SUMMARY OF THE DOCTORAL DISSERTATION

MSc Eng. Filip Lewandowski

"Development of Heat Treatment Conditions for Forged Switch Rails Used in Railway Turnouts with Enhanced Operational Properties"

This doctoral dissertation focuses on investigating processes occurring in the microstructure in rail steels during the forging process of the railway switch blade end. The purpose of forging the rail is to adapt the geometry of its end so that the processed element can be connected to the railway turnout structure. The switch rail undergoes rolling, heat treatment (optionally), forging, optional post-forging heat treatment, and machining. The dissertation addresses the changes that occur during forging and subsequent heat treatment, identifying this issue as a research gap worth investigating—especially considering that the switch blade is a failure-prone element, and its proper properties are critical to railway traffic safety.

The dissertation discusses the changes occurring in pearlitic rail steels, which currently have the widest application in conventional railway track construction. It was observed that the properties of pearlitic steels are linked to the shape of the microstructure obtained through thermo-mechanical processing. The mechanical properties of rail steels depend on the achieved interlamellar spacing and the size of the pearlite colonies. It was assumed that the most wear-prone part of the rail cross-section is the so-called “rail head.” Literature review indicates that in pearlitic structures, increased hardness correlates with an increase in the yield strength and tensile strength of the material. Therefore, hardness was adopted as the key indicator of favorable properties in the steels under consideration.

Based on FEM simulation results, it was determined that in the rail head area, the strain reaches $\varepsilon = 0.5–0.7$, which, according to literature data, does not adversely affect the material properties. In further studies, a local drop in hardness was observed on the surface of the rail head in the heated but non-forged zone. During industrial tests at a heat treatment station, the surface of the rail head was cooled at a rate of 3.08°C/s. As a result of the heat treatment, a hardness distribution was obtained that was close to the line defining the lower hardness limit. The microstructure was characterized by an interlamellar spacing ranging from 124 to 234 nm and a pearlite colony size between 9.83 and 19.29 µm. Microstructural analysis showed local presence of a ferrite network at the boundaries of prior austenite grains. SEM and TEM observations revealed phenomena such as cementite lamellae fragmentation, dislocation pile-up at cementite plates, and the occurrence of local flow bands in the material.

In order to optimize the technology, a suitable cooling medium was sought. Compressed air was selected, enabling a cooling rate of 3.7°C/s. It was determined that dilatometric testing would be used to study the effect of cooling at rates ranging from 2 to 10°C/s. Based on the obtained results, it was concluded that the cooling rate across the rail head section must fall

within the range of 2–6°C/s, resulting in a hardness between 345 and 379 HV, interlamellar spacing of 77.65–115.06 nm, pearlite colony size of 7–14 µm, and a troostitic structure.

In the next stage, a laboratory station for cooling rail segments was built. FEM simulations were carried out to determine the cooling rate distribution in the rail head cross-section. The model included a modified configuration of the compressed air stream enveloping the rail head, compared to the industrial setup. The most favorable cooling distribution was achieved with a surface cooling rate of approximately 5°C/s. Under these conditions, a hardness close to the maximum value of 400 HV was achieved, and the interlamellar spacing ranged between 89.83 and 118.36 nm.

Based on the collected results, correlations were determined between processing parameters, steel properties, and microstructural morphology. The dissertation also proposes a modification to the cooling method for the rail head, aimed at homogenizing and improving the mechanical properties along the entire forged and heat-treated section of the switch rail