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

Data-Driven Selection of Hardening Routes for Low-Alloy Medium-Carbon Spring Steel Using Multi-Objective Materials Design

Dr. Mateusz Kwiatkowski, Faculty of Mechanical Engineering, Gdańsk University of Technology, Narutowicza 11/12, 80-233 Gdańsk, Poland

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

This paper employs a multi-objective materials design
approach to select optimal hardening routes for low‑alloy
medium-carbon spring steel. A database was compiled
from experimental studies comparing quench–temper, austempering, and induction surface hardening, including mechanical properties, fatigue performance, and dimensional stability. Machine-learning surrogate models based on Gaussian process regression were trained to capture relationships between processing parameters and target properties. Pareto fronts were generated to identify non-dominated treatments for various performance envelopes relevant to automotive suspensions. Results show that quench–partition–temper variants outperform conventional quenched–tempered conditions when strength and fatigue resistance are prioritized, while austempering emerges when toughness and low distortion are critical. The methodology demonstrates how prior detailed comparisons of hardening methods can be used as structured input data for modern materials design frameworks.

References

1. González, Rodrigo, Pedro E. J. Rivera-Díaz-del-Castillo, and Roger C. Reed. 2011. “Bayesian
Inference to Predict Strength of Steels.” Acta
Materialia 59 (11): 4294–4302.
2. Krauss, George. 2005. Steels: Processing, Structure, and Performance. Materials Park, OH: ASM International.
3. Lombardi, Chiara, et al. 2018. “Design of Quenching and Partitioning Treatments by Integrated Simulation and Optimization.” Materials & Design 150: 62–73.
4. Matlock, David K., and John G. Speer. 2004. “Processing Opportunities for New Advanced

High-Strength Sheet Steels.” Materials and Manufacturing Processes 19 (4): 527–40.
5. Ooi, S. W., A. J. B. Pullen, and R. A. Farrugia. 2013. “Modelling Heat Treatment Influence on Mechanical Properties of Spring Steels.” Materials Science and Technology 29 (7): 792–800.
6. Santos, Miguel A., and Luís M. Costa. 2019. “Integrated Design of Spring Steel Heat Treatments Using Surrogate Models.” Materials & Design 181: 107938.
7. Zhang, Wei, Yao Sun, and Zhen Zhang. 2017. “Influence of Surface Treatments and Hardening on VHCF Behaviour of Spring Steel.” International Journal of Fatigue 101: 1–11.

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.