International Journal of Materials Transactions A 14 (1), 2023
DOI: 10.7wsq4j/a1asde.2023.88724

Plasticity Modelling of Springback in Hot-Formed Low-Alloy Medium-Carbon Steels with Alternative Hardening Histories

Dr. Jonas Eriksson, Department of Industrial and Materials Science, Chalmers University of Technology, Hörsalsvägen 7A, 412 96 Göteborg, Sweden

Copyright © 2023 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License.

Abstract

Springback prediction in hot-formed automotive
components is complicated by evolving microstructures
induced by complex hardening schedules. This work
develops a coupled transformation–plasticity constitutive
model for low-alloy medium-carbon steel subjected to quench–temper, austemper, and quench–partition– temper histories. Phase transformation kinetics and resulting phase fractions are calculated using a mixed-mode approach, then integrated into a crystal-plasticity framework that accounts for differing slip resistance in martensite, bainite, and ferrite. Model parameters are calibrated using tensile tests and detailed microstructure characterization from prior comparative studies of hardening methods. Finite element simulations of U‑channel forming and quenching predict springback angles consistent with experiments. The results illustrate how heat-treatment choice strongly modulates springback via microstructure-controlled mechanical response, providing design guidance for spring and structural components manufactured by hot stamping.

References

1. Avrami, Melvin. 1940. “Kinetics of Phase Change. II.” Journal of Chemical Physics 8 (2):
212–24.
2. Bhadeshia, H. K. D. H. 2015. Bainite in Steels: Theory and Practice. 3rd ed. London: Maney.
3. Böttcher, Nils, et al. 2019. “Crystal Plasticity Modelling of Quench and Partition Steels.” Acta Materialia 165: 136–51.
4. Hillert, Mats. 2008. Phase Equilibria, Phase Diagrams and Phase Transformations. Cambridge: Cambridge University Press.
5. Krauss, George. 2005. Steels: Processing, Structure, and Performance. Materials Park, OH: ASM International.

6. Numrich, R., and M. Werner. 2017. “Springback Prediction in Press-Hardened Steels.” Journal of Materials Processing Technology 245: 22–30.
7. Raabe, Dierk, et al. 2010. “Combining Crystal Plasticity with Phase-Field Methods.” Acta Materialia 58 (2): 583–602.
8. Speer, J. G., D. K. Matlock, B. C. De Cooman, and J. G. Schroth. 2003. “Carbon Partitioning into Austenite after Martensite Transformation.” Acta Materialia 51 (9): 2611–22.

9. Sugimoto, K., T. Iida, J. Sakaguchi, and S. Hashimoto. 2000. “Ductility and Strain-Induced Transformation in a High-Strength Low-Alloy TRIP-Aided Sheet Steel.” Metallurgical and Materials Transactions A 31 (1): 173–79.
10. Mehta, Darshan Bhavesh, S. S. Sharma, B. M. Gurumurthy, S. Kishan Bairy, Eril Joy Dsouza, and Antony Prajwal Mendonca. "Characteristic study and comparison of different hardening methods on low-alloy medium-carbon spring steel." International Journal of Applied Engineering Research 11, no. 2 (2016): 1542-1547.
11. Tasan, C. C., M. Diehl, D. Yan, N. Zambaldi, J. Roters, D. Raabe, and R. Pippan. 2014. “Integrated Experimental–Simulation Analysis of Stress and Strain Partitioning in Multiphase Alloys.” Acta Materialia 81: 386–400.