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► **To cite this version:**

Yitong Yang, Sabine Weiss. In-situ investigation on cyclic bending deformation of oligo-crystalline 316LVM steel for coronary stent application with EBSD. International Conference on Strength of Materials 2022, Jun 2022, Metz, France. hal-03829658

HAL Id: hal-03829658

<https://hal.science/hal-03829658v1>

Submitted on 25 Oct 2022

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ICSMA19 Metz, France, June 26 - July 1, 2022
International Conference on Strength of Materials

The intended destination for publication is the 1st option, on the EPIscience platform.

In-situ investigation on cyclic bending deformation of oligo-crystalline 316LVM steel for coronary stent application with EBSD

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The objective of this work is to investigate the strain localization and slip activation of the microstructure of oligo-crystalline 316LVM steel struts evolving during different cyclic bending deformation stages (number of cycles) and loading conditions (maximum stress and neutral). A micro-scale three-point bending fixture was designed and incorporated into a micro tensile/compression machine inside a scanning electron microscope (SEM) to perform in-situ electron backscatter diffraction (EBSD) measurements during different phases of cyclic fatigue testing. The following results were obtained: 1) The quantitative strain could be compared after each stage of deformation. 2) The rotation of the grains orientations is observed during the cyclic deformation while the morphology did not change significantly. The results contribute to the understanding of the evolution of the microstructure at low strain variations under bending fatigue conditions, and can support the prediction of the fatigue life of 316LVM stainless steel oligocrystalline microdevices like coronary artery stents.

Keywords:

Oligo-crystalline microstructure, in-situ bending fatigue test, EBSD, 316LVM austenitic steel, coronary stent,

1. introduction.

Austenitic stainless steel provides excellent corrosion resistance against physiological environment. Specifically, 316LVM stainless steel has high purity and cleanliness level due to the production by vacuum melting- as well as an excellent biocompatibility [6]. Therefore, it is widely used as medical implant, such as temporary implants, joint implants and artery stents. To minimize the physical and financial burden of the patient, the understanding of the metal-physical phenomena to improve the long lasting functionality and durability of the implant is essential. One of the major factors affecting the mechanical properties of coarse crystalline metallic materials is the size effect. The yield strength increases as the average grain size decrease in polycrystalline metallic materials [1] because the dislocation movement is hindered by grain boundaries. Various studies on size effects in copper, gold, titanium alloys and steel showed a different relation between strength and grain size. [2] [3] [4] [5]. However, the bending deformation has not been thoroughly investigated to date. In this study, the cyclic bending behavior of oligo-crystalline 316LVM thin sheets is investigated. The low cycle fatigue behavior and the microstructure changes are examined by means of in-situ SEM and EBSD.

2. Materials and Experimental Methods

The austenitic stainless steel 316LVM was cut into thin sheets with 0.5mm thickness and annealed to coarsen the grain to create similar conditions (grain size to component size ratio) like in micro devices. The chemical composition of the material is shown in Table 1.

Table1 Chemical composition of the investigated 316LVM stainless steel

C	Cr	Cu	Mn	Mo	N	Ni	P	S	Si
0.015	17.6	0.12	1.67	2.8	0.083	14.26	0.019	0.001	0.5

The thin sheets were sealed in glass tubes filled with Argon protective gas and annealed at 1250°C for 96 hours to obtain oligo-crystalline microstructure and to avoid oxidation of the surface. The material was rapidly quenched in water to room temperature by destroying the glass tubes under water. The samples were cut by laser cutting into the bending sample shape for the in-situ bending tests. (Figure 1)

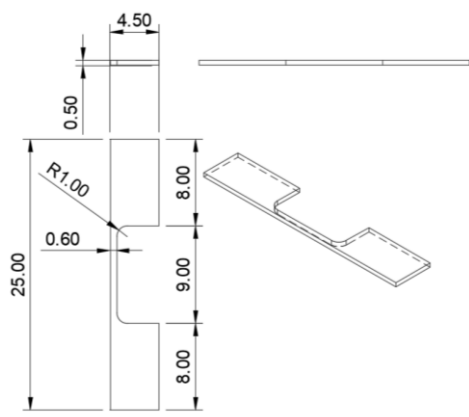


Figure 1 sample dimension.

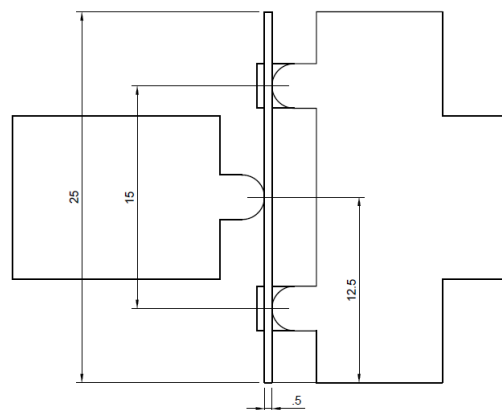


Figure 2, schema of bending set up

The sample was then installed on the custom built 3-point bending holder of the micro tensile device from Kammrath & Weiss GmbH (Schwerte, Germany). The schematic bending set up is shown in Figure 2. The maximum speed of the micro-tensile device is 20 $\mu\text{m/s}$ and the bending depth is 200 μm . The frequency was set to 0.1Hz.

The in-situ measurements were performed inside a Mira 2XMH SEM from Tescan (Brno, Czech Republic) The EBSD scans were performed before bending, and after 10, 100 and 1000 cycles, respectively, with an EDAX/TEAM EBSD system (New Jersey, USA). The Step size of the EBSD measurement was set to 0.5 μm .

3. Results

3.1 Cyclic bending deformation

The diagram of low cycle fatigue stress- amplitude-as a function of number of cycles is shown in Figure 3. The test was performed at $R=1$ for in total 1000 cycles. The initial stress amplitude is around 400 MPa, The S-N curve is flat after a slight slope down to 280 MPa at 200 cycles, due to the oligo-crystalline microstructure. Such a deformation behavior is similar to the one of single crystals. Comparable results have been reported by Donnelly et al [6], who suggested that the size effect of the ratio of sample size to grain size affected the dislocation movement.

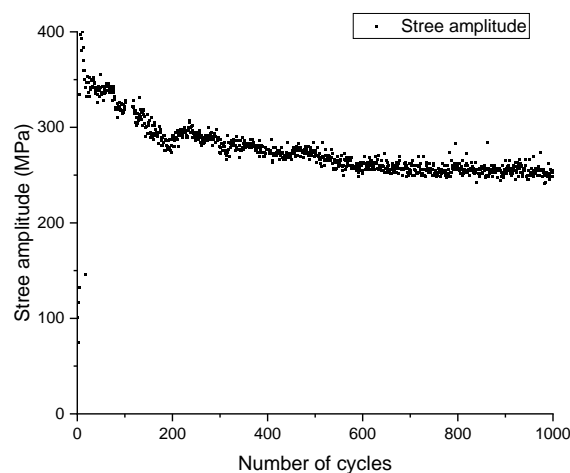


Figure 3 SN curve until 1000cycles.

3.2 Microstructure characterization

The inverse pole figure (IPF) maps (figure 4) demonstrate the grain structure and the orientation of the [001] directions of the sample in the initial state and after 10, 100 and 1000 cycles, respectively. The morphology of the grains as well as their orientation did not change significantly during bending deformation. The material was able to recover to the initial state after the load is released for less than 1000 cycles. After 1000 cycles, the sample remained slightly bended after the load release. This plastic deformation has influence on the orientation of the grains as visible in Figure 6.

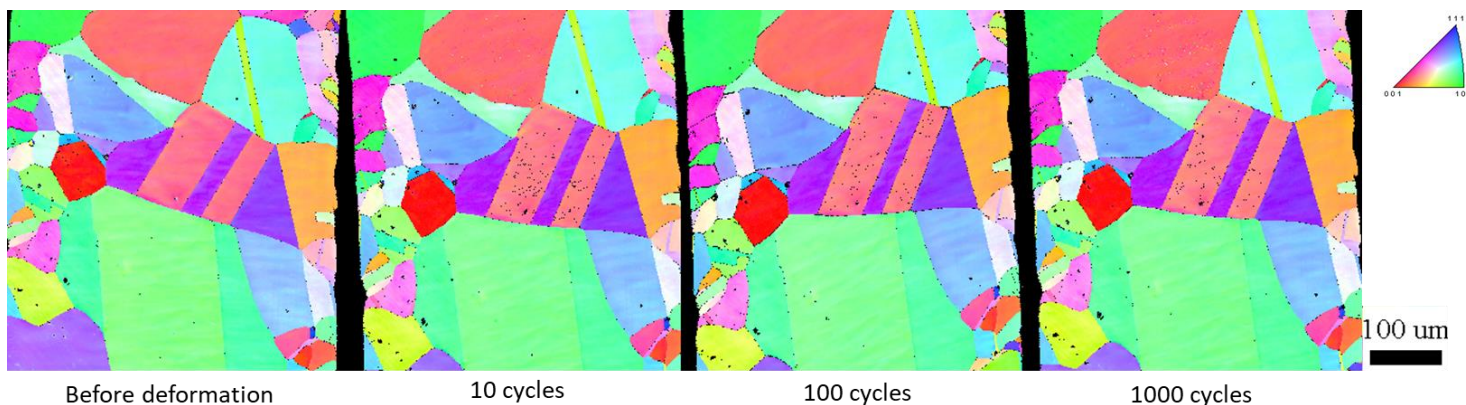


Figure 4, IPF maps of the sample.

To illustrate the strain distribution within the grains after cyclic bending, Grain Reference Orientation Deviation maps of the compression area of the sample are shown in Figure 5. The GROD maps display the misorientation between the individual grains and the reference orientation. In this study, the orientation in the area with the lowest kernel average misorientation value was selected as the reference orientation. The gradient of the GROD value qualitatively represents the accumulation of plastic deformation. Before deformation, grain a) on the right sample rim in the center is in direct contact with the bending pin (see marking in figure 5). After cyclic deformation, the GROD value of this grain increased significantly, while neighboring grains are far less influenced.

The GROD gradient within the grains indicates that the plastic deformation is concentrated close to the grain boundaries. For example, in grain a), the deformation accumulates at the grain boundary at its left bottom side, in the area of highest tension within this grain.

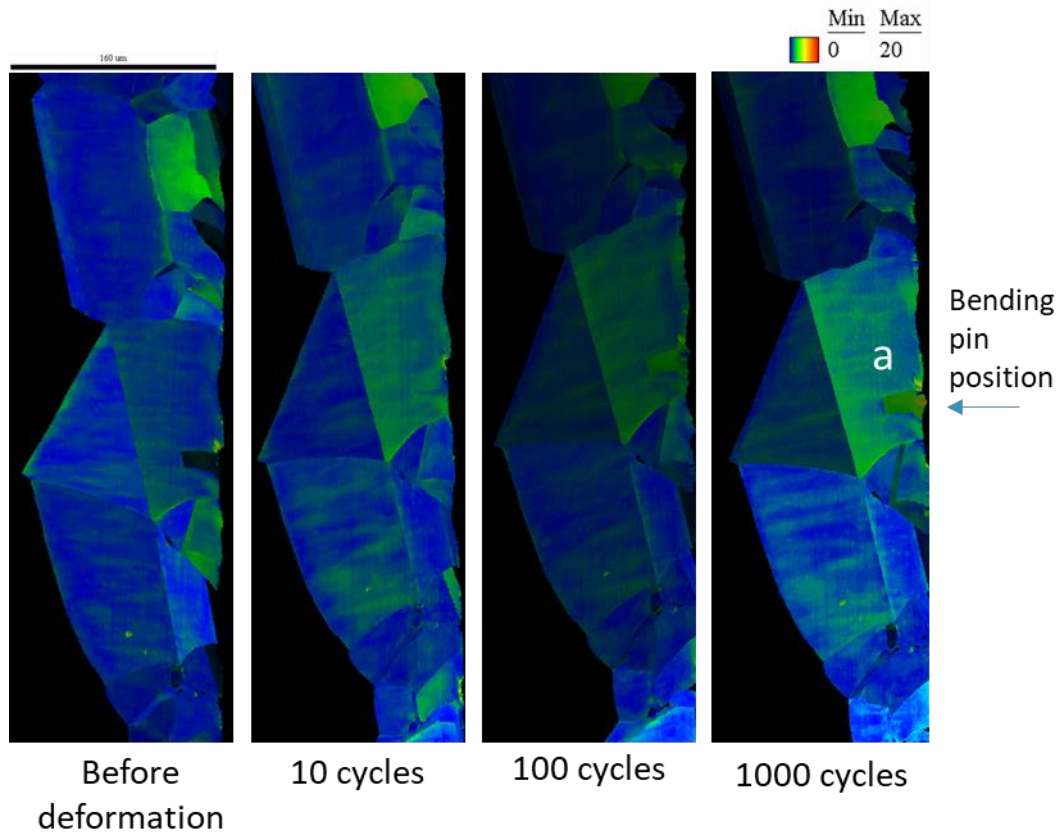


Figure 5. GROD map of the contraction area of the sample

The [111] inverse pole figure of some representative individual grains within the contraction area of the sample is shown in Figure 6. The points with red, blue, green, purple, yellow and pink color represent the orientations of grains a-e (marked in figure 6), respectively. The points 1 to 4 represent the orientations of the respective grain at each stage of the cyclic deformation (i.e. 0, 10, 100 and 1000 cycles). As shown in figure 6, grains a, b, c and e turn in direction [011]. Grain d and f rotated in direction [331]. More data points are required to

determine a systematic of grain orientation rotations during cyclic bending deformation.^f

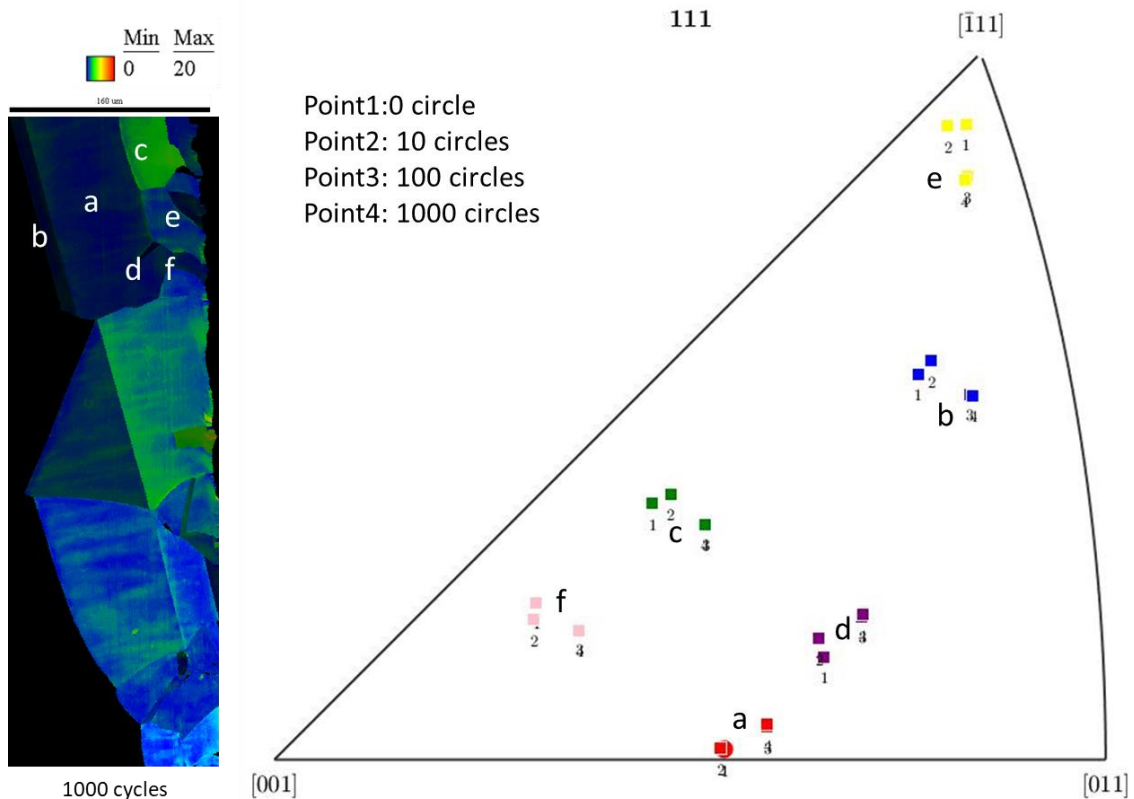


Figure 56, [111] inverse pole figure of grains in upper part of the contraction area.

4. Conclusion

The present work focused on in situ observation of the fatigue behavior and the microstructure evolution of thin oligocrystalline sheets of 316LVM stainless steel in low cycle bending fatigue condition.

-The following results were obtained:

1. The S-N curves are flat compared to the ones of standard specimen. This could be related to the size effect of the oligo-crystalline microstructure, which leads to a deformation behavior similar to the one of single crystals.

2. The strain could be qualitatively compared after each stage of deformation.
3. The strain within the grain is concentrated along the grain boundaries.
4. Rotation of the grain orientations took place during cyclic deformation while the morphology of the grains did not change significantly.

5. Acknowledgements

The authors would like to thank the “Deutsche Forschungsgemeinschaft” (DFG) for financial support under contract “WE 2671/11-1”.

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