Experimental report

12/02/2021

Proposal: **1-02-285** **Council:** 10/2019

Title: Measurement of round robin for residual stress measurement standardization

Research area: Engineering

This proposal is a new proposal

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Samples: S355jr steel, horseshoe round robin standard

Instrument	Requested days	Allocated days	From	To
SALSA	2	2	11/09/2020	15/09/2020

Abstract:

Knowledge of how residual stresses arise and develop during component manufacturing and operation is essential for optimizing component designs, increasing component stability and lifetime, and reducing unnecessary safety factors. To get this knowledge, we however, need to be able to characterize these stresses. Neutron diffraction is the optimal way to measure residual stresses in engineering components because of their high penetrating power and non-destructive nature. Its use in industry is, however, still very limited because the barriers for using these techniques and understanding (and trusting) the results are high. By working towards standardized measurement and data processing and analysis procedures we are breaking down these barriers. One step towards defining these standardized procedures and getting industry to trust the data is to benchmark neutron diffraction with other residual stress measurement techniques - including (some of) the (semi) destructive techniques that are used and trusted in industry. We are doing this by measuring a standard round robin sample using the different techniques where neutron diffraction is of key importance.

Measurement of round robin for residual stress measurement standardization
Experimental dates: 11.09.2020-12.09.2020

Aim and experimental plan
The experiment is part of a benchmark study where diffraction data from reference samples with a well-defined strain gradient are collected using lab x-ray, synchrotron x-ray radiation and neutrons. Three identical samples were machined from S355jr steel and measured using each of the techniques. However, as reproducibility of neutron measurements has previously been conducted at SALSA this was not repeated. Instead the samples were tightened to different degrees, inducing stresses to different levels. Additionally detailed near surface scans were performed to ensure that we get the full strain gradient.

Previous results
So far, we have measured the samples using two different setups: the ID15A beamline at ESRF and the portable X-ray based stress measurement equipment from stresstech. Three identical samples have been measured with each technique to test the reproducibility.

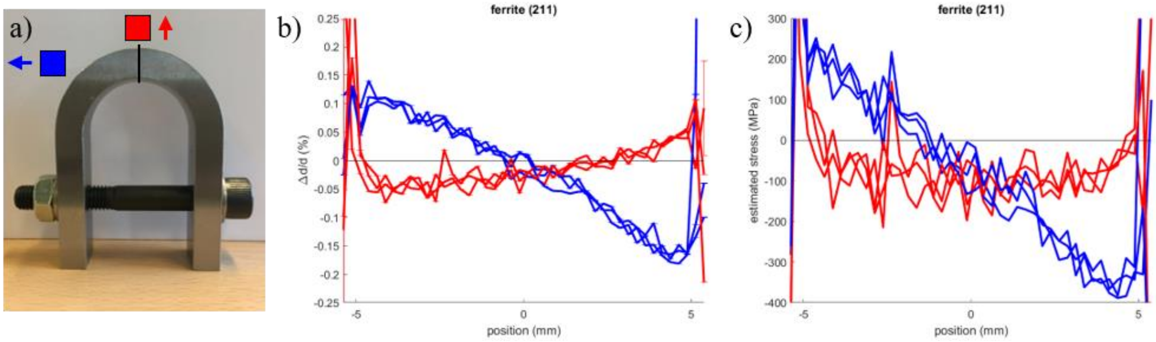


Figure 1: Results from measurements at ID15A at ESRF.

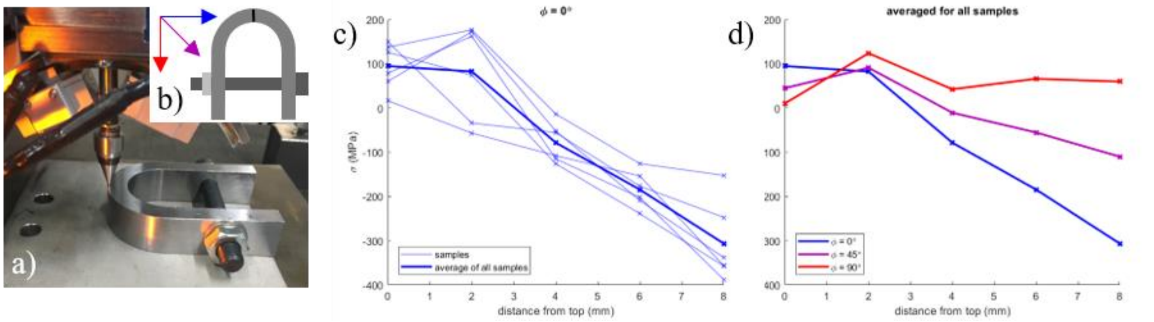
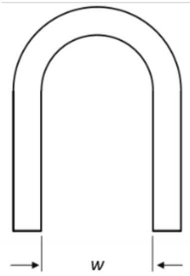


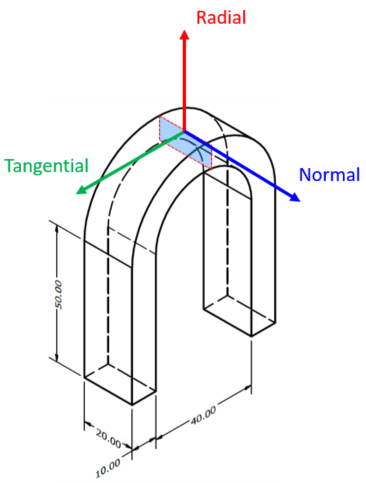
Figure 2: Results from the data collected with the portable stresstech equipment using the $\sin^2\psi$ method.

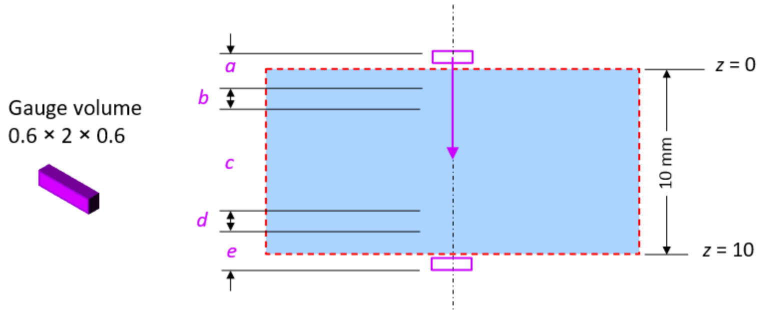
The ESRF ID15A data are very consistent and agree with the values expected from the simulations. The data from the stresstech equipment are a bit more scattered, which is not unsurprising as only the first few microns of the surface are probed with this technique. Besides this, the strain values of the very top points of the horseshoe are lower than expected from the simulations and ESRF data. To test whether this is from edge effects, such as pseudo-strain, the samples were measured from the top using the same equipment which gave an average strain along “the blue direction” of 331.2 MPa which is very close to the 316.6 MPa predicted from the simulations.

Performed experiment
The experiment was (due to COVID restrictions) conducted as mail-in.
Three samples were measured in the stress conditions explained in the table below.

sample label	condition	w (mm)	Δw (mm)
1	Unstressed	39.9	0
3	Stress 1	39.6	0.3
2	Stress 2	38.2	1.7







Scan name	Scan range, z	Step [mm]
a	-0.8 to 1.0	0.1
b	1.2 to 2.0	0.2
c	2.5 to 7.5	0.5
d	8.0 to 8.8	0.2
e	9.0 to 10.8	0.1

Figure 3: strain directions measured.

Figure 4: Details on scanning strategy. For some of the tangential scans slightly different step sizes are used (I'm guessing due to time limitations).

Each of the samples were measured in three orthogonal directions as depicted in figure 3. To optimize the use of beamtime, different regions of the sample were scanned using different step size as described in figure 4.
Experimental parameters:

- λ = 1.64 Å
- 2θ = 89 (ferrite (211))
- Primary slits: vertical = 2 mm, horizontal = 0.6 mm + oscillation
- Secondary slits: horizontal = 0.6 mm
- Hexapod orientation: radial: ω = -45.5°, normal: ω = 44.5°, tangential: ω = 134.5°.

Two d0 samples in the form of small cubes of the same material were measured. The average of their peak center are used in the strain evaluation.

Preliminary results

The preliminary results of the bulk parts of the experiments are shown in figure 6.
The evaluation of the edge scan data is in progress as they are significantly more tedious. Some of the tangential scans were conducted with larger stepsizes as for the other directions. The stresses are calculated for the points where data for all directions very available (and for a few points where the strain could be estimated from closely neighboring points).
The stresses are calculated using E = 210,000 MPa, ν = 0.29.

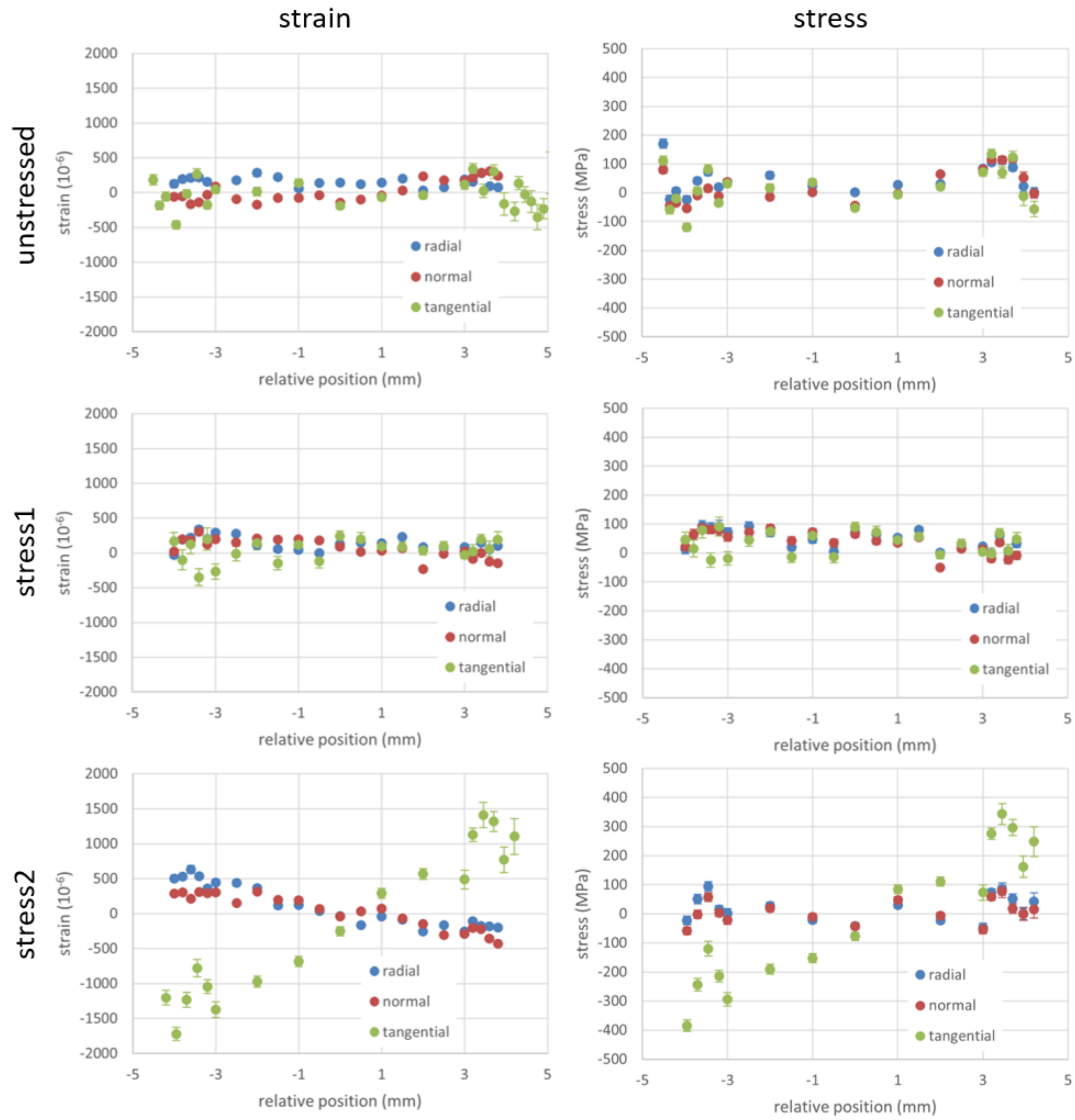


Figure 6: Preliminary results showing only the bulk measurements.

Preliminary conclusions

Like for the previous results a very clear and linear stress gradient is seen along the tangential direction in the sample stress2. It is also clear that the gradient is larger than for the previous data – stresses of app. 300 MPa are already reached app. 2 mm from the surface (3 mm from the center of this sample whereas that value was not reached until the edge for the other samples. This is expected as the applied stresses were smaller for the previous data (Δw = 1.5 mm) as compared to here (Δw = 1.7 mm). Modelling of the stress conditions used in this experiment will verify the differences.

For the unstrained sample, no significant neither strain nor stress is observed. This confirms that the stresses observed in the sample stress2 are indeed induced by the tightening of the bolt and not an effect of e.g. the fabrication process.

In the sample stress1 a very slight strain can be speculated along the tangential direction. This is however not clear in the stresses. The edge data might be able will help determining this speculation. Because of the very limited applied stresses for this sample (Δw = 0.3 mm) only very limited strains/stresses are expected in this sample. Modelling of the stress conditions can again verify this.