Bainitic rails intended for highly-loaded tracks – the nature of fatigue cracking mechanisms in mixed mode loading conditions

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Bainitic steel *Fatigue crack growth* *Mixed-mode loading*

Abstract In recent years, the application of advanced bainitic steels in railway infrastructure has attracted the interest of researchers and industry due to their promising mechanical properties in comparison to conventional pearlitic steels. The majority of the published works concerned issues related to wear resistance [1], rolling contact fatigue [2], low cycle fatigue [3], fatigue crack growth rate [4,5], and fracture toughness [6]. In the conducted investigations, an effort was focused on determining the influence of the metastable bainitic structure on fatigue cracking processes under mixed-mode loading conditions. The research material was the developed bainitic rail subjected to continuous cooling after the hot forming processes. The microstructure consisted of bainitic ferrite laths characterized by a sub-micrometer scale, retained austenite with filmy and blocky morphology, and a low fraction of M/A constituents. As it is known, especially during heavy loading operating conditions, a complex stress state occurs on the running surface due to material flaws. The issue related to fatigue crack mechanisms subjected to mixed-mode loading conditions in bainitic steels has not been explained in the literature and industrial project reports, which is particularly important in ensuring the integrity of railway tracks. Considering the significance of this issue, the principal motivation of this research was to explain the mechanisms of fatigue fracture of bainitic steel under a complex stress state. Specific mixed-mode conditions (I+II, I+III) and fatigue crack growth rate was related to the microstructure morphology. The results indicate that the mixed-mode loading conditions significantly affect the mechanisms and rate of fatigue fracture. The analysis of investigations provides a good insight into the design of new advanced steels intended for rail infrastructure applications characterized by enhanced fatigue performance with consideration of heavy exploitation conditions.

Bibliography:

[1] Liu J, Li Y, Zhang Y, Hu Y, Shi L, Ding H, et al. Dry Rolling/Sliding Wear of Bainitic Rail Steels under Different Contact Stresses and Slip Ratios. Materials (Basel) 2020;13:4678. https://doi.org/10.3390/ma13204678.

[2] Gui X, Wang K, Gao G, Misra RDK, Tan Z, Bai B. Rolling contact fatigue of bainitic rail steels: The significance of microstructure. Mater Sci Eng A 2016;657:82–5. https://doi.org/10.1016/j.msea.2016.01.052.

[3] Adamczyk-Cieślak B, Koralnik M, Kuziak R, Brynk T, Zygmunt T, Mizera J. Low-cycle fatigue behaviour and microstructural evolution of pearlitic and bainitic steels. Mater Sci Eng A 2019;747:144–53. https://doi.org/10.1016/j.msea.2019.01.043.

[4] Królicka A, Lesiuk G, Radwański K, Kuziak R, Janik A, Mech R, et al. Comparison of Fatigue Crack Growth Rate: Pearlitic Rail versus Bainitic Rail. Int J Fatigue 2021:106280. https://doi.org/10.1016/j.ijfatigue.2021.106280.

[5] Aglan H, Fateh M. Fracture and fatigue crack growth analysis of rail steels. J Mech Mater Struct 2007;2:335–46. https://doi.org/10.2140/jomms.2007.2.335.

[6] Królicka A, Lesiuk G, Kuziak R, Radwański K, Janik A. The role of microstructure morphology on fracture mechanisms of continuously cooled bainitic rail. Metall Mater Trans A 2022.