In depth analysis of Zinc coatings using in-situ Nano tensile test with DIC and EBSD

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Introduction

Zinc coatings are widely utilized in the steel industry to protect their steel sheets from corrosion. Thereby acting as a diffusion barrier, while also taking the role as a sacrificial anode and thus protecting the steel sheets. The hexagonal closed packed (HCP) structure of zinc correlates to a strong variation in the critical resolved shear stress (CRSS) between the 33 available slip systems (SS) [1]. As a consequence zinc exhibits a strong anisotropic behaviour which often ends up in a brittle facture as the majority of the 33 SS are not able to activate before fracture occurs. Many macroscopic bulk zinc single crystal [2,3,4] test have been studied in the past as well as polycrystalline zinc coatings [5,6]. However literature is greatly lacking the understanding of how the knowledge about the plasticity of single crystal transfers to a polycrystalline zinc coating. Therefore in this study it was revealed how plasticity changes by going from a single to a bi-crystal configuration. On top of that it was demonstrated that zinc, against known literature, can exhibit a global strain of above 40%, thus being more ductile then most steels, under the right circumstances.

Experimental Setup

To study the fundamental plasticity of Zinc, single and bi-crystal specimens are extracted directly from the Zinc coating by means of using Focused Ion Beam (FIB) milling. The bi-crystals are made out of the same grains as the single crystals, which allows for a direct comparison of the deformation behaviour between a single crystal and a bi-crystal configuration. The specimens are shaped into hammer like tensile specimens with a gauge length of about 10 µm (see Figure 1 right) for the in-house developed Nano tensile machine (see Figure 1 left), which already showed fruitful results in the past [7]. To push the results even further a brand new developed technique for the identification of Slip systems, which is called the SSLIP Method, was utilized for the analysis of the specimen [8]. This identification method requires the crystallographic orientation (obtained through Electron back Scatter diffraction (EBSD), see Figure 2 bottom left) and the full displacement field (obtained through Digital Image correlation (DIC) with an InSn pattern (size:100 nm) (see Figure 2 right hand side)) in order to determine all active Slip systems and their shear strain at a given position of the specimen.

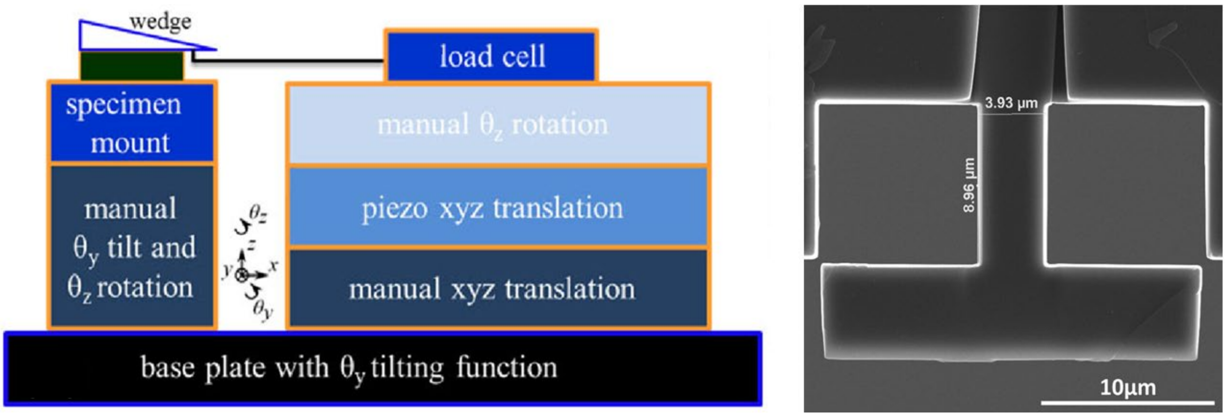

Figure 1 Left: Schematic Overview of nano tensile stage [7]. Right: Example of a nano tensile specimen of ferrite [7].

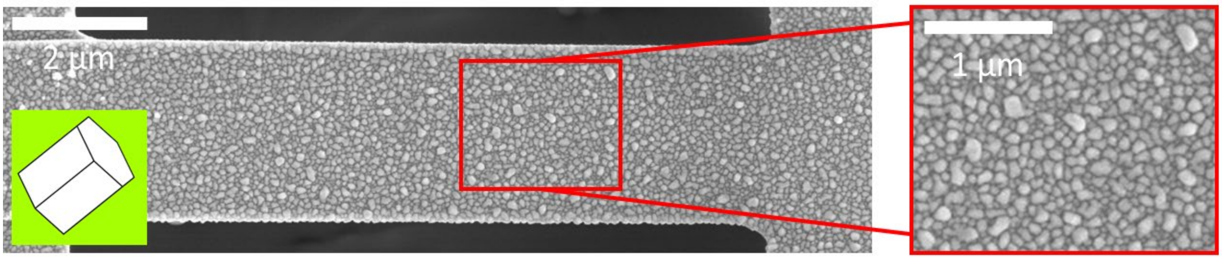

Figure 2 Left: Zinc single crystal Nano tensile specimen with InSn particles (average size: 100 nm) on top of the surface. Bottom Left Inset: Crystal orientation obtained from Electron Back Scatter Diffraction. Right: Magnified section of gauge area showing the InSn pattern.

Results and conclusion

Within this study it was demonstrated that the new methodology for the identification of SS works correctly as shown in the example below in Figure 3. The top plot of the figure demonstrates the equivalent strain map, obtained from digital image correlation, overlayed with the secondary electron image of the single crystal gauge, from the specimen shown in Figure 2, in the deformed configuration after applying a stress of 130 MPa. The bottom plot shows the slip activity map of SS#1 obtained from the SSLIP analysis, which perfectly coincides with the slip traces observed in the equivalent strain map. Therefore SS\#1 (Basal) is a good kinematic description of the deformation observed for this specimen. Furthermore the SS identification showed that multiple SS can activate simultaneously or sequentially even in single crystal specimens, thus the methodology has enabled an in depth study of the evolution shear strain and the activation of crystallographic slip. In comparison to the single crystal tests, the bi-crystal specimens showed a significantly different deformation behaviour, giving deep insight on the impact of the compatibility forces induced by the neighbouring grain. Furthermore grain boundary sliding was observed to be the dominating deformation mechanism in one of the bi-crystals. The nano-tensile test of the bi-crystals together with their corresponding single crystal specimen have been successfully conducted. Detailed analysis of these tests has let to novel insights into the micromechanics of zinc, which will be presented at the BSSM 2023 conference.

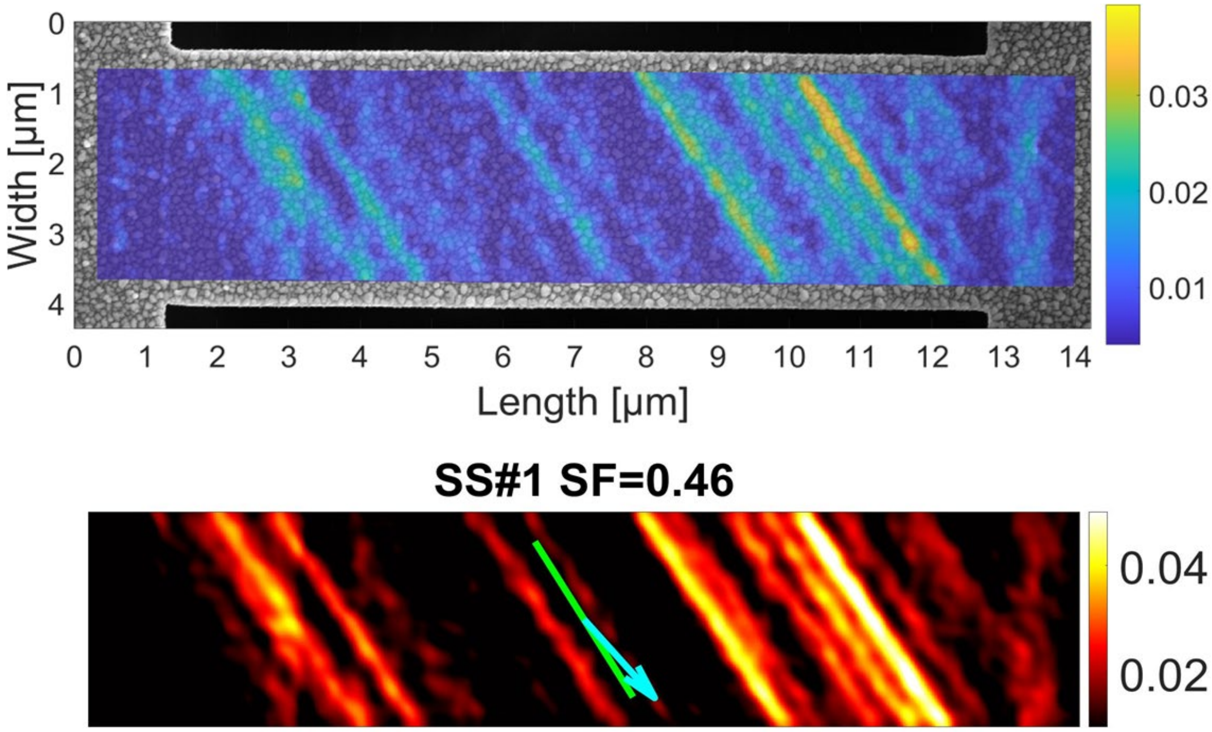

Figure 3 Top: Equivalent strain map obtained from Digital image correlation overlayed on a secondary electron image for the specimen shown in Figure 2. Bottom: Shear strain map obtained from SSLIP method analysis for SS#1 (basal slip) with a Schmid factor (SF) of 0.46, plotted together with the slip trace (green line in the centre) and the slip direction projected into 2D (turquoise arrow in the centre).

References

[1] Parisot, R., Forest, S., Gourgues, A. F., Pineau, A., & Mareuse, D. (2000). Modeling the mechanical behavior of a multicrystalline zinc coating on a hot-dip galvanized steel sheet. *Computational Materials Science*, *19*(1-4), 189-204.

[2] Bell, R. L., & Cahn, R. W. (1957). The dynamics of twinning and the interrelation of slip and twinning in zinc crystals. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, *239*(1219), 494-521.

[3] Burr, D. J., & Thompson, N. (1965). Twinning and fracture in zinc single crystals. *Philosophical Magazine*, *12*(116), 229-244.

[4] Rosenbaum, H. S. (1961). Non-basal slip and twin accommodation in zinc crystals. *Acta Metallurgica*, *9*(8), 742-748.

[5] Song, G. M., & Sloof, W. G. (2011). Characterization of the failure behavior of zinc coating on dual phase steel under tensile deformation. *Materials Science and Engineering: A*, *528*(21), 6432-6437.

[6] Parisot, R., Forest, S., Pineau, A., Grillon, F., Demonet, X., & Mataigne, J. M. (2004). Deformation and damage mechanisms of zinc coatings on hot-dip galvanized steel sheets: Part i. deformation modes. *Metallurgical and Materials Transactions A*, *35*, 797-811.

[7] Du, C., Maresca, F., Geers, M. G., & Hoefnagels, J. P. (2018). Ferrite slip system activation investigated by uniaxial micro-tensile tests and simulations. Acta Materialia, 146, 314-327.

[8] Vermeij, T., Peerlings, R. H. J., Geers, M. G. D., & Hoefnagels, J. P. M. (2023). Automated identification of slip system activity fields from digital image correlation data. *Acta Materialia*, *243*, 118502.