A deconvolution method for the mapping of residual-stresses by X ray diffraction

Application to the validation of process simulations

Chedly Braham, Léo Morin, Pouya Tajdary, Gonzalo Gonzalez

A deconvolution method for the mapping of residual-stresses by X-ray diffraction

- **Introduction**
- **Principle of the method**
- **Application to SPD process (RCS)**
- **Conclusion**

Procédés et Ingénierie en Mécanique et Matériaux

Arts et Métiers Institute of Technology

le cnam

cnrs

Introduction

Context of this study : the XRD method for residual stresses

- XRD: accurate method for in-depth measurements of residual stresses
  - High accuracy and non-destructive way to determine residual stresses
  - Stress gradients in depth with a very good precision and resolution: with electro-polishing or multi-reflection grazing incidence *(M. Marciszko et al. 2014)*

- …but: Inaccurate method in the presence of high surface stress gradients
  - Stress obtained by XRD : convolution of the local stress over the irradiated area (*Kahloun et al., 1994; Hennion et al., 2000; Kahloun et al., 2014*)
  - The irradiated area cannot be reduced because it must contain enough crystallites to be statistically representative

→ In the presence of high lateral stress gradients inherent averaging effects are expected to occur

Introduction

Context of this study : the XRD method for residual stresses

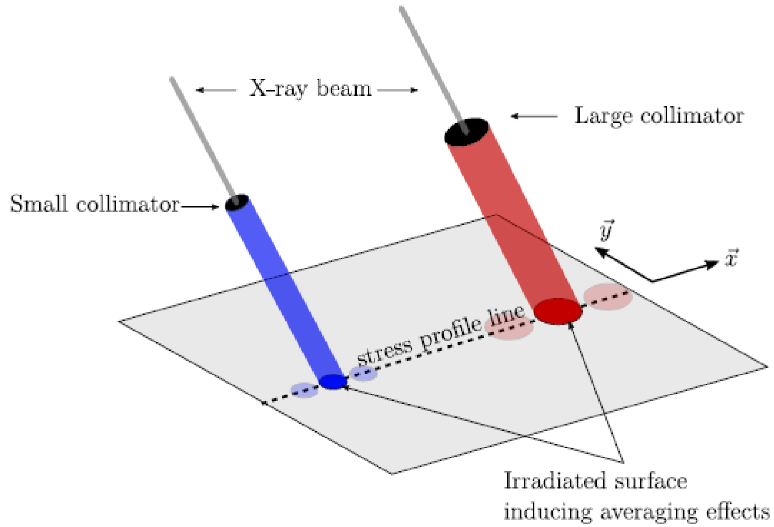
- XRD: accurate method for in-depth measurements of residual stresses
  - High accuracy and non-destructive way to determine residual stresses
  - Stress gradients in depth with a very good precision and resolution: with electro-polishing or multi-reflection grazing incidence *(M. Marciszko et al. 2014)*

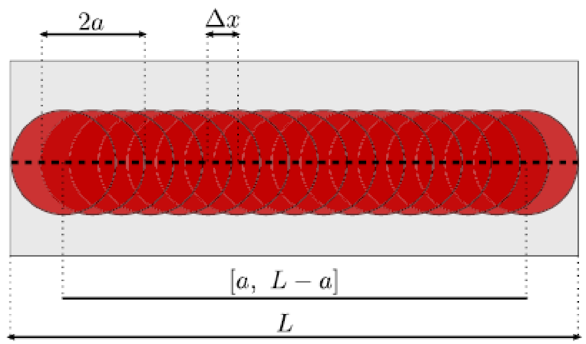
- …but: Inaccurate method in the presence of high surface stress gradients
  - Stress obtained by XRD : convolution of the local stress over the irradiated area (*Kahloun et al., 1994; Hennion et al., 2000; Kahloun et al., 2014*)
  - The irradiated area cannot be reduced because it must contain enough crystallites to be statistically representative

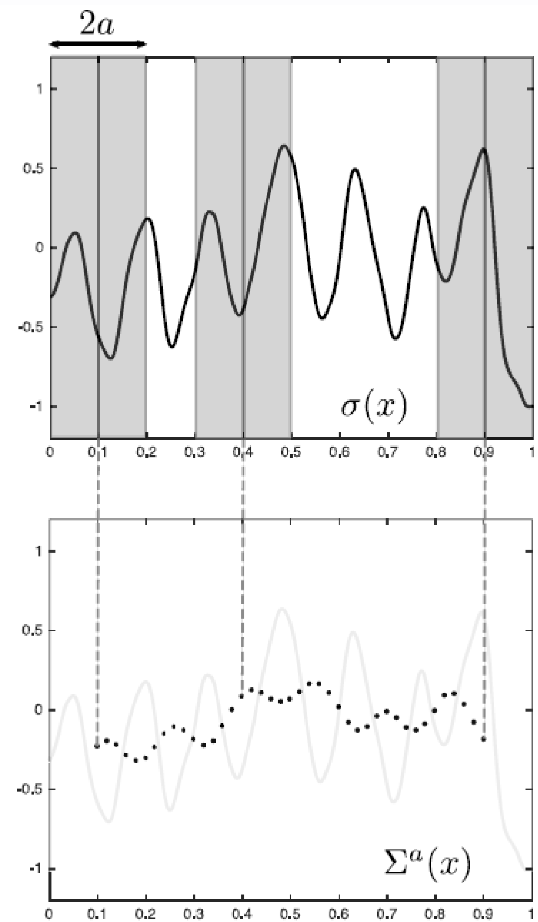
→ In the presence of high lateral stress gradients inherent averaging effects are expected to occur

Introduction

On the importance of averaging effects in XRD measurements

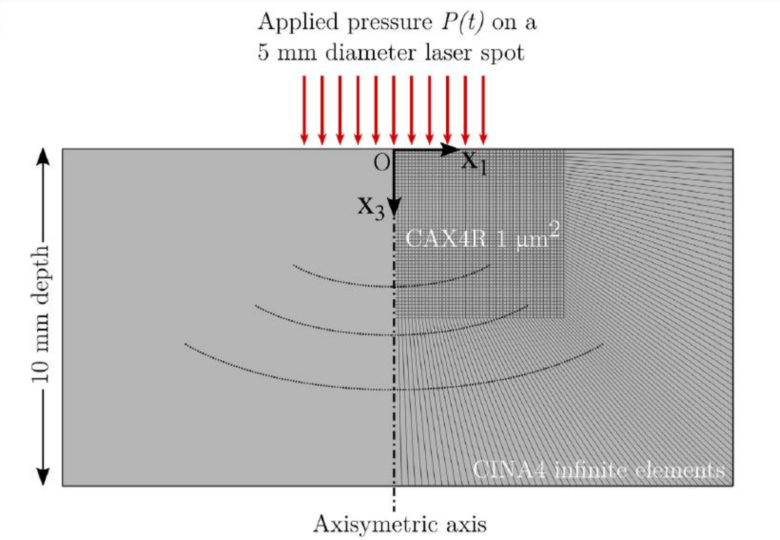


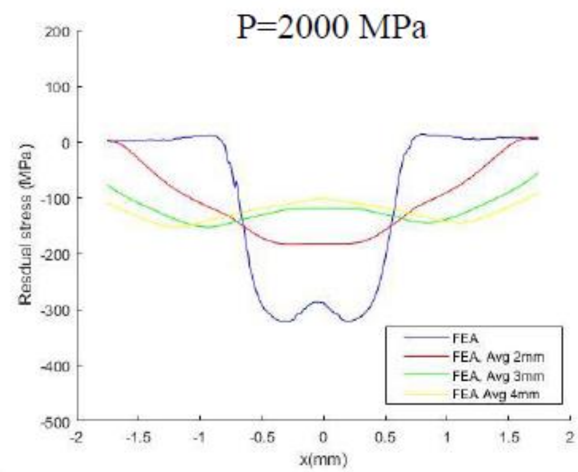


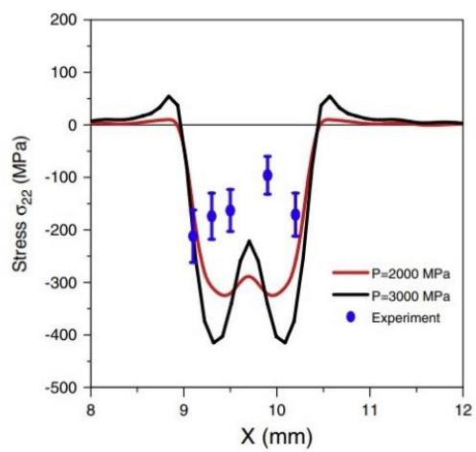


Introduction

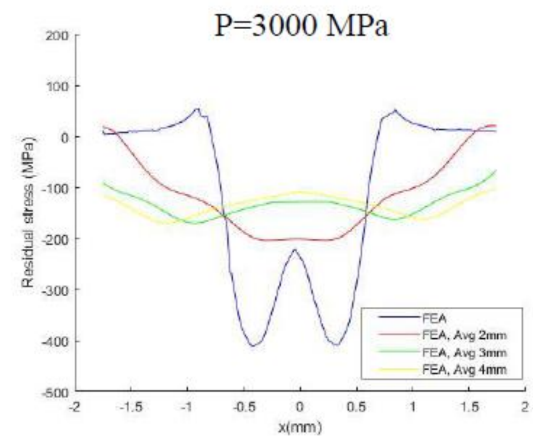
A test case : residual stresses in Laser Shock Peening







(P.Peyre et al. 2015)



A reconstruction method of residual stresses based on XRD

Principles of the method (1D case)

- Reconstruct the local stress field σ from an average measure Σ^a (over the irradiated area) obtained by XRD

$$\Sigma^a(x) = \frac{1}{2a} \int_{x-a}^{x+a} \sigma(u)\mathrm{d}u$$

- Using a regular measurement grid and expressing this integral with a discrete rule, one can establish a linear relation between the pointvalues of σ and Σ^a

$$\mathbf{\Sigma}^a = \mathbf{R}^a \boldsymbol{\sigma}$$

- (Approximate) inversion of this system leads to the reconstructed stress field

$$\boldsymbol{\sigma} = (\mathbf{R}^a)^+ \mathbf{\Sigma}^a$$

A reconstruction method of residual stresses based on XRD

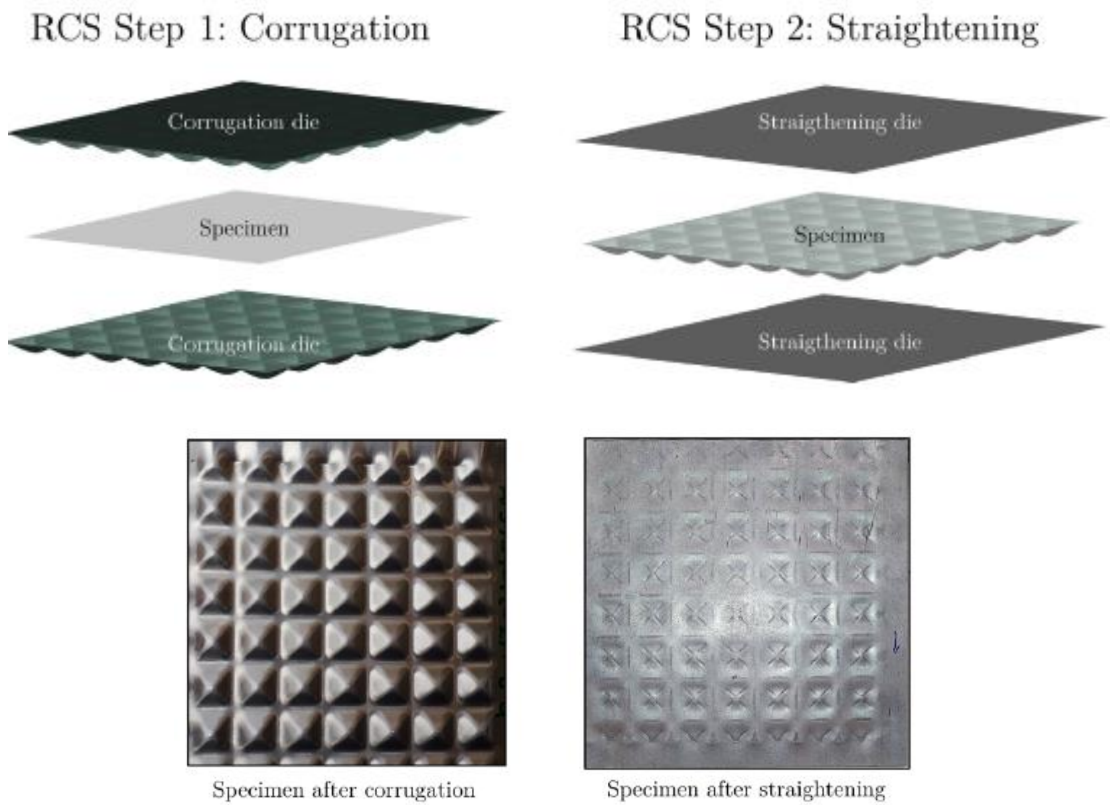
Practical implementation

- In practice, several issues are observed on the reconstruction due to:
  - The presence of noise on the measurements
  - The low number of equations (the system is underdetermined)
- Improvements of the method include
  - Automatic smoothing of the experimental datasets
  - Use of several collimator for the measurements (inducing several average datasets) to evaluate the averaging effect
- The method is then based on an automatic sampling (using a robot) → 1D line profile
- Extension from 1D to 2D mapping using regular sampling in two directions

Application to the reconstruction of 1D stress profiles

Application to simulated data (reference case)

- Method is first assessed in a reference case with simulated data: FEM simulation of the RCS process *(P. Tajdary et al., 2021; L. Morin et al., 2021)*

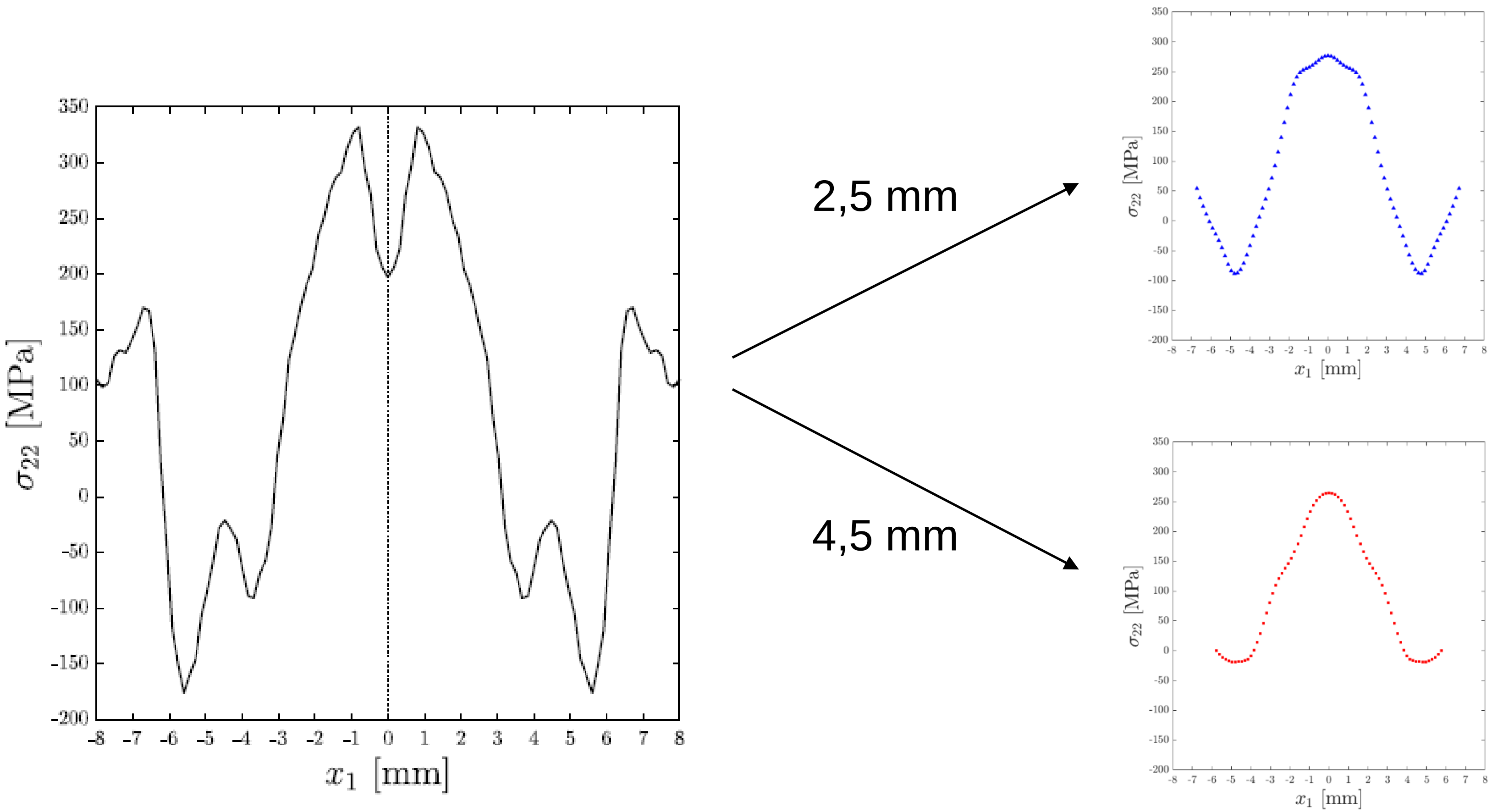


1-Pass RCS with aluminum alloy AA6061-T6

Application to the reconstruction of 1D stress profiles

Application to simulated data (reference case)

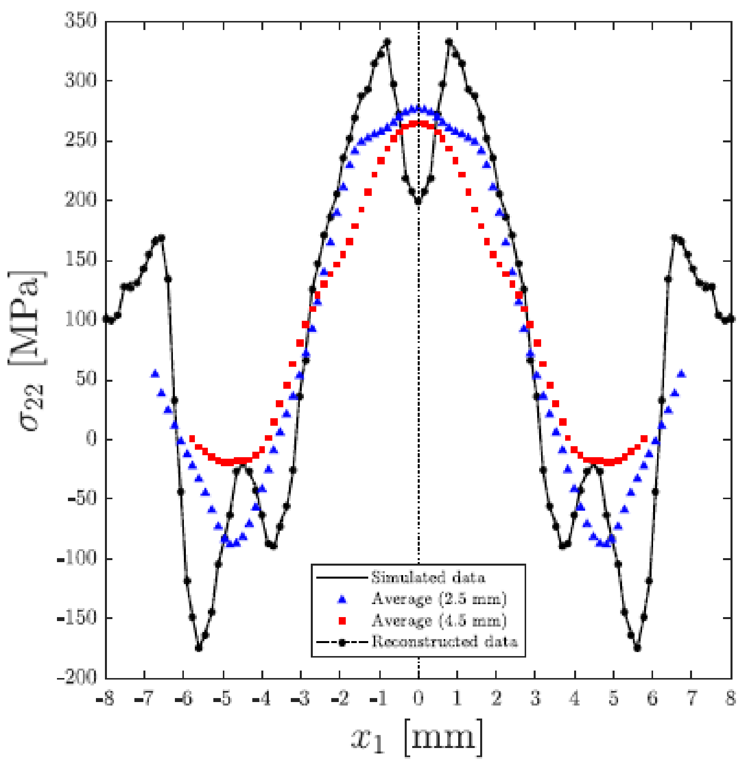
- Average datasets are constructed from the local profile using two collimators (Irradiated area diameter 2.5 mm and 4.5 mm)



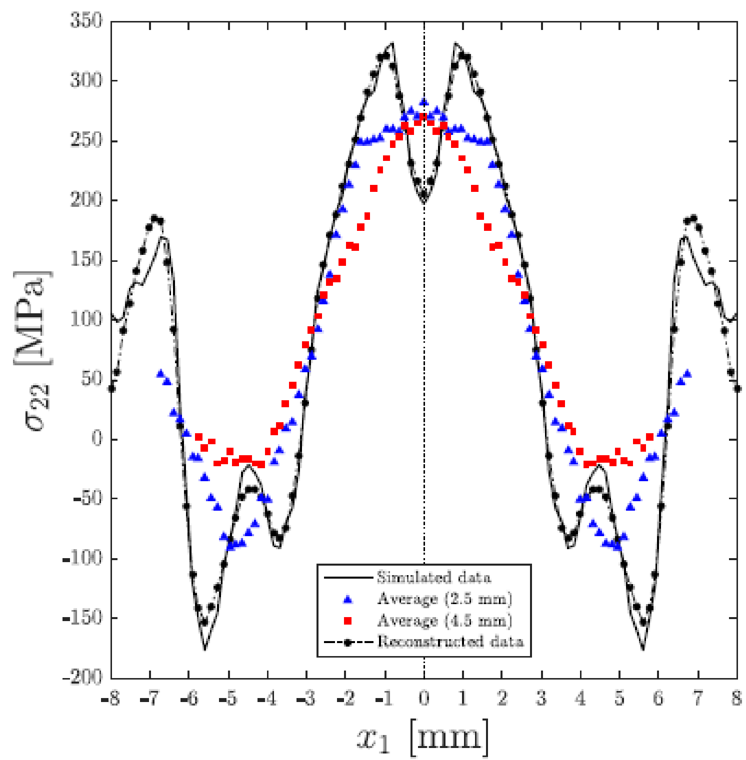
Application to the reconstruction of 1D stress profiles

Application to simulated data (reference case)

Reconstructed data is calculated from the average datasets and compared to the initial reference solution



without noise



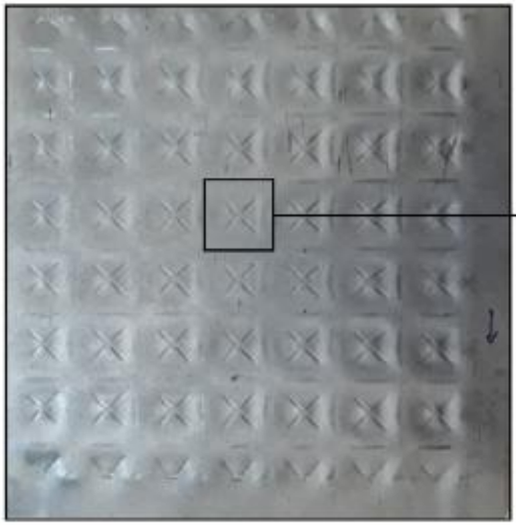
with noise on the datasets

Application to the reconstruction of 1D stress profiles

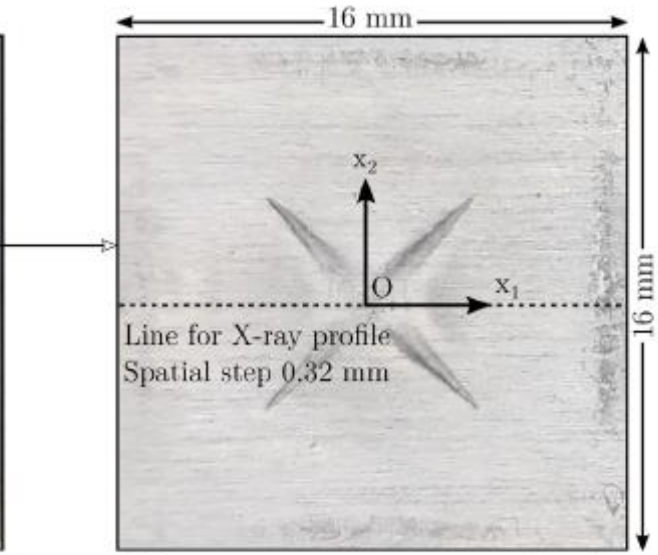
Application to experimental data

- Method is applied to experimental measurements of RCS

Specimen after corrugation



Specimen after straightening

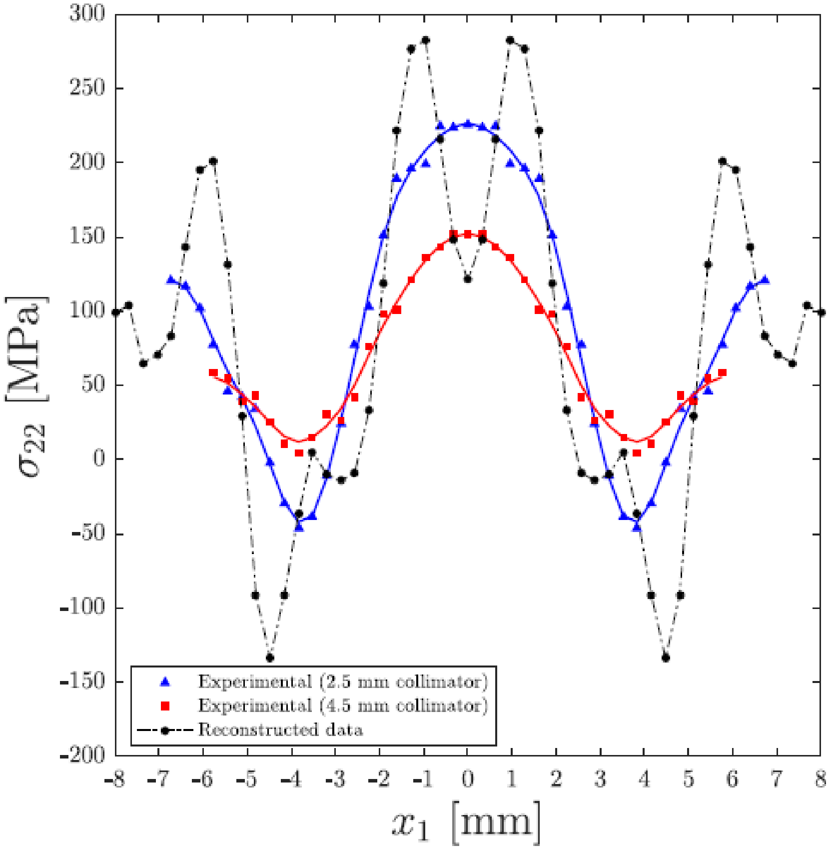


Elementary pattern considered for X-ray measurements

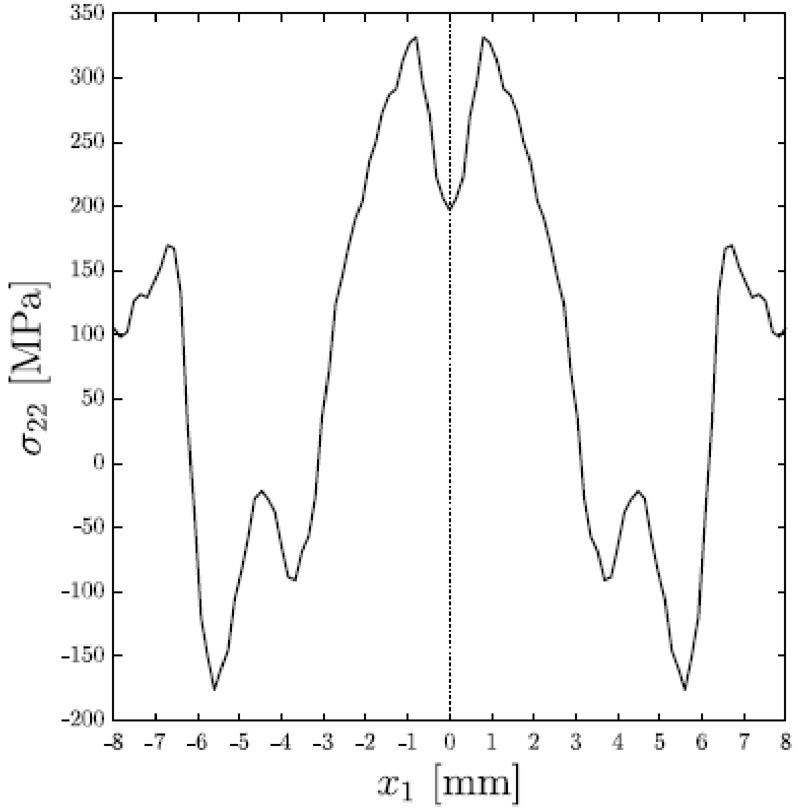
- Spatial step : 0.32 mm (50 points on the line)
- 2 collimators used : 2.5 mm and 4.5 mm diam.of irradiated surf.

Application to the reconstruction of 1D stress profiles

Application to experimental data



Experimental datasets and reconstructed stress

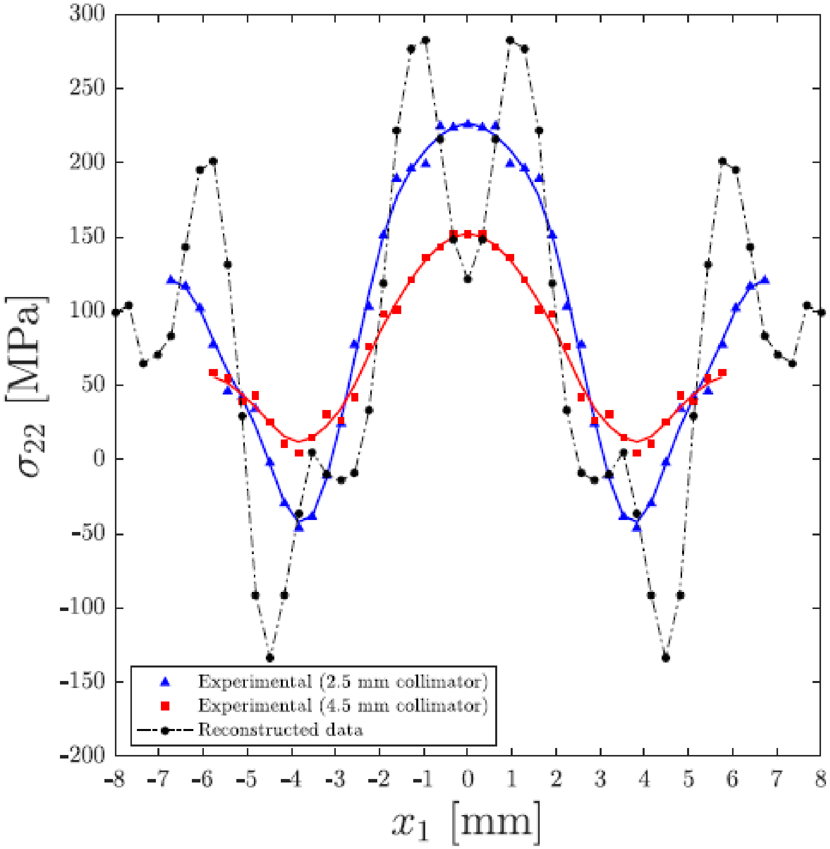


Numerical results for comparison

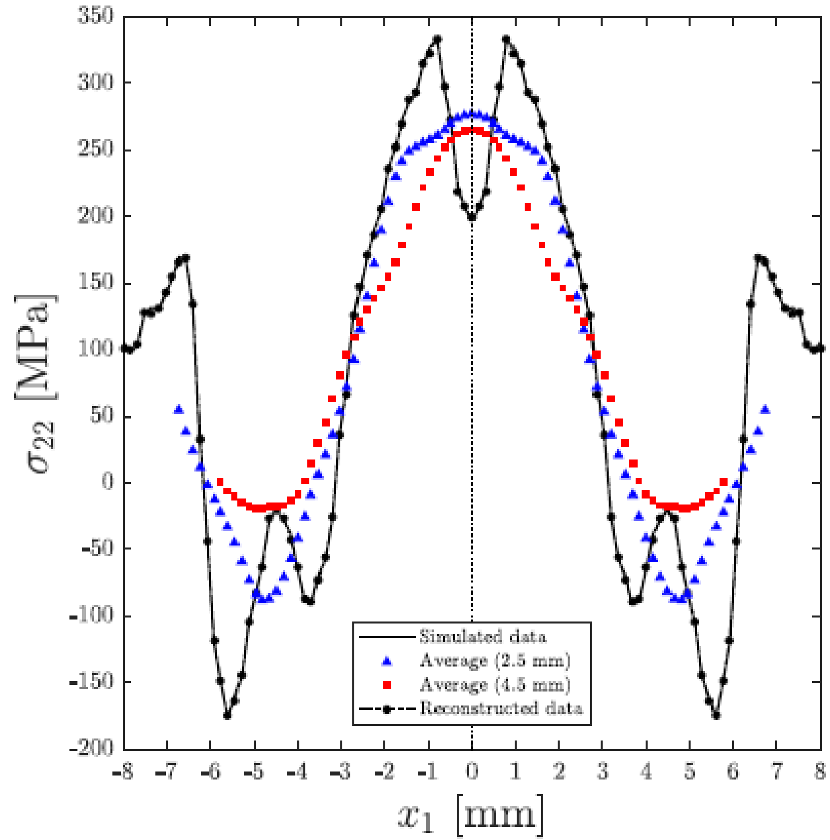
Application to the reconstruction of 1D stress profiles

Application to experimental data

Psi-tilt method: 2 ϕ and 13 ψ per point



Experimental datasets and reconstructed stress

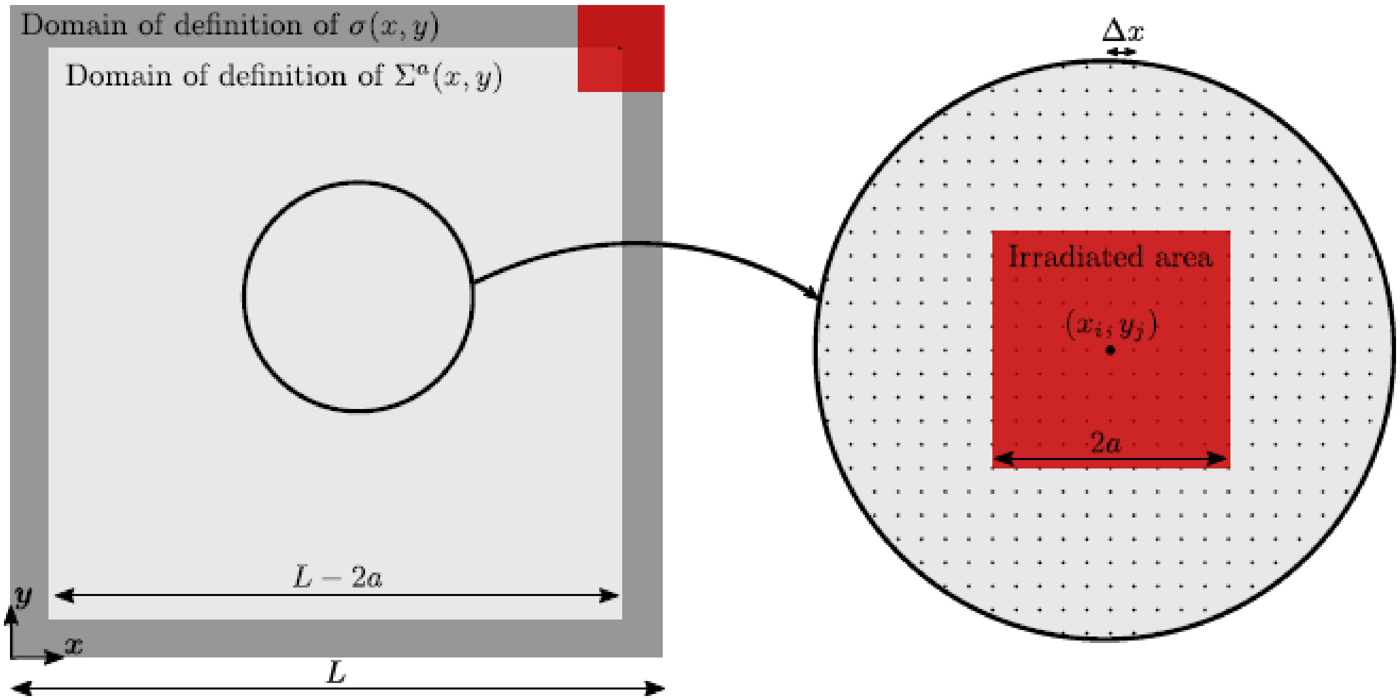


Numerical results for comparison

Application to the reconstruction of 2D mapping

Extension to 2D mapping

- Extension to 2D mapping using regular sampling in two directions



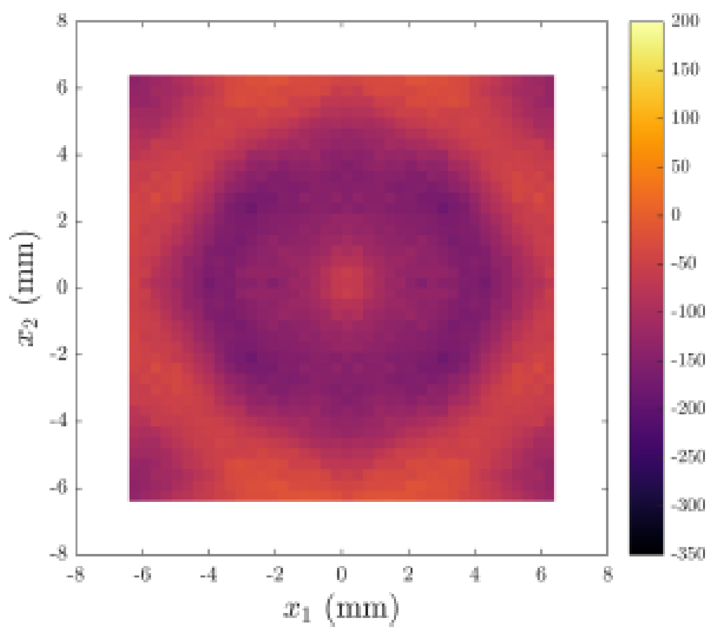
- Linear relation between local and average stresses can be also obtained

Application to the reconstruction of 2D mapping

Application to experimental data

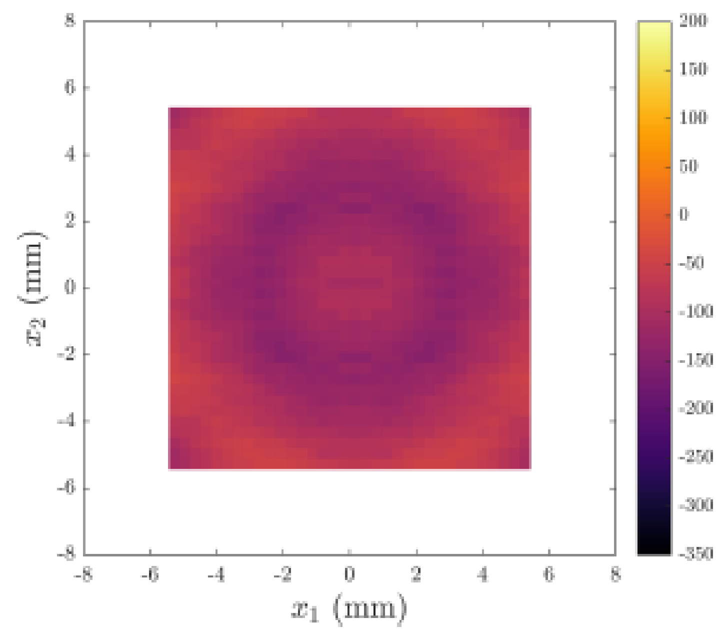
- Application to a 2D mapping with 0.32 mm (2500 points)

  $\sigma_{11} + \sigma_{22}$ from ε_{33}: one direction $\phi = 0$ and 13 $\psi = 0$ per point



Average dataset with ϕ2.5 mm collimator

$\sigma \in [-180, -13]$ MPa



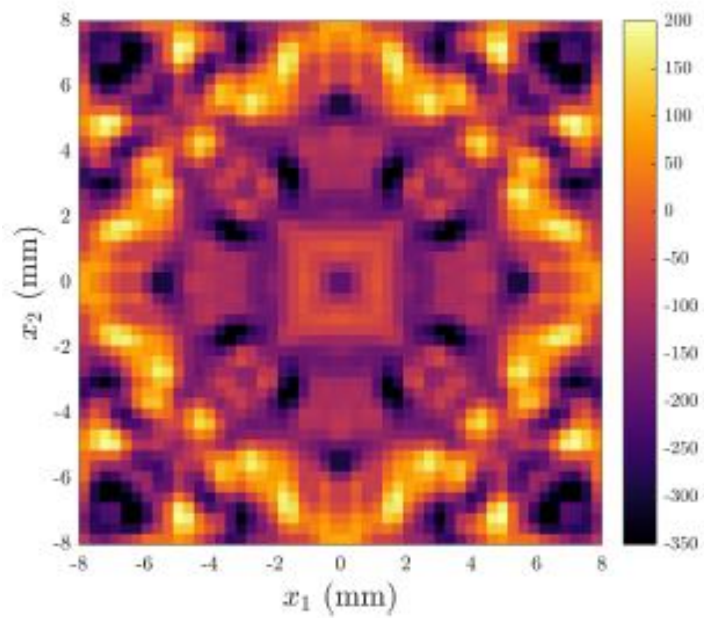
Average dataset with ϕ4.5 mm collimator

$\sigma \in [-147, -44]$ MPa

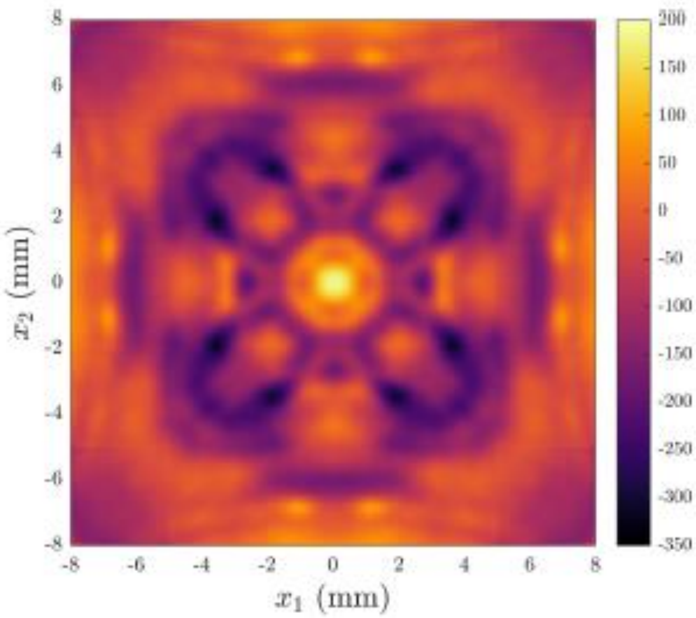
- High averaging effects observed

Application to the reconstruction of 2D mapping

Application to experimental data



Reconstructed field from XRD measurements



Local FEM Results

Conclusion

- A deconvolution method was proposed to determine the surface profile of residual-stresses by X-ray diffraction with high spatial resolution.
- The XRD measurements were performed by using a robot diffractometer.
- It was successfully applied to specimen processed by RCS on one dimension and then extended to a 2D mapping.
- Despite requiring an extensive number of measurement points, this method is useful for validating FEM simulation models of processes inducing high-gradient surface stresses.