# Development of Quenching Process Recipe Using Simulation by JMatPro and Comsol

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**Abstract**
Quenching, a critical process in the heat treatment of railway wheels, significantly affects the mechanical properties and performance of the final product. The development of an optimized quenching process recipe is essential to ensure the durability and safety of railway wheels. This study aims to develop a quenching process recipe using advanced simulation tools, specifically by Comsol and JMatPro, to achieve a better understanding and control of the quenching process for railway wheels.

**Keywords:** JMatPro, Railway wheels, EN13262, Quenching, Pearlitic microstructure

## Introduction

In high-speed railway wheels, achieving an optimal balance between wear resistance and heat-crack resistance is essential, as outlined in the requirements of EN13262, the European standard for railway wheels. This standard specifies the required mechanical properties, including hardness and impact resistance, for different steel grades used in railway wheels. However, achieving both strong wear resistance and heat-crack resistance presents a unique challenge due to the conflicting nature of these properties. Wear resistance is typically increased by adding alloying elements to harden the steel, which can result in martensitic or bainitic structures prone to heat cracking. On the other hand, improving heat-crack resistance demands a tougher structure, often pearlitic, which reduces hardness and wear resistance.[1]

The ideal solution to meet EN13262 requirements is a fine pearlitic structure that provides an optimal balance. While pearlitic steel may not achieve the same hardness as martensitic or bainitic alternatives, it offers the toughness needed to resist heat cracks while still providing sufficient hardness for adequate wear resistance. This balance meets the stringent standards of EN13262, ensuring that railway wheels perform reliably under the extreme stresses and thermal variations experienced in high-speed rail applications.

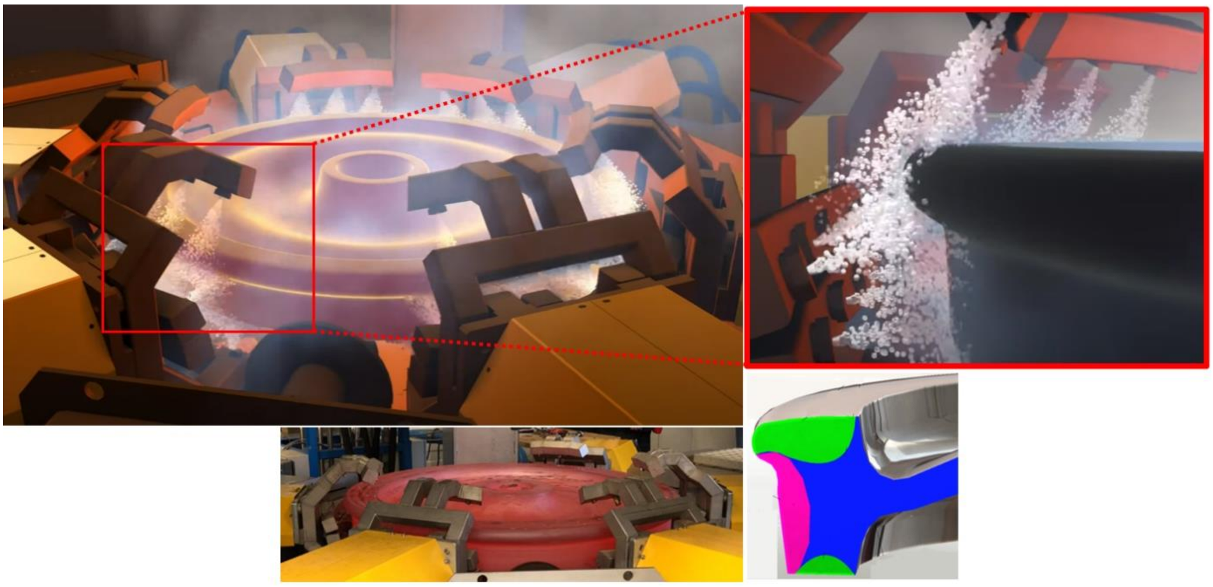

*Figure 1. Device for the precise heat treatment of railway wheels*

## Technology Description and Process parameters

Figure 1 illustrates a technology device designed for the precise heat treatment of railway wheels or similar steel wheels. This device incorporates a tread hardening and additional features for selectively hardening a secondary zone on the side of the wheel tread. Hardening is accomplished using adjustable nozzles that apply cooling media, such as water or air, to targeted areas. These nozzles are independently positionable and controllable to ensure precise treatment of both the tread and transition zones. The device also includes rotating rollers to support various wheel sizes, ensuring that film boiling does not occur during heat transfer.

An algorithm detailed in patent DE102010033473 [2] manages the many parameters involved. This algorithm combines data from numerous previously tested wheels, experimental procedures, and decision-making processes to define optimal parameters for achieving superior mechanical properties as per EN13262. This is crucial for manufacturers looking to develop new alloys and heat treatment processes that extend wheel lifespan without frequent inspections. For instance, Bonatrans offers its advanced BONASTAR® steel grades [3], which provide up to 30% greater mileage without additional approvals, aiming for a lifespan exceeding 2,000,000 km. The company achieves this precision through a refined production process and meticulous parameter adjustments.

Simulating the process can significantly aid in creating a database of potential cooling scenarios and determining optimal process parameters. This simulation involves two components: heat transfer and cooling rate simulation, and material transformation and hardness evolution. Each simulation must be validated before it can inform the decision-making process. The focus of this study is the simulation of material transformation and hardness evolution, specifically using the Jominy test as outlined in standard ISO 642 [4], and verifying the simulation outputs.

Figure 2 shows the simulation process for the Jominy test, which models how cooling rates influence phase transformation. The simulation starts by inputting the chemical composition and grain size of the material into JMatPro to generate the TTT (Time-Temperature-Transformation) diagram. This diagram provides crucial information on how the material's phases change under specific thermal conditions. Next, COMSOL is used to simulate the phase transformations over time at different points along the material, incorporating the cooling rates. This step allows us to observe how the microstructure evolves during the cooling process. Additionally, the simulation calculates the corresponding changes in hardness values caused by the phase transformations in the material. This approach offers a detailed understanding of how different regions of the material respond to heat treatment, providing essential data for optimizing mechanical properties based on the microstructure.

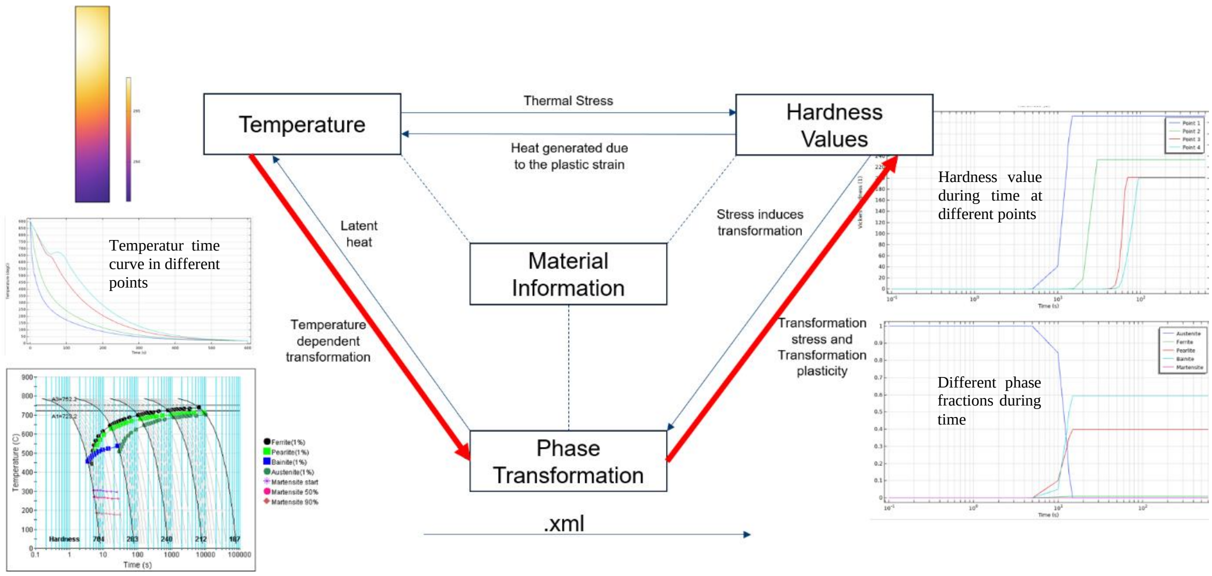


*Figure 2. Simulation process for the Jominy test*

## Simulation Results and Discussion

The simulation is conducted for steel grade 1045, with a chemical composition consisting of C 0.42, Mn 0.72, Si 0.22, Cr 0.11, and Ni 0.18. The hardenability curve for this specific steel grade is well-documented in the Timken Handbook [5] and has also been validated in research by Nunura et al. [6]. Additionally, the microstructure data following the Jominy test can be directly derived from JMatPro software, which provides essential insights into the behavior of different phases within the steel during the cooling process.

The simulation results are displayed in Figure 3. Figure 3a clearly shows that the prediction of hardness as a function of distance from the quenched end, using COMSOL, aligns well with experimental data, demonstrating acceptable accuracy.

Moreover, the volume fraction of martensite predicted by the simulation also matches closely with both Ref-1 [6] and the results derived from JMatPro, further validating the accuracy of the COMSOL model for this specific phase. However, discrepancies arise in the predictions for bainite and pearlite phases. The results for these phases in COMSOL, as well as the data imported from JMatPro, show a need for further refinement. The accuracy for bainite and pearlite phases does not meet the same standard as for martensite, suggesting that the current model may require additional adjustments.

## Conclusions

Simulation can play an effective role in setting parameters in the heat treatment process. The concept of digital design for heat treatment needs precise modeling of phase transformations, cooling rates, and material properties to optimize mechanical performance. In this study, the simulation for steel grade 1045 using COMSOL and JMatPro demonstrated good accuracy in predicting hardness and martensite volume fraction after the Jominy test, as validated by experimental data and literature references. However, the prediction accuracy for bainite and pearlite phases requires further improvement. A parametric study and fine-tuning of the simulation inputs, such as phase kinetics and cooling behavior, could enhance the model's reliability.

## References


[1] EN 13262, Railway applications - Wheelsets and bogies - Wheels - Product requirements.

[2] DE102010033473, Verfahren zur Wärmebehandlung des Radkranzes von Schienenfahrzeugrädern

[3] BONASTAR®4BD product specification, (Link)

[4] DIN EN ISO 642, Steel - Hardenability test by end quenching (Jominy test)

[5] Practical Data for Metallurgists 18th Edition, Timken steel

[6] Nunura et. al., Numerical – Experimental correlation of microstructures, cooling rates and mechanical properties of AISI 1045 steel during the Jominy end-quench test, Materials & Design 76 (2015) 230-243


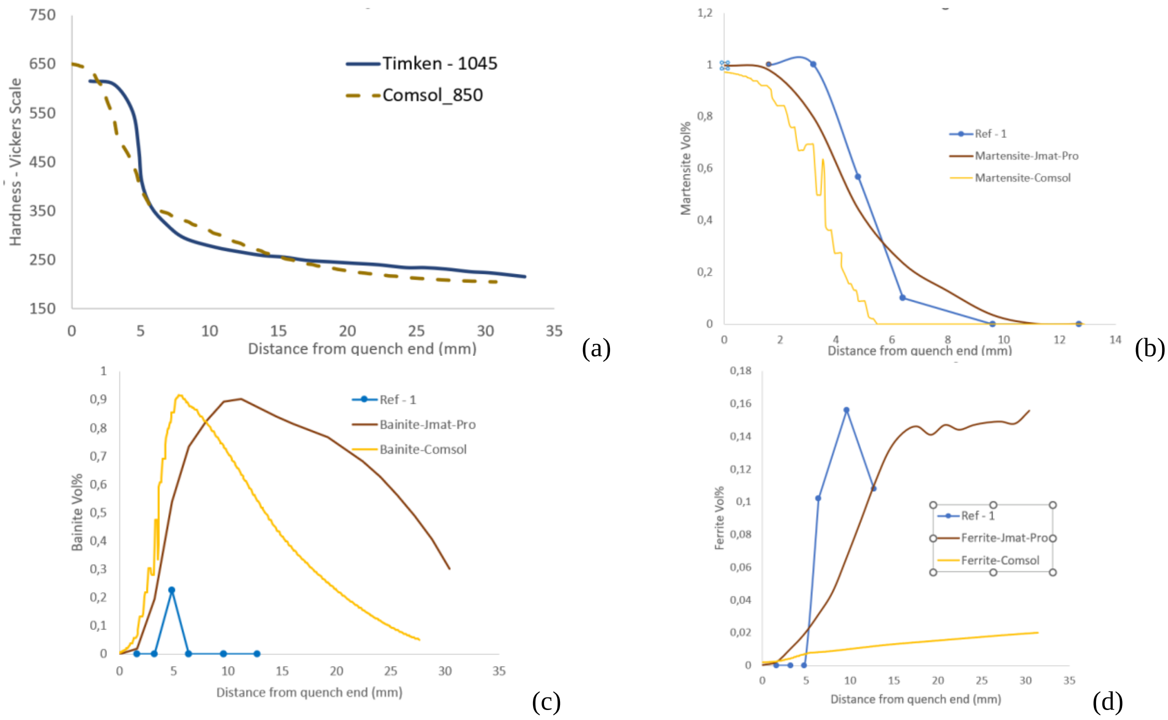


*Figure 3. Simulation results (a) hardness values (b) martensite vol% (c) bainite vol% (d) ferrite vol%*