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HEAT TREATMENT

Precision Heat Treatment in Railway Wheels: From Thermal Control to Lifecycle Confidence

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Railway wheels endure millions of stress cycles over their service life. Every revolution transfers dynamic forces through the wheel–rail interface, subjecting the steel to rolling contact fatigue, thermal shocks from braking, and environmental extremes from summer heat to winter ice. Their performance — and failure — often hinges not on visible design flaws, but on invisible material conditions deep within the steel.

In high-speed passenger service, a single wheel must withstand years of service at over 250 km/h without dimensional distortion or crack initiation. In heavy-haul freight, wheels are expected to carry extreme axle loads while resisting wear from abrasive conditions. Add to this the constant vibration, occasional overloads, and exposure to moisture, and it becomes clear: the wheel is not just a mechanical component — it is a safety-critical, high-performance system. Any compromise in material quality, heat treatment, or process consistency can lead to premature failure, unplanned downtime, and costly service disruptions.

Because of these extreme demands, railway wheels are governed by rigorous technical standards. In Europe, EN 13262 defines the material grades, mechanical properties, dimensional tolerances, and non-destructive testing criteria for new wheels. It specifies hardness ranges, residual stress limits, and approved microstructures, ensuring both safety and interchangeability. In India, IRS R-34 defines equivalent requirements adapted to local operating conditions and track infrastructure. In CIS countries, the GOST 10791 standard governs wheel manufacturing and testing, with its own methods for hardness, ultra-

sonic inspection, and residual stress verification.

These standards are more than a formality; they are contractual gatekeepers. Without documented compliance, a wheel cannot enter service with operators like Deutsche Bahn or Indian Railways. Compliance demands more than just meeting final hardness numbers — it requires traceable quality control from billet to finished wheel, adherence to approved heat treatment cycles, and proven capability to detect and reject substandard product before delivery. In short, standards are the universal technical language that connects manufacturers, equipment suppliers, and railway operators.

While standards set the targets, every wheel project is unique. Customer orders differ in wheel diameter, service frequency, alloy chemistry, and heat treatment requirements. For Andritz, as a supplier of complete production lines, the challenge is not only to deliver robust manufacturing equipment — but also to ensure that the wheels produced on it will consistently meet the demanding specifications of EN, IRS, or GOST.

This is where our role extends beyond machinery. Every heat treatment line we design is tailored to the customer's alloy grade, wheel geometry, and performance targets. We apply metallurgical expertise to define the quenching profile, control cooling uniformity, and achieve the exact hardness gradient and residual stress profile required. That means balancing thermal cycles, transformation kinetics, and process stability — not in theory, but in the reality of a production floor.

When a customer invests in an Andritz line, they are not just buying a piece of equipment. They are gaining a process partner — one that delivers both the physical hardware and the knowledge to run it for first-time-right results. Each project is an exploration into the optimal combination of process parameters and material behavior, ensuring that the end product is not only compliant on paper, but proven in performance.

Section 2: The Solution – Smart Heat Treatment with Application Focus

Developing the right heat treatment parameters for railway wheels is a complex challenge—one that cannot be solved by theory alone. In practice, experimental iteration remains the most reliable method to ensure that a new material and process combination meets the demanding quality requirements defined in international standards. To support this, the Andritz heat treatment laboratory is equipped with a unique full-scale testing facility Fig. 1. Here, we can replicate the actual furnace temperature cycles and apply finely controlled cooling at the wheel rim, simulating production conditions with exceptional precision. Beyond the ability to run real tests, the lab allows for advanced instrumentation and measurements not feasible in production—providing deeper insight into process behavior.

This capability is not only technical; it is strategic. It helps de-risk development, support customer-specific adaptations, and ultimately shorten time-to-market for new products.

These experimental insights form the backbone of a continually expanding database — an internal knowledge system that records and analyzes the performance of various materials, geometries, and heat treatment parameters. With each trial, whether successful or failed, we build a clearer map of what works under which conditions. This database has become a functional tool for decision-making, enabling us to recommend optimized process settings even in the most demanding applications. In fact, Andritz holds a patent for structuring this database and using it as a predictive asset. The system transforms experience from the past into present-day process control—allowing engineers to move forward with con-

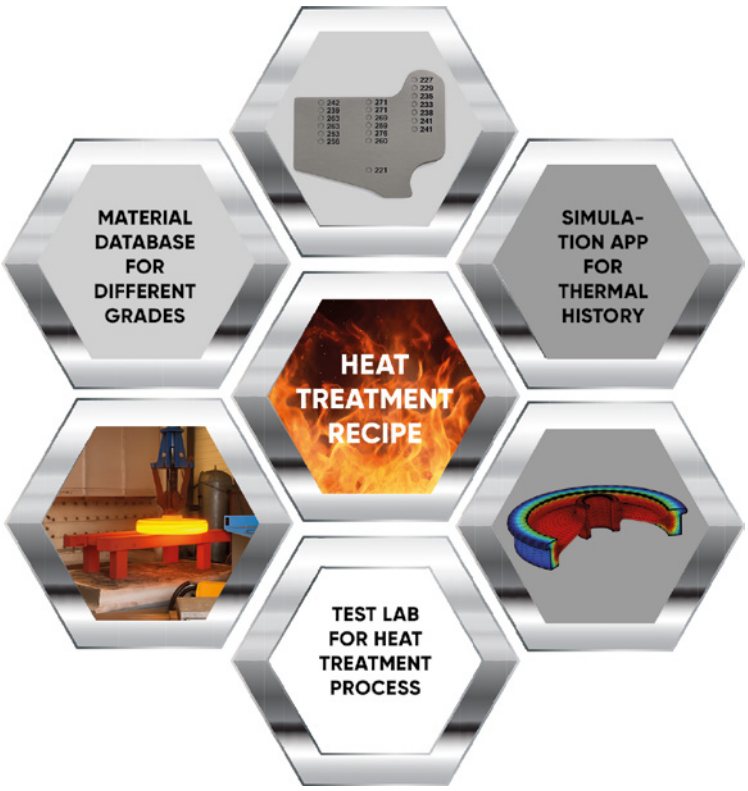

Figure 1: Andritz elements to develop a recipe for heat treatment of railway wheels
Source: ANDRITZ Metals Germany GmbH

fidence, backed by a record of proven outcomes.

To further support robust process development, Andritz has also developed a dedicated simulation application. This tool enables users to virtually model the entire heat treatment cycle of a railway wheel, including heating, cooling, and transformation dynamics. Unlike generic simulations, this app is calibrated with real laboratory data and built on state-of-the-art physical models. The output is not just theoretical curves—it delivers validated predictions of temperature evolution, phase distribution, and resulting hardness across the wheel cross-section. By combining scientific modeling with real-world calibration, we close the loop between theory and practice—bringing academic depth into industrial use.

Together, these elements—experimental capability, a curated process database, and advanced simulation—form an integrated platform that we offer to our customers. When we deliver a heat treatment solution, we deliver more than hardware. We deliver a recipe: a validated process, an operational roadmap, and the know-how to consistently produce wheels that meet specification. Our goal is to share not just equipment, but expertise—ensuring that each customer can achieve reliable, high-quality results with speed and confidence. In doing so, we turn technical innovation into business value.

Section 3: Accurate temperature profile in Theory and Practice

A key part of this approach is measuring process variables during experimental trials or in industrial operations. The measurement of these process variables is crucial for validating subsequent process simulations. During the heat treatment process of railway wheels, it is essential to maintain precise temperature control to ensure optimal distribution within the wheel. This is critical as it directly affects the resulting microstructure, which is essential for the quality and performance of the wheels.

However, determining temperature profiles in a wheel during a continuous heat treatment process is challenging. This is particularly evident in the quenching process that follows the normalization of the wheels. To ensure the desired hardness values and maintain sufficient formability, it is necessary to reach certain temperature gradients at the outer tread of the wheel.

The temperatures need to be acquired along the cross-section of the wheels to ensure the highest precision and avoid deviations through thermal conduction. This is especially true in a three-dimensional wheel with different cooling conditions on each surface. Due to these challenges, calculating temperature distributions from the surface temperatures can lead to inaccuracies.

Therefore, thermocouples are necessary to record the temperature curves during the heat treatment process. The thermocouples are placed in specific positions within the wheels, as required depending on the geometry. To ensure the accuracy of measurements and transferability to simulations, it is essential to position the thermocouples with precision.

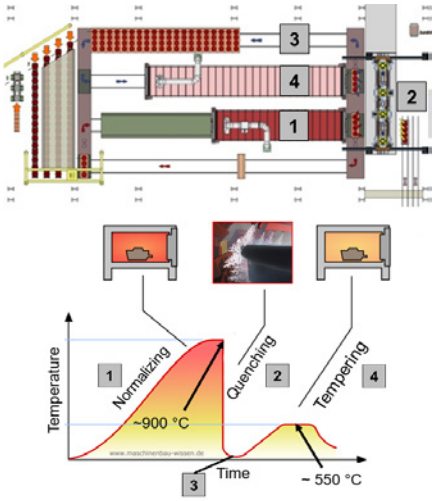

Figure 2: Plant layout for heat treatment of rail wheels (top) with resulting temperature curve (bottom)

Source: ANDRITZ Metals Germany GmbH

Table 1: Overview of possible process parameters of the TTS

temperature range	RT – 1500 °C
max. cooling rate	50 Ks^{-1}
max. heating rate	100 Ks^{-1}
max. degree of deformation	1.2
max. deformation rate, 1/s	50 s^{-1}
atmosphere	vacuum, Ar, He

Following the heat treatment process with the necessary measurement equipment for thermocouples is a task known for decades. However, it still poses challenges in terms of practical implementation. In this scenario, the mechanical systems for transferring and quenching the wheels are designed to minimize distance, thereby restricting the options to position the measurement equipment. Recording temperature profiles is a costly and time-consuming process due to the challenges involved and the fact that measurements can only be taken at discrete points.

The acquired temperatures are particularly valuable for the subsequent steps, as the temperatures across the wheel cross-section are then used to validate the simulations carried out with identical boundary conditions regarding process and material.

This validated simulation model allows for additional calculations on a wide variety of process parameters. This allows us to generate information beyond the discrete thermocouple measurements, enabling a more sophisticated prediction of material behavior. As the simulations are based on measurements taken under specific boundary conditions, the parameters investigated in the simulations must remain within certain limits to ensure reliable results. If significant variations are observed, additional valida-

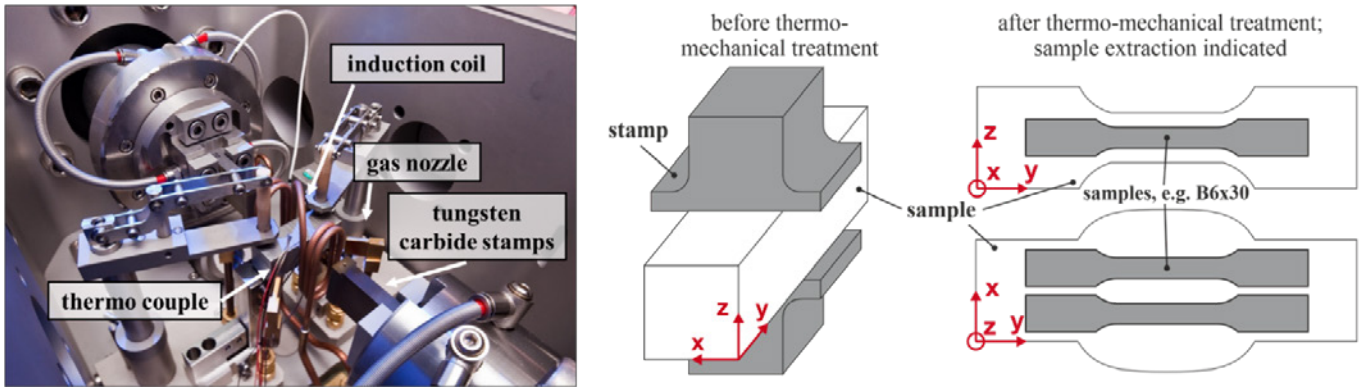

Figure 3: Thermomechanical Treatment Simulator at IEHK Steel Institute at RWTH Aachen University (left); schematic representation of secondary sample extraction (right)

Source: IEHK Steel Institute at RWTH Aachen University

tion measurements will be required to ensure the accuracy of the results. This underscores the importance of incorporating practical measurements as a fundamental basis for predicting and understanding mechanical behavior, emphasizing the efficacy of the simulation model as a powerful tool. Therefore, the increased effort expended during practical measurements in the lab or at customer sites is justified.

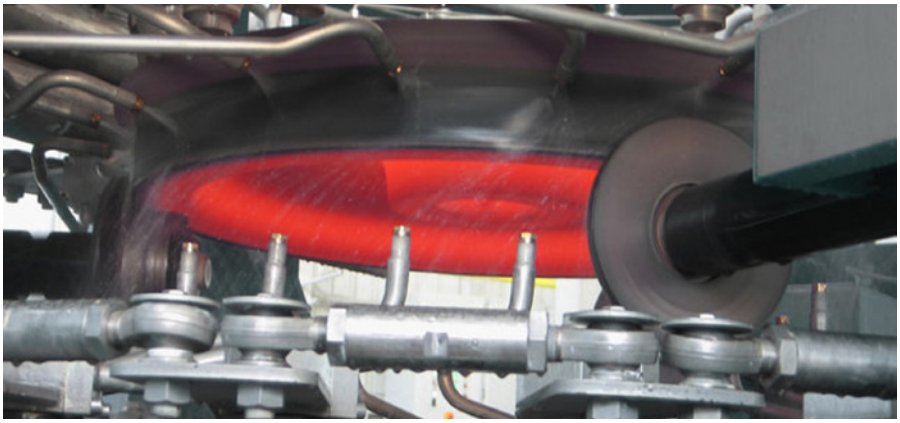

Figure 4: Accurate cooling of wheel on the rim which results in a high compressive stress required in EN 13262 standard

Source: ANDRITZ Metals Germany GmbH

Section 4: Physical Simulation of Material and Heat Effect

At the IEHK Steel Institute of RWTH Aachen University, thermo-mechanical processing is either performed in the "Thermomechanical Treatment Simulator" (TTS) or in different deformation dilatometers. The TTS is equipped with an induction heating, pressurized gas cooling, tungsten carbide stamps for hot deformation as well as temperature control for the precise modelling of thermomechanical process routes. A view inside the vacuum chamber as well as schematic drawing of the extraction of secondary samples is displayed in Fig. 3.

For most standard dilatometers, the sample volume is limited to > 1 cm^3, which allows only hardness measurements besides microstructure analysis, whereas more detailed information on the mechanical properties remain unobtained. The TTS-samples have a standard size of 20x20x80 mm^3, which allows the production of tensile and sub-sized Charpy samples.

The TTS was developed to physically simulate a variety of thermomechanical processing, like hot rolling and hot forging, as well as multi-step heat treatment processes. An overview of the standard parameters is displayed in Table 1. Based on industrial data on the desired time-temperature profiles, for example, of a quench and tempering treatment, variations in process parameters can be varied on smaller samples, which still allow the extraction of secondary samples, like Charpy-V-notch samples or tensile tests samples. Following this approach, the TTS enables rapid parameter screening which allows the reduction of time and cost intensive industrial full-scale trials.

Besides the characterization of the mechanical properties, microstructures are further investigated by light optical or state-of-the-art electron microscopy (LOM, EM), to reveal the effect of the parameter variations on the micro- and nanostructure of the steels.

The proposed concept is not limited to investigate process parameter variations, as it also can be applied to investigate the effects of variations in chemical compositions, potentially introduced by higher recycling rates. If combined with rapid alloy prototyping (e.g., by additive manufacturing), the combined approach enables the determination of correlations between composition, process and performance for the creation of large material databases.

In geometrically complex forgings like railway wheels, microstructures and resultingly the mechanical properties differ, as the local cooling varies, final-

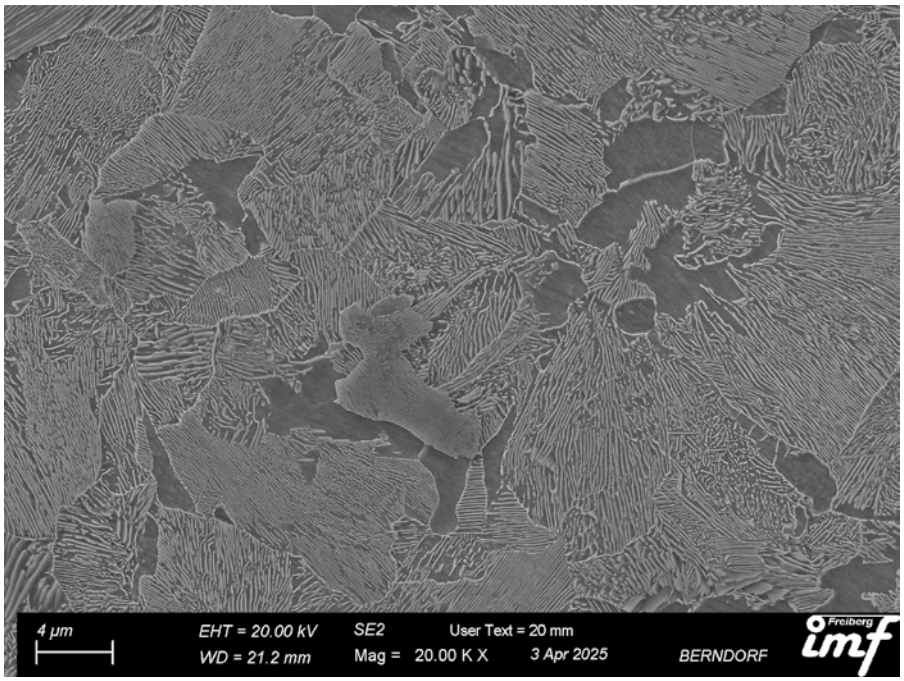

Figure 5: Fine Pearlitic structure with homogeneously distributed Ferrite phase (less than 10 vol%) which is a requirement of German railway standard

Source: ANDRITZ Metals Germany GmbH

ly effecting the phase transformation. These differences can lead to the formation of undesired phases (in the present case bainite) or the coarsening of the microstructure, including the pearlite grain size and pearlite lamellar spacing. Based on numerical methods, local cooling conditions can be simulated with large certainty; however, the simulation of resulting microstructures and properties are more complex, resulting in time and cost intensive simulation. The calculated local time-temperature profiles however, can be used for a physical simulation of the cooling conditions utilizing the TTS to assess the influence on the mechanical properties and predict the effect of process variations and can vice-versa be used for optimization purposes. By a variation of the parameters a large number of process parameters can be iteratively optimize, while a material database can be created for future optimization or simulative approaches.

Section 5: The Impact – From Parts to Partnership

At Andritz, the completion of a heat treatment project is not the end—it is the beginning of a strategic collaboration. Our goal is not simply to build a line, but to empower our partners to succeed in one of the most demanding and high-performance industries: railway wheel manufacturing Figure 4. We measure our success by the ability of our customers to deliver best-in-class products to the market—safely, reliably, and competitively, for example in Figure 5. That's why we stay engaged beyond commissioning, sharing the full scope of our know-how, from process recipes to operational guidance. With our full-scale testing, process database, and validated simulation tools, we provide more than technical support—we provide a business enabler. By translating deep metallurgical insight into stable, repeatable production outcomes, we help our partners turn advanced heat treatment into a long-term competitive advantage.

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