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## ABSTRACT:

### Mechanisms of Zn-Induced Metal Embrittlement in Steels

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Zn coatings are typically applied to steels in the liquid state. During spot welding, this coating is also presumed to remelt, and the subsequent embrittlement of the welded steel is therefore commonly associated with the presence of liquid Zn. However, whether the liquid phase itself, and hence temperatures above the Zn melting point, are necessary for the embrittlement phenomenon has so far remained unclear.

In a series of thermodynamic investigations [1-4], we show that a Zn-segregation transition in BCC-Fe grain boundaries occurs over a broad temperature range, associated with a magnetic miscibility gap in the Fe-Zn system, and can play a central role in the embrittlement. Although this range includes the melting temperature of Zn, the segregation transition can occur fully in the solid state. The resulting nanoscale, high-concentration Zn patches at grain boundaries are shown to constitute viable nucleation sites for a Zn-rich liquid phase and/or a  $\Gamma$  precipitate. More importantly, the work of separation is found to decrease drastically already before any phase change takes place.

The present results indicate that Zn-induced embrittlement in steels cannot be viewed solely as a liquid-metal embrittlement phenomenon. Instead, it should be understood more generally as a segregation-mediated grain-boundary instability, in which interfacial thermodynamics, local chemical transitions, and decohesion are the primary events, while liquid or intermetallic phase formation may follow as secondary consequences. This perspective opens a route toward a more unified thermodynamic description of Zn-induced liquid and solid metal embrittlement in steels.

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[2] Y. Ikeda, T. Wallis, R. Maaß and R.D. Kamachali, *Acta Mater.*, 296, 121134 (2025).

[3] Y. Ikeda, H.C. Ni, A. Chakraborty, H. Ghassemi-Armaki, J.M. Zuo, R.D. Kamachali and R. Maaß, *Acta Mater.*, 259, 119243 (2023).

[4] A. Ahmadian, D. Scheiber, X. Zhou, B. Gault, L. Romaner, R.D. Kamachali, W. Ecker, G. Dehm and C.H. Liebscher, *Adv. Mater.*, 35, 2211796 (2023).