia Borg

# Automotive projects 2023

- **Weldability and Implementation of 3rd generation steels**

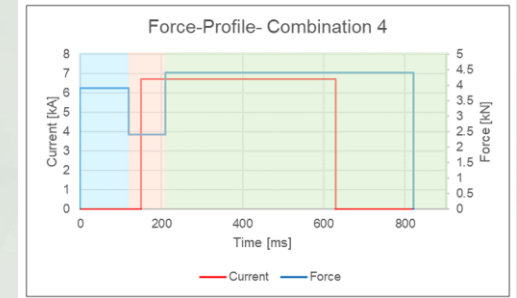
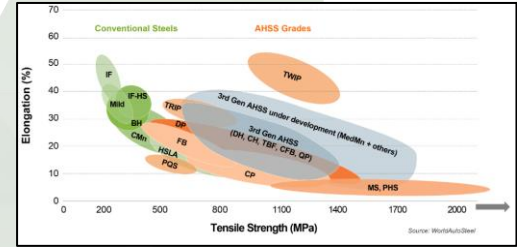
Higher-strength levels mean steel parts can be manufactured at minimum thickness while still meeting the strength requirements for crash and performance. 3rd generation of AHSS, have increased elongation as well as increased strength. But they come with the disadvantage: low weldability, susceptible to different forms of cracking. Liquid metal embrittlement (LME) when RSW is influenced by welding parameters like current, time, electrode force, and alignment. While advanced high-strength steel (AHSS) shows increased sensitivity, LME is more dependent on chemical composition and microstructure than strength. Proper parameter control can minimize LME risk.

- **Increased weldability by the use of a force-profile**

RSW is commonly used and already implemented in the industry. This project investigates how the process can be optimised to further increase the weldability of advanced material combinations and increase process robustness. Lowering the F in the initial face raises the heat generation and start the nugget growth. Then raises again for controlled nugget growth. Result: varying electrode force improves the current range for most tested materials, though it does not enhance weldability in cases of material variation or adhesive use. Optimized force profiles boost weldability without extending process times, but developing these profiles is more time-consuming and most beneficial for challenging material combinations.

- **Nut welding to high- and ultra high strength steels**

Nut welding is well-known technique commonly used in the industry. It is robust for welding of mild steel, but there is a need for research and guidelines when applied to more advanced high- and ultra high strength steels. Increased use of higher strength material decreases the product weight enabling more light weight and fuel efficient vehicles.



# Automotive projects 2024

- **Repair cast Alu**

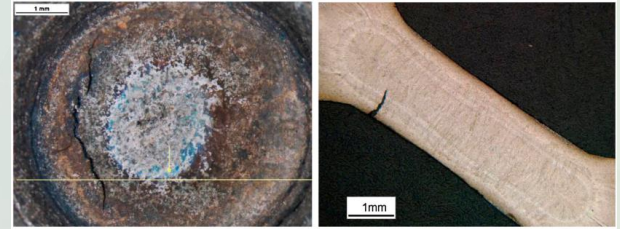
The use of aluminium castings are increasing rapidly in the automotive industry in order to decrease product weight and environmental impact. The ability to repair defects and fractures is of high importance for increased sustainability. The project aims to evaluate and compare methods, and in the long run develop strategies, for repair welding of aluminium castings. The project will contain a literature study of earlier work in the field and experimental studies of advantages and disadvantages with different methods, for example DED (WAAM, LMD), MIG, TIG etc. The results will be compiled in order to initiate the work with a guideline presenting best practice for repair welding of aluminium castings.

- **Evaluation of risk for LME in hot formed galvanized steels**

Hot formed galvanized steels shows susceptibility to LME during hot forming due to the exposure of heat in combination with the Zn-coating. This may indicate a risk for LME during welding (RSW) of the same material. There are different ways of producing parts with Zn coated hot forming steels. They can be hot formed in uncoated condition, EG coated at RT and then welded or hot forming in Zn coated state and welded. Does this influence the risk for LME? How does retained austenite influence the risk for LME?

- **Delayed cracks in laser-welded 3Gen**

Follow up to the projects CJS 2022 “Improving fatigue properties in laser stitch welds” (Appl. Automotive) and CJS 2023 “Weldability and Implementation of 3rd generation steels II” regarding delayed cracks in 3Gen steels. The mechanism behind it is not clear. There have been recent investigations that give contradictory results. In addition, there are different evaluation methods. How mitigate the phenomenon? Ramping? Oscillation?



(a)

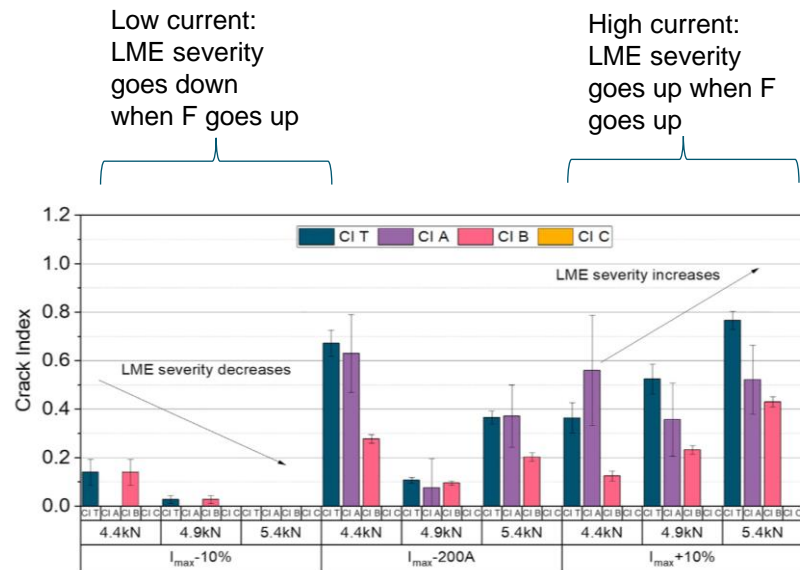
(b)



# LME in RSW II - Force

## Pia 1

- LME in RSW II
- Deltagande företag: SSAB, Scania, Gestmap
- Forskningsområde: JOIT/A
- Forskningsfråga: Påverkan av elektrodkraft F på LME under RSW av zinkbelagda höghållfasta stål (AHSS).
- Utrustning/teknik: RSW
- Material: zinkbelagt AHSS
- Resultat: Högre F minskar LME-sprickor vid låg värmetillförsel (lägre I, t). Vid hög värmetillförsel med **svetssprut** ökar dock sprickbildningen på grund av plötslig insjunkning och snabbare kylning. Detta visar den komplexa rollen av F i LME och behovet av anpassade svetsparametrar.



Crack Index of Total and Individual Type crack at various heat input levels with 4.4 kN, 4.9 kN and 5.4 kN electrode forces; CI T is crack index calculated from all cracking data (Type A, B and C cracks); CI A is crack index calculated for Type A cracks. From S. Song et al, "Influence of expulsion and heat extraction resulting from changes to electrode force on liquid metal embrittlement during resistance spot welding", *Journal of Materials Research and Technology*, vol. 23, s. 1458–1470, mar. 2023, doi: 10.1016/j.jmrt.2023.01.093.

# JODIMACO-EVOLVE

SWERIM



# Presentation of project aim and framework

**Aim:**

This project will utilise a design for circularity perspective and new joining solutions to enable implementation of mix-material joining of difficult material combinations, such as mega castings to ultra-high strength steels.

**Vinnova FFI****Budget:**

6.737 MSEK

**Time frame:**

Start 2024-06

Finish 2026-09-30

**Participants:**

Volvo Cars

Scania

EJOT

RB&W

ArcelorMittal

AGES

Hydro Extruded Solutions

Gestamp

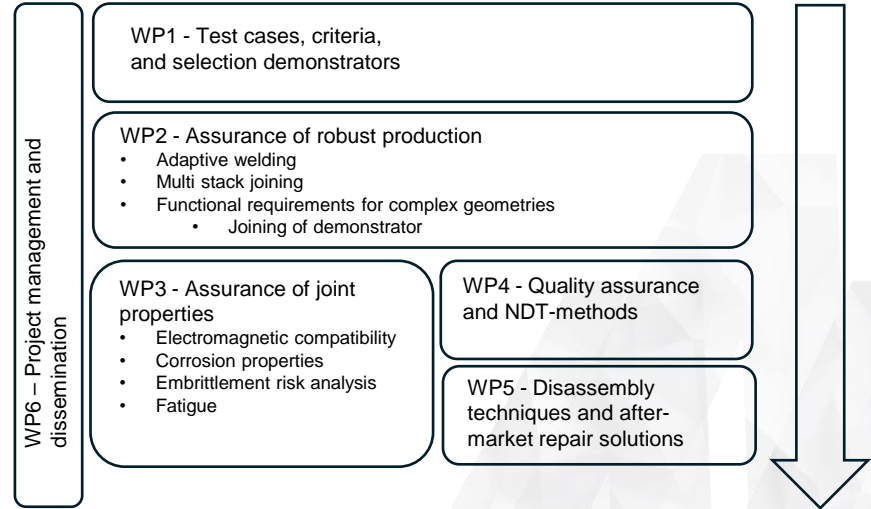
Northvolt

Swerim



# Work packages

- WP1 – Test cases, criteria, and selection demonstrators
- WP2 – Assurance of robust production
- WP3 – Assurance of joint properties
- WP4 – Quality assurance and NDT-methods
- WP5 – Disassembly techniques and after-market repair solutions
- WP6 – Project management, dissemination

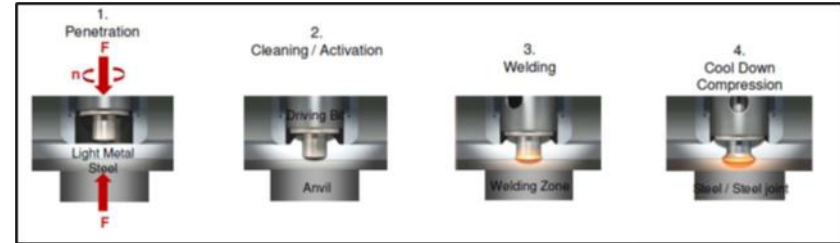


# FEW (Friction element welding)

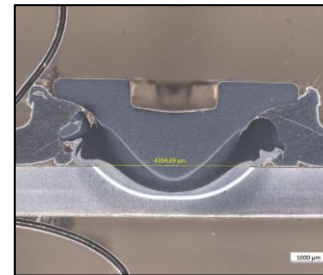
**Method:** a blank holder applies pressure to the two parts and the friction element is accelerated. Frictional heat causes a plasticization in the material which allows the friction element to penetrate it. When the friction element comes into contact with the underlying part the frictional heat increases further and plasticizes the rivet and activates the surfaces. Welding beads are formed around the rivet, which is shortened because of the axial force and after a certain shortening the rotation is stopped. Additional force is now applied which results in a pressure welding effect that further shortens the rivet and produces a strong bond between rivet and base sheet.

## Pros & cons:

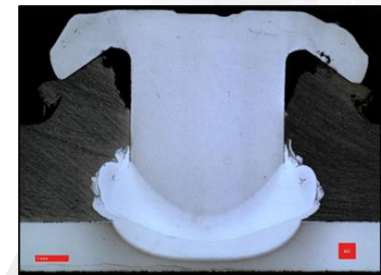
- + Does not require pre-punched holes
- + No surface preparation needed
- + Small heat affected zone
- + Can be used on brittle UHS steel
- Stress concentrations
- Potential damage from hole generation
- Adds weight
- Requires two-sided access



Ejoyeld process steps, EJOY



SRE element



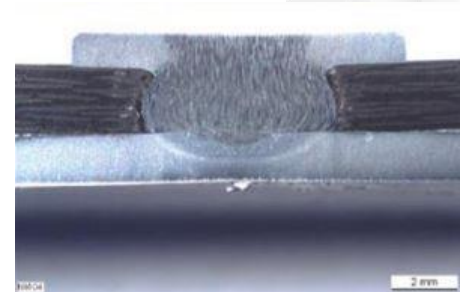
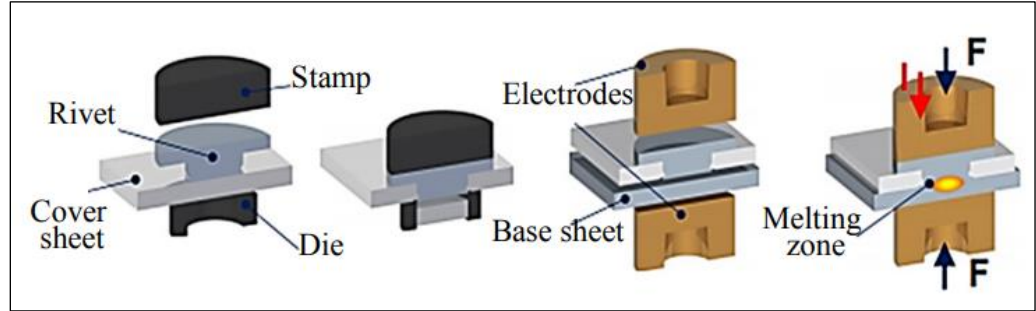
CFF element

# REW (Resistance element welding)

**Method:** a form of RSW developed for the joining of dissimilar material combinations by using a weld rivet. Requires that a hole is pre-punched in the cover sheet. Afterwards the weld rivet is inserted into the hole and electrodes are positioned. When pressure and electric current is applied a weld nugget is formed between the base sheet and the rivet. The electrode force is then increased and results in the rivet compressing and creates a force connection between cover sheet and rivet head.

## **Pros & cons:**

- + RSW equipment can be used
- + Fast method when cover sheet is prepared
- + Can be used on brittle UHS steels
- Requires a pre-punched hole
- Potential damage from hole generation
- Heat affected zone
- Stress concentrations

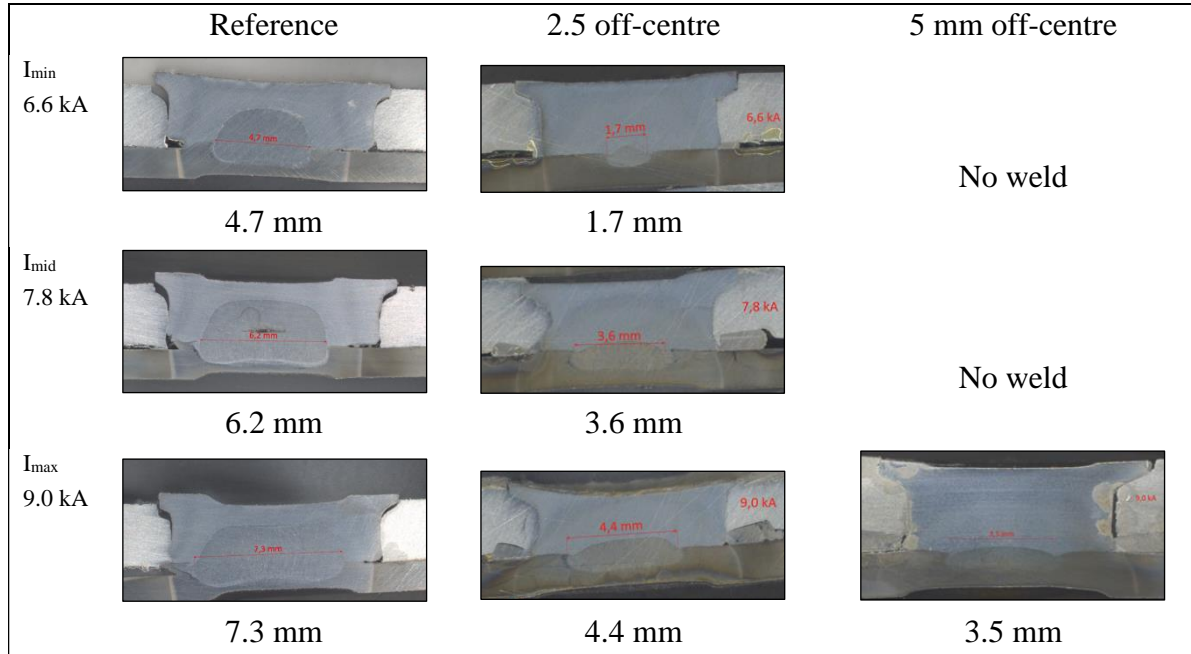


Sources: G. Meschut, O. Hahn, V. Janzen, and T. Olfemann, "Innovative joining technologies for multi-material structures," *Weld. World*, vol. 58, no. 1, pp. 65–75, 2014.

"Joining challenges in automotive lightweight applications," pp. 1–46, 2014.

# Results

## Process robustness and disturbance factors – Off-centered electrodes (Swerim) – REW



The tests performed with at Swerim with the electrodes placed off-centered relative the element decreases the weld size significantly, and increased risk for expulsion.

# Accessible work

## Publicly:

- Friction Element Welding of Ultra High Strength Steels to Aluminium Alloys  
Hilda Vestberg (LTU)
- Resistance Element Welding of Ultra High Strength Steel to Aluminium  
Malte Eriksson (KTH)
- Joining of Difficult Material Combinations – JODIMACO (Public report FFI)

**ISOLDE**

**SWERIM**



# Background

Welding of dissimilar materials comes with challenges such as large differences in melting temperature, thermal and electrical resistivity, thermal expansion coefficient, and metallurgical incompatibility, leading to formation of brittle intermetallic phases during welding.

Another possibility is to use mechanical joining methods for dissimilar materials. However, such methods entails use of mechanical fasteners which adds weight and requires additional equipment in production.

This project aims to evaluate two novel innovative solutions for using conventional RSW-equipment for joining of dissimilar material combinations

## Partners:

Swerim

RISE

Volvo Cars

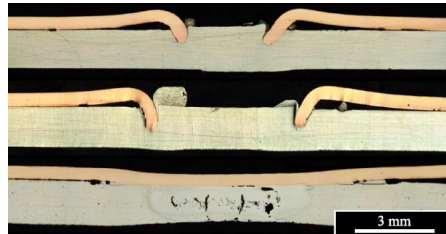
Hydro

AGES

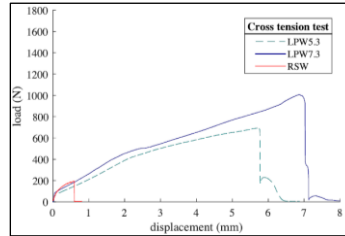
Arcelor Mittal

# Project idea

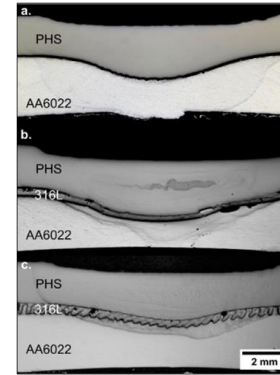
The results from these studies show that the mechanical properties are improved by the use of the new innovative techniques.



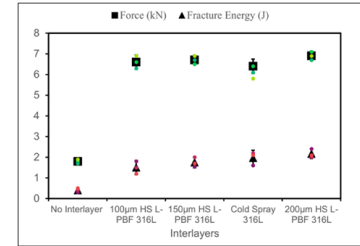
Cross-section of three joints of 0,5 mm Copper to 1,5 mm Aluminium. Top: LPW with 5 mm wide projection, center: LPW with 7 mm wide projection and bottom RSW.



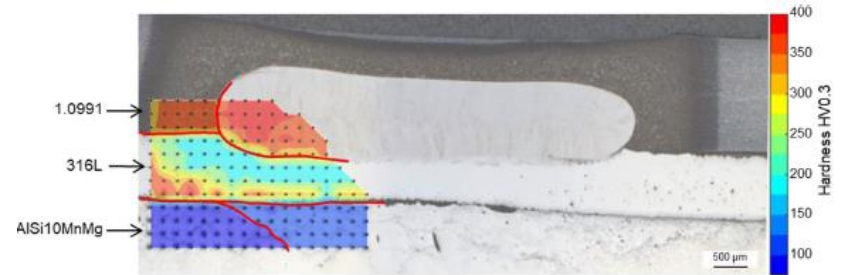
Results from cross-tension testing of the joints shown in the image above.

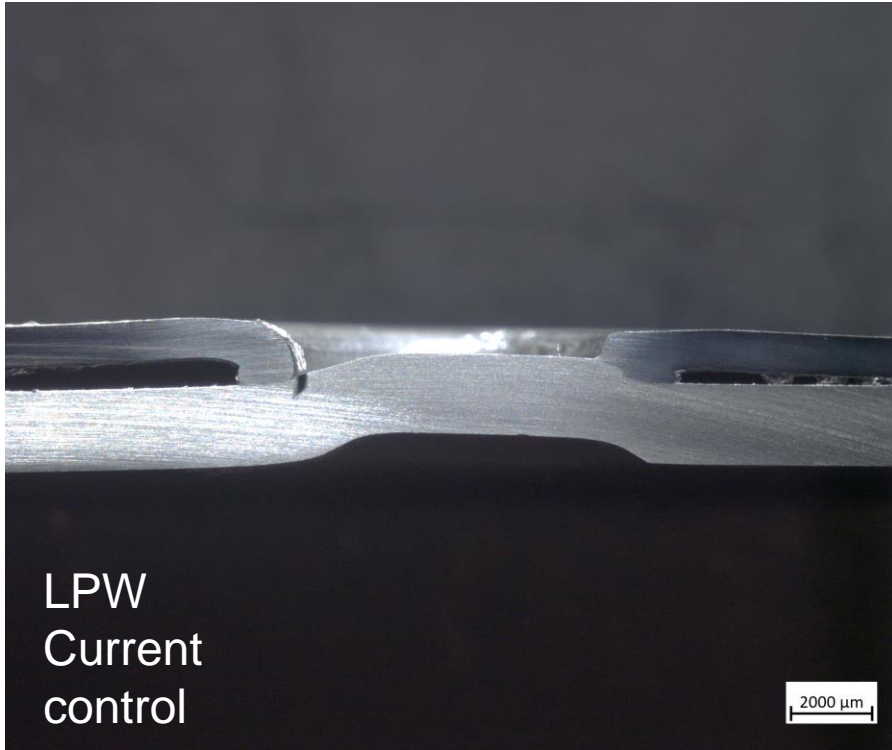


Macrograph of RSW joints: (a) no interlayer, (b) cold sprayed interlayer, (c) L-PBF interlayer



Results from tensile testing for the combinations with printed interlayer



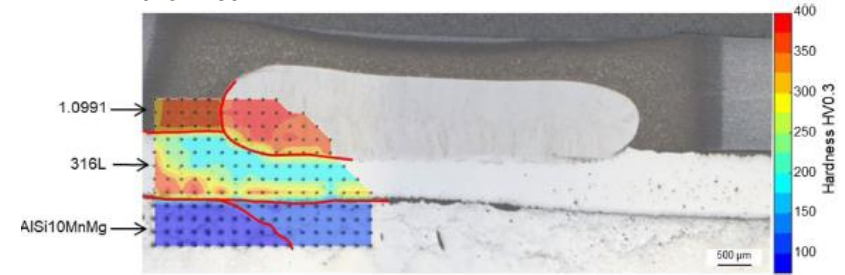


Aluminum has 60% of the thermal conductivity that copper  
Alu softens and allows penetration of Cu projections  
Very low force to avoid collapse of Cu projections

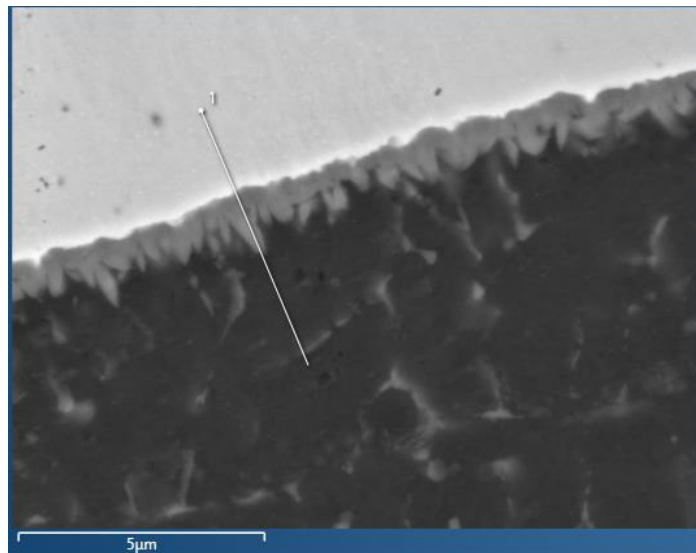
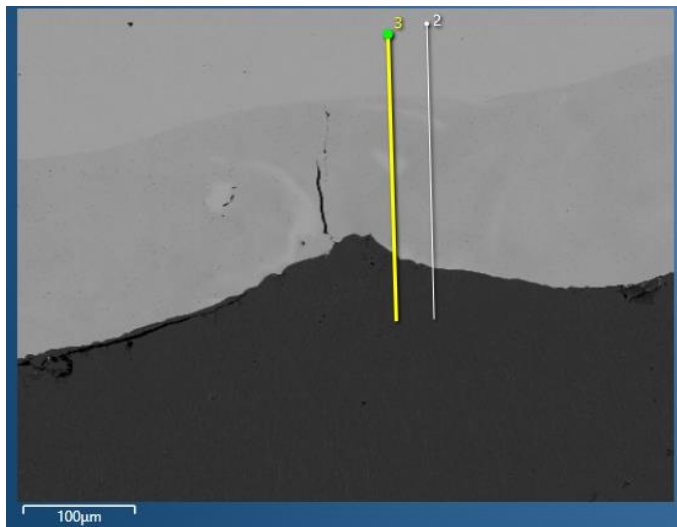


Rethinking





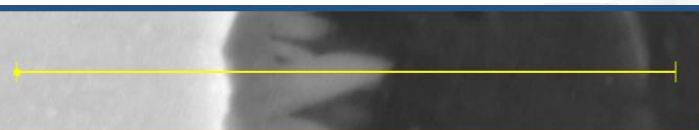
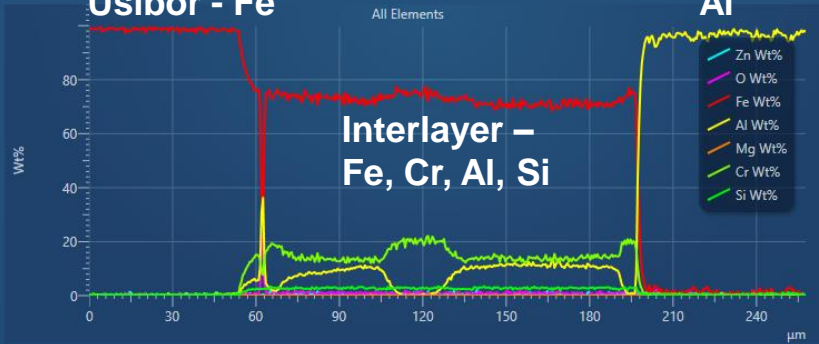
Cold spray less thermal oxides and  
intermetallic compounds between  
interlayer and alu



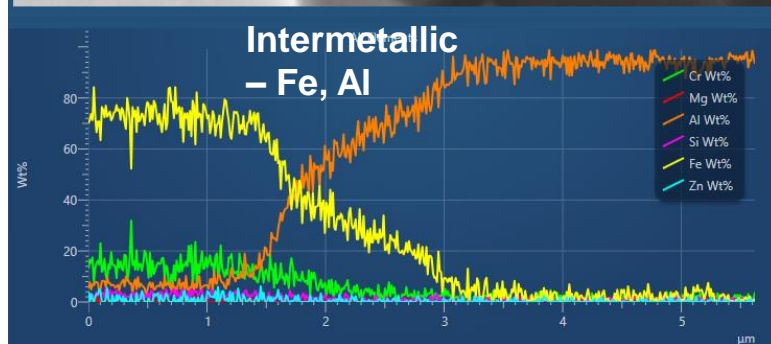
Usibor - Fe

Al

Interlayer -  
Fe, Cr, Al, Si



Intermetallic  
- Fe, Al



# PICTORIAL

SWERIM



# Project title: PICTORIAL – Predictive intelligent control for RSW

**Start: Sept 2023 Time: 29 months Budget: 7.8 MSEK Funding: FFI Circularity**

## Goal:

An ML-model for process monitoring of RSW in large scale production by gathering, sorting, and labeling relevant data of all individual spot welds in a production line, that will predict weld quality, perceive trends and act on irregularities.

## Objectives :

### An intelligent quality monitoring system to advance circularity

Repeatable high-quality welds in advanced light-weight materials is one of the key issues hindering development of lighter vehicles. New sustainable materials, like new AHSS and Aluminium are becoming more common in design and production. Their well-known production quality issues need to be addressed for producing good quality welds . Furthermore, stronger materials lead to the leaner designs, and the associated reduced sheet thicknesses also affect the weld quality by making joining more difficult.

### Integration of domain knowledge and data science

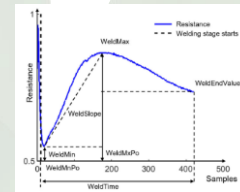
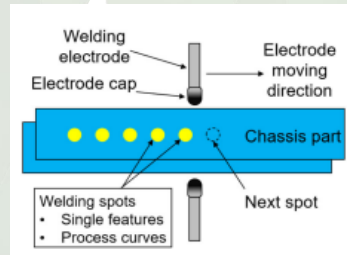
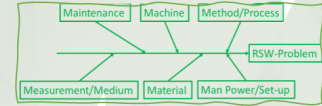
The result will be based on both welding knowledge and data science. Real production data will be used for training the model, something that is rare in the literature. Previously, simulated or experimental data have been used.

### Hastening change towards more sustainable materials

Therefore, an intelligent quality monitoring system/ML-model would be beneficial for the material change towards enhanced sustainability in production.

### The difficulty for the mathematical model of RSW

The RSW process involves interactions between electromagnetic, thermal, mechanical, and metallurgical phenomena to make the optimal weld nugget. At the same time, the huge amount of data created is either single features or time series, making it mathematically complex. The data must be reliable when collected and stored.



Project leader:



The project is supported from:



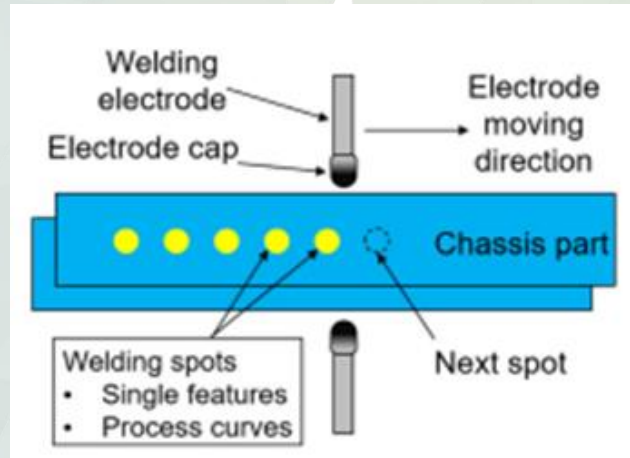
Fordonsstrategisk  
Forskning och  
Innovation



# What is resistance spot welding RSW?

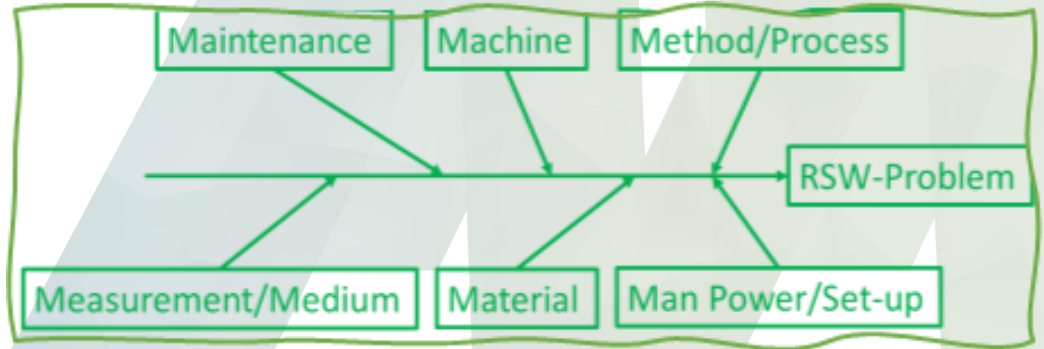
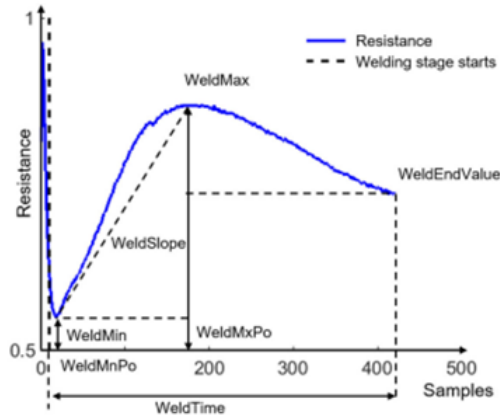
For each welding operation, data can be collected as both single features and time dependent process curves.

- Single ex: Spot No, time stamp, material, machine
- Time dependent ex: weld time, electrode wear, resistance,



# The difficulty for the mathematical model of RSW

- RSW process involves interactions between electromagnetic, thermal, mechanical, and metallurgical phenomena to make the optimal weld nugget.



# The application of machine learning ML in RSW

- Previous: studies using data-driven models for quality monitoring in RSW saw each spot weld as independent events, without considering that welding has complex dynamics, e.g., wearing of welding tools, different batches of incoming components, or production cycles. The data used to train the ML models were typically from lab experiments or synthetic data from simulations.
- Are models developed from laboratory data applicable in real production, as the welding conditions differs?
- Domain knowledge also is insufficiently considered in literature covering ML in welding. A synergic combination of both domain knowledge and ML algorithms will be more effective than each individually. The ML algorithms can find the hidden relationship between the input parameters and the response parameters, and the domain knowledge can guide the ML algorithms to restrict the search space and hence converge to a useful model more quickly.

# Initiala metoder

- Gaussian Process Regression
- Forgetting Factor Recursive Least Squares
- CNN Convonutional neural network
- Random Forest

# Challenges

- Getting promised data – IT-departments seeing security issues
- Data sharing
- Data at different sites not equal
- Engineers dislike towards “black boxes”
- Data scientist “limited knowledge” in Physics

**IDEAL**

**SWERIM**



**Start: 2022-11-01**

**Time: 2.5 years**

**Budget: 5.5 MSEK**

**Funding: LIGHTer Sept-22**

## Objective/goal:

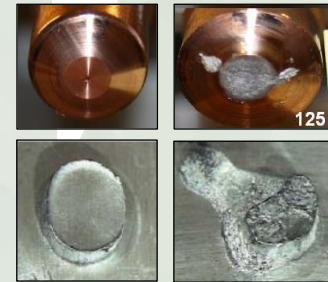
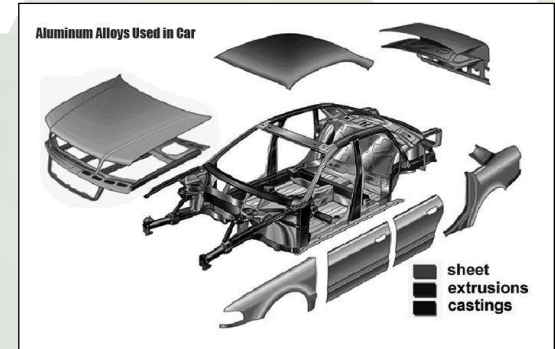
The overall aim of this project is to obtain increased knowledge regarding how material properties, defects and disturbance factors, process settings and choice of equipment impacts the resistance spot weldability of aluminium in order to enable increased use of aluminium castings, extrusions and sheet material.

## Focus/Scope:

Replacing steel structures with aluminium is an important strategy for light weighting in the automotive industry. To further increase the implementation of aluminum in car bodies, more robust and efficient joining methods are needed. The increased implementation of advanced aluminium components, such as mega-castings, will challenge the joining methods even further, since such components are known to have large deviations in surface properties, electrical- and thermal conductivity, hardness, and porosity, compared to conventional sheet materials. Therefore, to enable efficient and robust joining of new and advanced aluminium components, thorough research on how different material properties affect the weldability are needed, and possible process counteractions.

Thus, the focus has been divided into two main areas of exploration:

- Identify quality requirements for cast aluminium (surface properties, porosity, in-homogeneity, thickness variations etc.) and determine the impact on weldability.
- Examining the ability of adaptive RSW systems to compensate for quality variations in cast aluminium and the joinability of casting-, extrusions-, and sheet alloys.



**Project leader:**



The work is carried out within **LIGHTer**, a joint venture of



# Laser ultrasonics for non-destructive battery weld evaluation (LUNAR)

SWERIM

**Start: June 2024**

**Time: 9 months**

**Budget: 500 tkr + 500 tkr**

**Funding: FFI**

## Objective/goal:

This research proposal aims to investigate the feasibility of using the non-destructive, contactless method laser ultrasonics (LUS) for assessing the quality of laser welds of bus bars for EV battery production. LUS has shown promising advantages in terms of speed, ease of automation, and comparable accuracy when compared to conventional UT methods. LUS can enhance inspection processes with an automated contactless process which reduces the reliance on manual labor and eliminates the operator variability.

## Focus/Scope:

Focus is on measuring weld area in laser welded bus bars, by:

- Investigating the capability of using laser ultrasound for measuring current-carrying area in aluminium combinations in EV-battery production.
- Compare the project's finding with the state-of-art NDT-techniques
- Assessing the possibility of using LUS for measuring weld area during production and possible future implementation strategies.

## Deliverables:

- Correlation plot showing measured weld area with LUS vs. destructive and/or CT.
- Requirement specification of hardware and measurement methodology
- Literature study (Investigation if other NDT techniques on the market may be applicable)

## Proposed project structure:

### Swerim

- WP1 Define test matrix and sample outtake
- WP2 LUS measurements of samples and data analysis
- WP3 Destructive testing and sample characterization
- WP5 Project management and reporting

## Partners:

Scania, VCC, Norrvolt

### Project leader:

Pia Borg/G31

Mikael Malmström/Anton Jansson/G35



## Project target level:

- Pre study
- Concept ready
- Ready for implementation

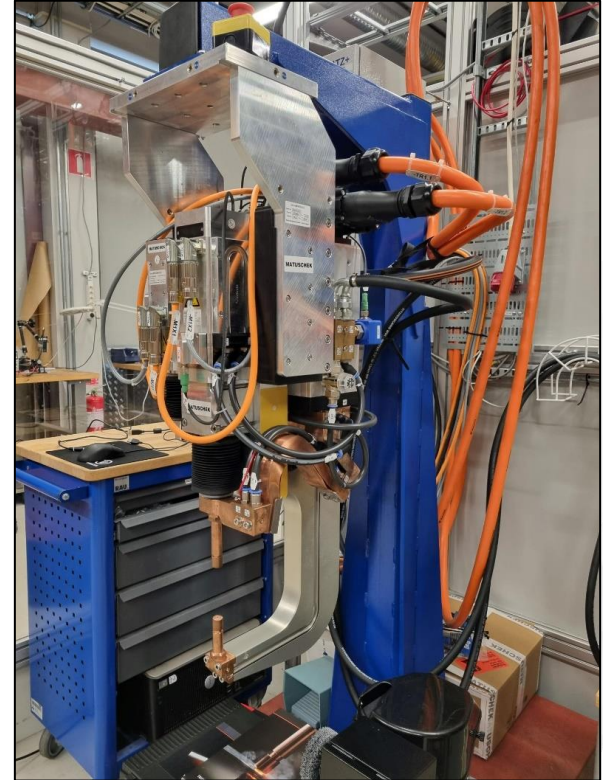
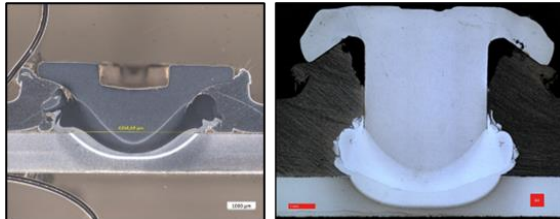
# Tillskott i fogningshallen

Komplett punktsvetsssystem för aluminiumsvetsning (AluSpatz) →

- Ström upp till 80 kA
- CapClean för elektrodformering

EJOWELD

friktionselements-vetsning för artolika material



# Joining at Swerim

**Swerim's Testbed Joining** allows you to test new advanced and world leading techniques for joining **your application** in our lab in Kista.

## Typical projects

- Optimize joining process parameters
- PWT (fatigue improvement)
- Improve process productivity
- Prototype production
- Joining in electrification – laser, laser-hybrid, friction element joining, RSW etc.
- Multi-material joining
- WAAM and LMD

**Virtual tour and more info via link or QR**

<https://www.swerim.se/test-demo/fogning>





**SWERIM**