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Identification of Twin Formation in Additively Manufactured Stainless Steel by *In-Situ* EBSD

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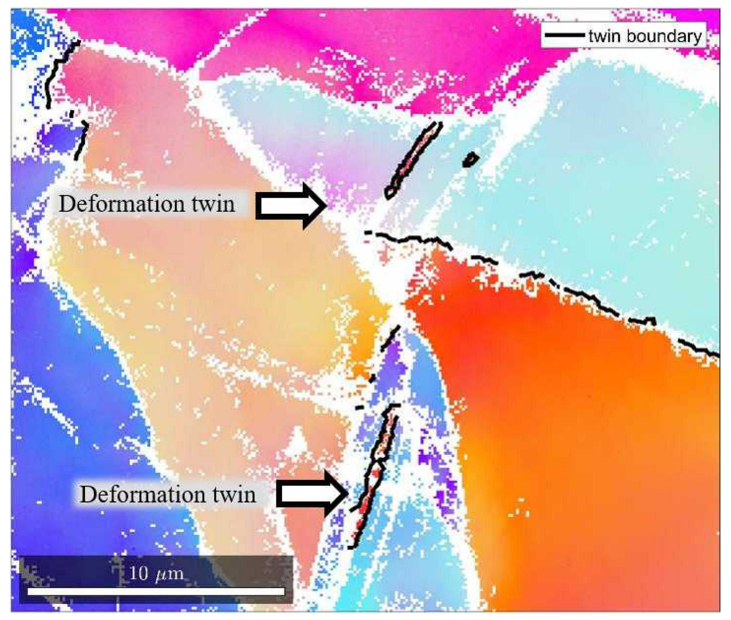
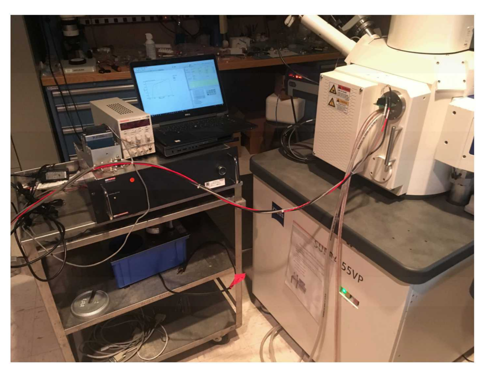
Introduction

A recent study of additively manufactured austenitic stainless steels (300 series) observed that deformation twinning, which is not typically observed in wrought products, occurs in this material [1]. This was thought to enable higher strength and ductility. This study addresses two questions using *in-situ* tensile testing: ***(1) When during deformation does twinning begin, and (2) is deformation accommodated by a mix of slip and twinning?***

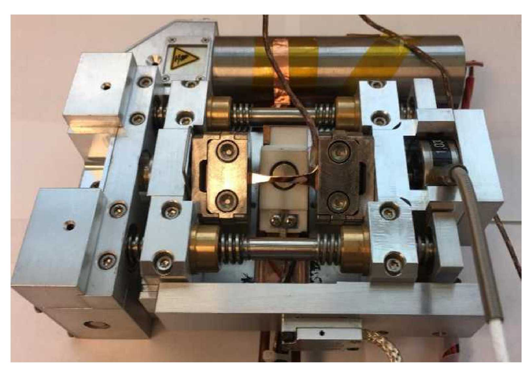


Set Up

As-built additively manufactured stainless steel specimens were tensile tested *in-situ* in a Zeiss Supra 55-VP Field Emission Scanning Electron Microscope equipped with an Oxford Symmetry CMOS Electron Backscatter Detector. A MTI Instruments Tensile tester was used to perform mechanical testing. The SEM was operated at an accelerating voltage of 20 kV, and 80x80 μm areas were scanned using a 300nm step size to observe twinning.



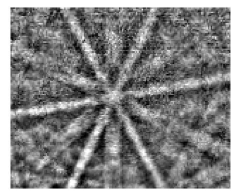
In-Situ Set-Up



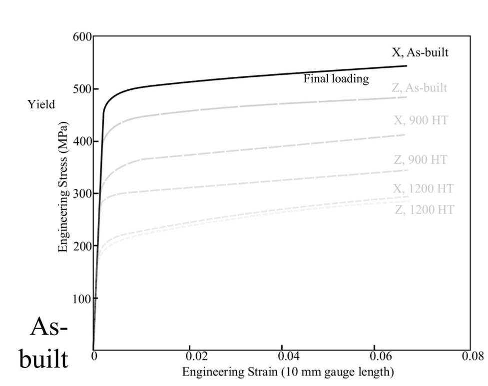
MTI Instruments Tensile Tester

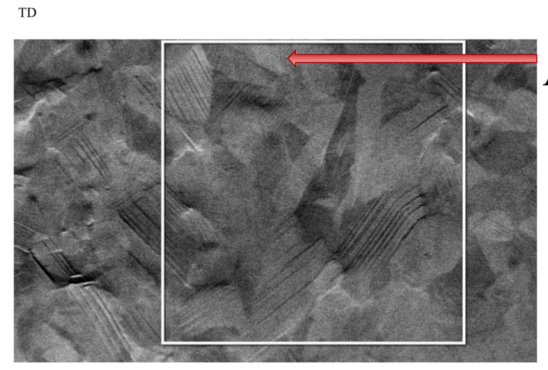
Tensile Tester and Oxford Symmetry Detector Positioning within the SEM

Challenges



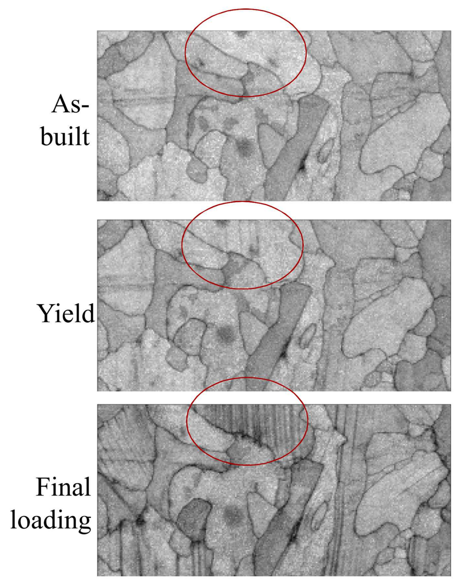
Distance to EBSD detector resulted in grain drop off due to insufficient poles for indexing





Are these lines slip traces or twins?

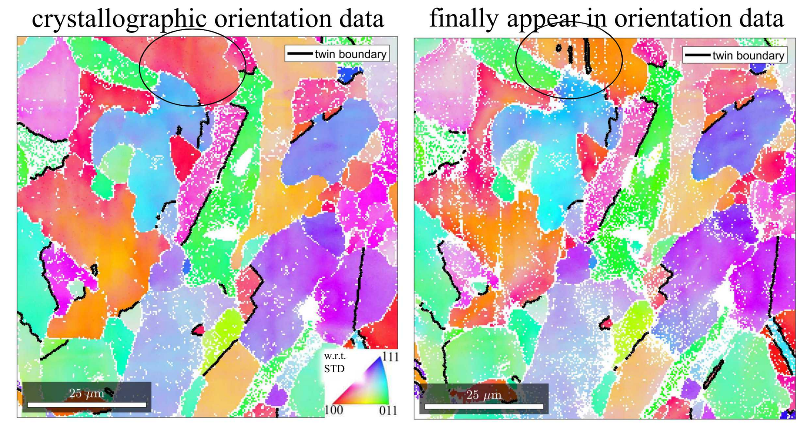
<u>We can't tell from crystallographic orientation data, even at 50 nm stepsize!</u>



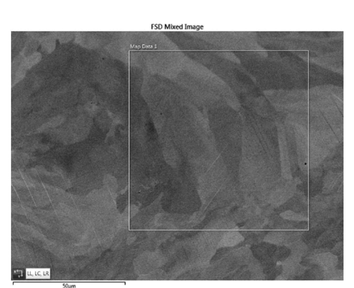
<u>But we can differentiate between twins and slip lines from image quality maps!</u>

Yield – twins do not appear in crystallographic orientation data

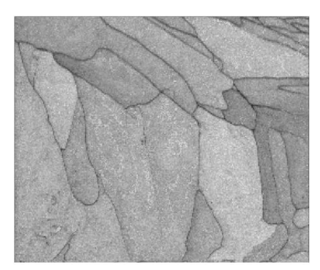
Final loading: largest twins finally appear in orientation data



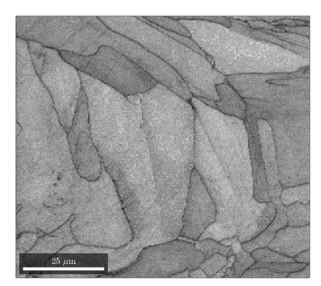
Key Results



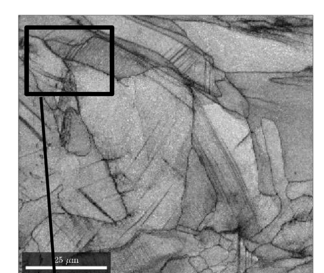
ECC map at yield: straight lines observed on surface of grains. *In-situ* testing allowed us to make the subsequent determination that these are twins.



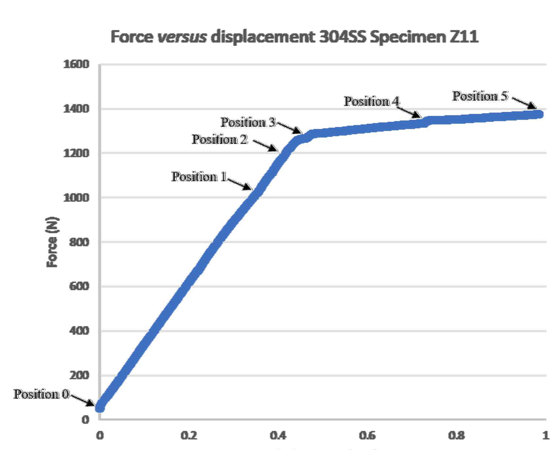
BC map at yield: twins still too small to be identified in image quality data



BC map after plastic deformation: twins large enough to show up in image quality data but too small to index



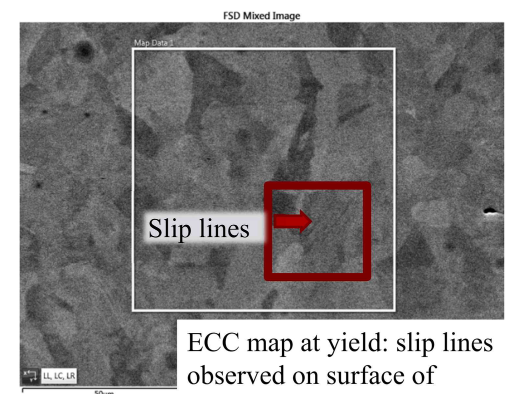
BC map after final loading increment: twins large enough to be indexed



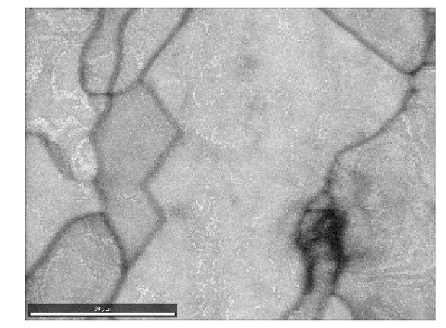
Typical data from as-built Z specimen is provided. These data are typical of both as-built X and Z specimens.

These data highlight that **deformation twinning began at yield.**

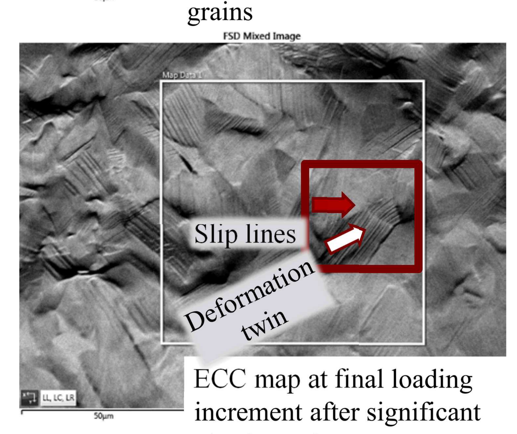
IPF map colored with respect to the STD with twin boundaries overlaid



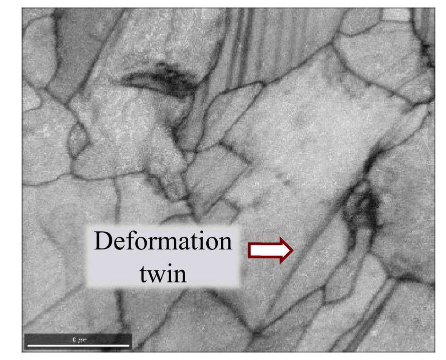
ECC map at yield: slip lines observed on surface of grains



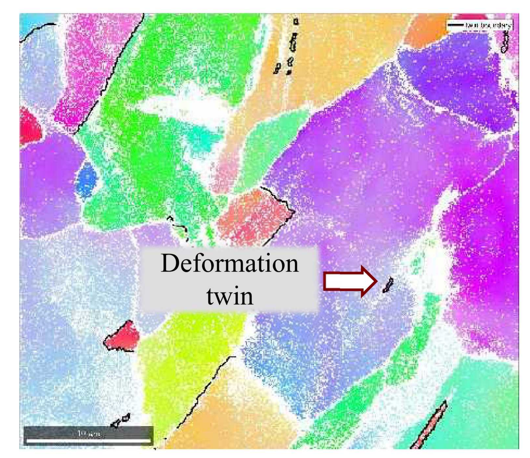
BC map at yield: no twins identified



ECC map at final loading increment after significant plastic strain



BC map at final loading increment



IPF map colored with respect to the STD with twin boundaries overlaid

- Some grains initially deformed only by slip, while others only deformed by twinning.
- The grain highlighted here initially deformed by slip but, eventually, a deformation twin developed. Is there a critical resolved stress or strain for twinning?
- *More data are necessary to determine if the competition between twinning and slip depends on grain orientation, grain size, dislocation cell structure, etc.*

Conclusions

In-situ EBSD data differentiated between slip lines and incipient twins (identical in SEM images).

While incipient twins are too small to be indexed by EBSD, they could be observed in pattern quality maps. These features could then be tracked until, upon subsequent deformation, they were large enough to index as twins. By performing *in-situ* testing, it was possible to determine when the twins first appeared. Twinning began at yield as indicated in the Force Versus Displacement plot (Position 2).

Deformation was accommodated by a combination of slip and twinning. The competition between the two will be the subject of future work.

References:
[1] Y.M. Wang et. al., Nature Materials **17** (2017), p. 63

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NNSA National Nuclear Security Administration

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