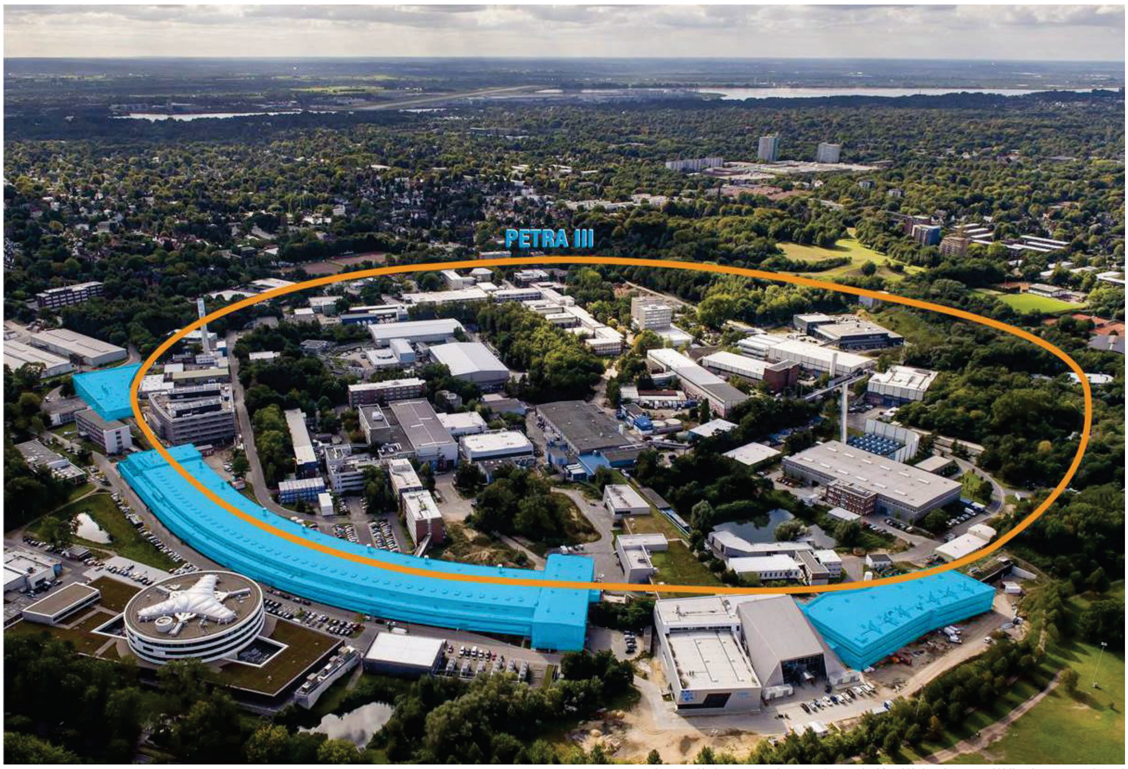
Synchrotron x-ray testing for automotive materials components

Public report



https://photon-science.desy.de/facilities/petra_iii/index_eng.html

Project within FFI
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Date 2025-09-25

Fordonsstrategisk Forskning och Innovation

Content

1. Summary

The FFI project validated synchrotron X-ray diffraction for residual stress analysis in cast aluminium and forged steel parts. It refined Scatterin's algorithms, highlighted challenges in simulation accuracy, and revealed stress variations linked to manufacturing. The project strengthened virtual testing, supported design optimization, and demonstrated in an excellent way the value of startup collaboration in advancing structural material technologies.

2. Sammanfattning på svenska

FFI-projektet validerade synkrotronröntgendiffraktion för analys av restspänningar i gjutna aluminium- och smidda ståldelar. Scatterins algoritmer förfinades och projektet belyste utmaningar i simuleringsnoggrannhet och visade på spänningsvariationer kopplade till tillverkningsmetoder. Projektet stärkte arbetet med virtuella tester, stödde designoptimering och visade på ett utmärkt sätt värdet av samarbete med startups för att främja teknologier inom konstruktionsmaterial.

3. Background

The project was initiated to explore advanced X-ray diffraction for residual stress analysis in automotive components. It was part of the FFI Accelerate Startup Partnership, aiming to validate Scatterin's technology on real cases and support innovation in the Swedish automotive sector. The collaboration addressed the industry's need for deeper material insights and improved simulation accuracy.

4. Purpose, research questions and method

Purpose:

The project aimed to demonstrate how advanced synchrotron X-ray diffraction (S-XRD) technology, combined with Scatterin's software, could improve residual stress measurements in automotive components.

Research questions:

- Can synchrotron S-XRD provide deeper and more accurate residual stress data in real automotive parts?
- How do these measurements compare with simulation predictions?
- What value does this bring to automotive design and validation?

Method:

The project was carried out through defined work packages: coordination, synchrotron experiments on selected components, and analysis of composition and residual stresses. Results were compared with simulations, and findings were shared in presentations and documentation.

- **Synchrotron facility:** PETRA III, DESY
- **Beamline:** P21.2, The Swedish materials science beamline, Diffraction & Imaging
- **Data analysis:** Scatterin SaaS software for calibration, integration, residual stress analysis and phase quantification.

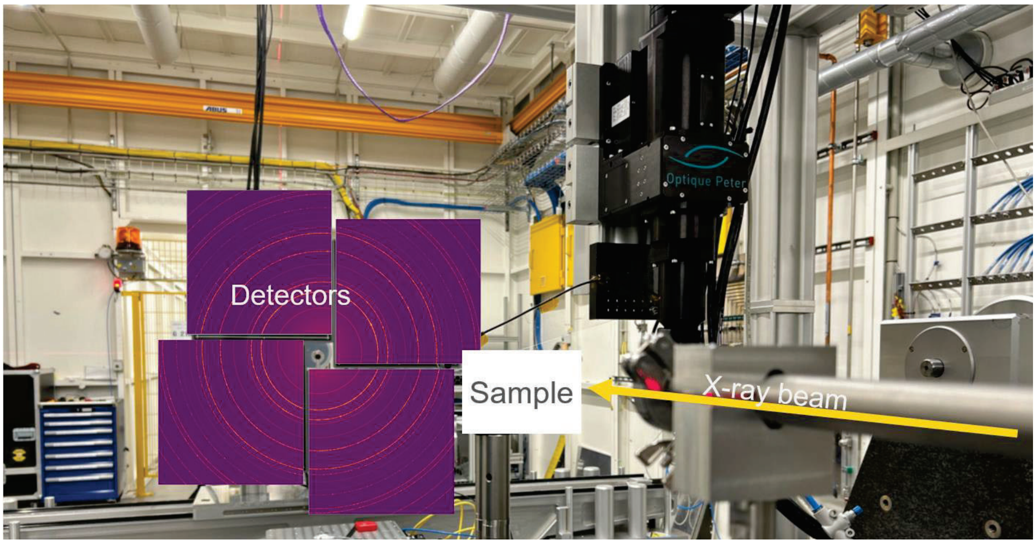

Figure 1. Basic set-up in the measurement station.

Two different component types were studied:

1. A high-pressure die-cast (HPDC) aluminium component was examined. Four distinct areas from three separate components were analyzed. The parts were sectioned into

smaller pieces to fit within the measurement station, as shown in Figure 2.
For each component, an area measuring 20 mm in height by 90 mm in width was scanned. The scan consisted of 11 horizontally oriented lines, spaced 2.0 mm apart. Along each line, 180 measurements were taken at intervals of 0.5 mm. Measurement results were averaged through the thickness. Stress calculations based on strain values were performed under plane-stress conditions.

2. A steel part, made from rod. The rod is joined to a plate through a riveting method. This joining creates built-in residual stress in the material. Measurements were performed along lines in different places in the rod where average residual stresses were extracted.

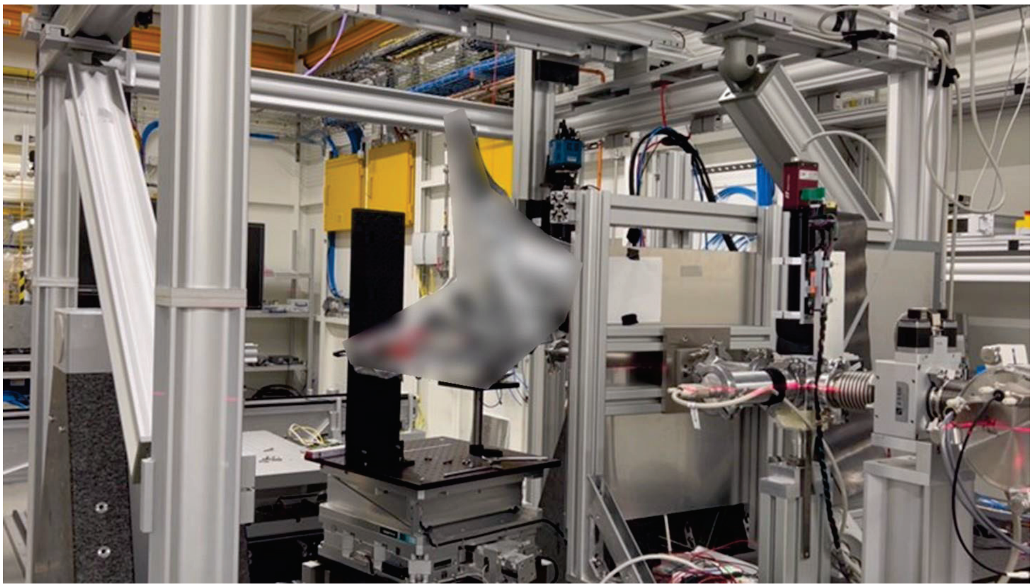

Figure 2. Cast component mounted in measurement station.

5. Objective

The project aimed to demonstrate and validate advanced synchrotron X-ray diffraction (S-XRD) technology, together with Scatterin's software, for improved measurement of residual stresses in automotive components. The goals were to:

- Show that synchrotron S-XRD can provide deeper and more accurate residual stress data in real automotive parts.
- Compare these measurements with simulation predictions to identify challenges and added value.

- Enable knowledge transfer and documentation, supporting future development and implementation of advanced S-XRD methods.

The project was carried out according to the original plan, and all key goals were met as intended.

6. Results and deliverables

WP2: Synchrotron experiments

Purpose: Conduct synchrotron X-ray diffraction (S-XRD) measurements on selected automotive components—specifically cast aluminum and forged steel parts.
Results: Synchrotron measurements were successfully performed on both types of components, according to the method described above. Several scans were performed and used for further analysis and processing.

- The experiments demonstrated the feasibility of using synchrotron technology for high-resolution, non-destructive stress analysis in automotive components.

WP3: Data Evaluation

Purpose: Analyze the synchrotron data and refine Scatterin's software algorithms for automotive applications.
Results:

- Scatterin optimized its SaaS algorithms to handle the unique properties of HPDC aluminum.
- The analysis provided deeper insights into phase composition, grain size, and residual stress distribution.
- The data supported further development of Scatterin's technology and validated its applicability to industrial use cases.

HPDC component: Stress profiles revealed significant differences depending on ingate removal timing. An example of stress in one of the scan areas is presented in Figure 3.

Forged steel component: Two manufacturing methods (riveting) were compared, showing distinct residual stress patterns, see Figure 4.

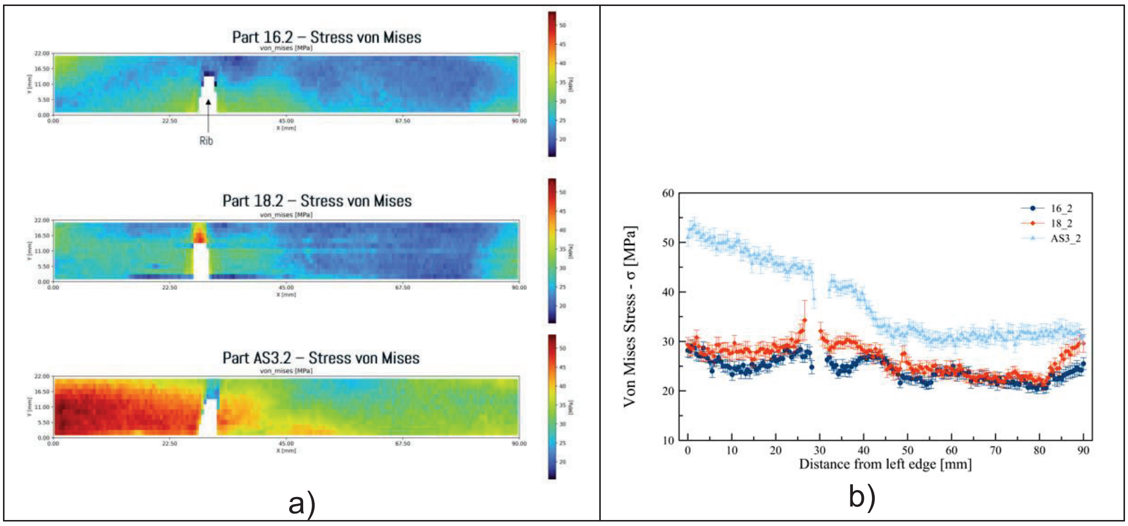

Figure 3. a) Distribution of von Mises stresses over a 20 mm x 90 m area. b) von Mises stresses along a line mid height in the scan area.

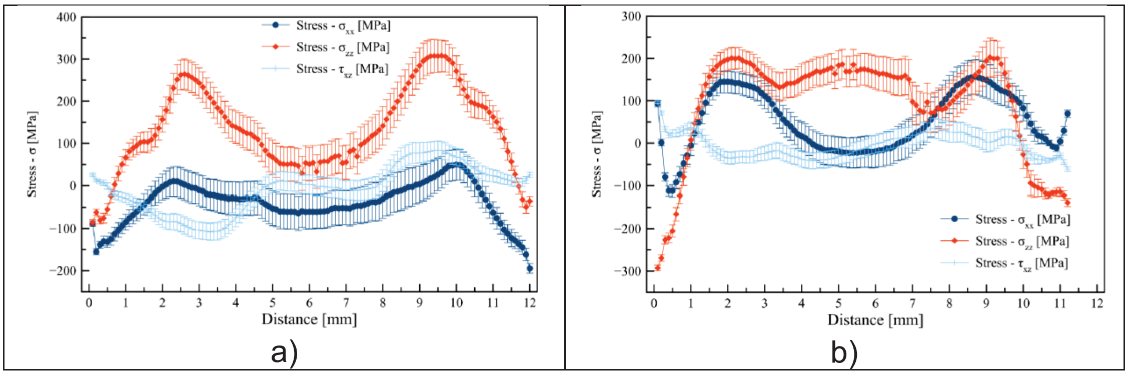

Figure 4. Residual stresses measured in the forged steel component, manufactured using two different riveting methods.

WP4: FE-Model Validation

Purpose: Compare experimental results with Volvo Cars’ finite element (FE) simulations to validate predictive models.

Results:

- A simplified simulation method was used to predict residual stresses in the cast component. This method only accounts for the thermal effects from the quenching operation.
- Comparison between the measurements and predictions showed that the simplified simulation method does not predict the stress state accurately enough, see Figure 5. More stress-creating mechanisms need to be taken into account.

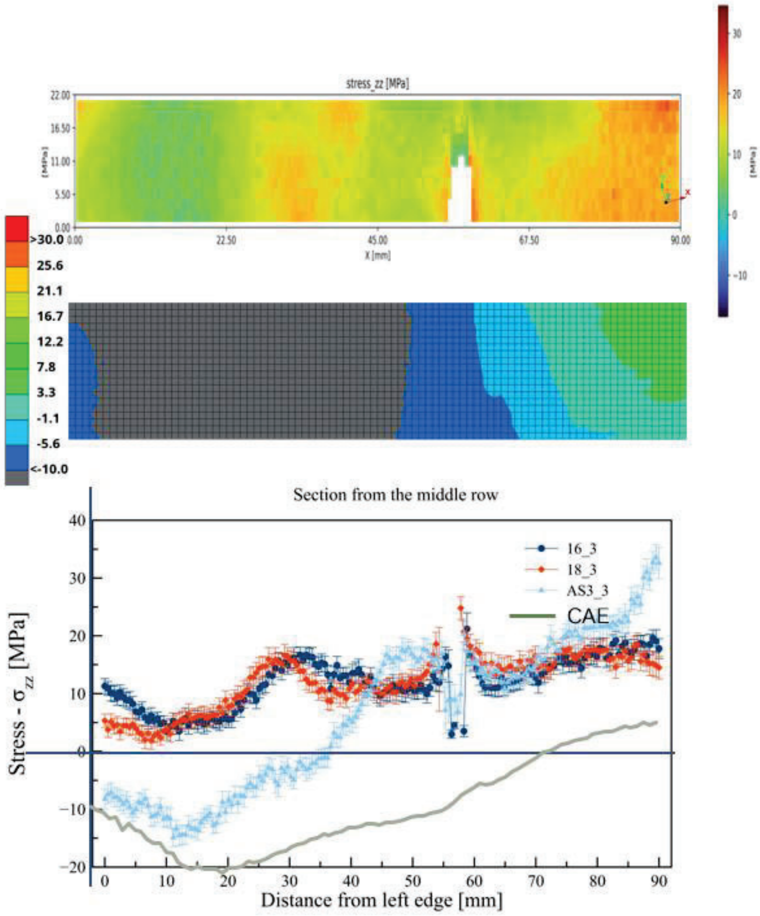

Figure 5. S-XRD measured residual stresses compared with predicted stresses using CAE-analysis.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	This project demonstrated the applicability of an important tool for understanding materials behaviour.
Be passed on to other advanced technological development projects	X	
Be passed on to product development projects	X	With time.
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

8. Conclusions and future research

The project confirmed that synchrotron X-ray diffraction (S-XRD) is a powerful tool for non-destructive residual stress analysis in automotive components. It successfully characterised stress state variations in cast aluminum and forged steel parts, linked to manufacturing methods. Scatterin's algorithms were successfully refined for industrial use, and Volvo Cars' FE simulations were compared against measured data. These results strengthen future design strategies and highlighted the importance of accurate simulation methods, as well as deeper understanding of materials behaviour. The collaboration also demonstrated the value of startup partnerships in accelerating innovation within structural materials and manufacturing technologies.

9. Participating parties and contact persons

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