EVALUATION OF HARDNESS AND TENSILE PROPERTIES OF RAILWAY AXLE STEEL USING ADVANCED INDENTATION SYSTEM

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Abstract

To ensure proper maintenance and remaining lifespan of railway axles it is important to correctly estimate its mechanical properties. In past many methods were introduced and standardized. However conventional methods often require samples to be extracted from examined parts which inevitably leads to destruction of said part. Recently featured Advanced Indentation System enables quasi-non-destructive testing and evaluation of tensile properties either in-situ or in laboratory environment.

This paper deals with characterization of hardness and tensile properties of railway axle made of EA4T steel using Advances Indentation System. While standard methods of hardness evaluation use optical microscopy and size of indent, indentation system uses depth of indent as main parameter for calculations. For evaluating tensile properties instrumented indentation technique (IIT) was used. Load-depth curves were obtained from loading-unloading cycles and later used to analyse tensile properties. The results were compared with standard Vickers hardness tests and data given by standards for railway axles and EA4T steel. Experimental data suggests that indentation method is suitable substitute for conventional methods of hardness and tensile properties.

Keywords: Vickers hardness, mechanical properties, advanced indentation system, EA4T steel, railway axle

1. INTRODUCTION

As railway axles are crucial parts supporting railway vehicles failure is not an option as it would have dire consequences. Since there cannot be any safeguards, the design must be reliable. To ensure every axle in series is properly made, standard tests are made on representative axle for each batch. Mechanical properties, such as hardness and/or tensile properties, of the railway axle were evaluated in [1-3]. Testing of tensile properties is generally destructive which makes them unfit for maintenance procedures for estimating remaining lifespan of parts. Automated indentation systems offer quasi-non-destructive test for testing in-situ [4-8]. To implement indentation system into practice it is needed to perform comparation studies between conventional methods of testing mechanical properties and new methods.

In this paper hardness and tensile properties measurement by IIT were performed and suitability of IIT as viable substitute for conventional methods was discussed. The aim of this paper is to test viability of the IIT method and validate its results.

2. EXPERIMENTAL PART

2.1. Material

The material used for study is radial segment of the railway axle. Based on chemical analysis it is made of EA4T steel. Diameter of the axle segment was 18 cm, and it was 3 cm thick. The surface had been grinded up to 2400 grit sandpaper. The segment of the axle with highlighted induction hardened layer is visible at **Figure 1**.

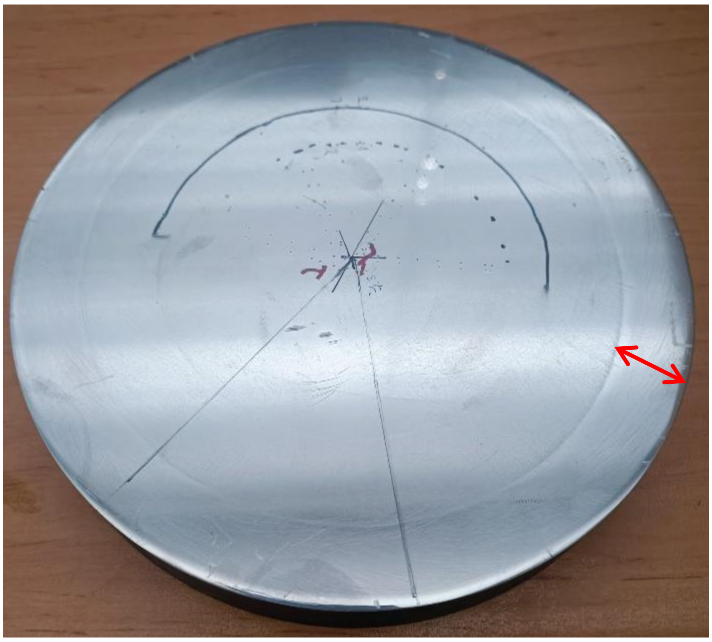

Figure 1 Segment of the railway axle with highlighted induction hardened layer

2.2. Hardness evaluation

Conventional hardness tests consist of loading an indenter and then calculating hardness from the size of indent. Unlike with optical microscopy methods, instrumented indentation technique focuses on measuring hardness by measuring depth of the indent and by calculation of contact surface from the measured depth [4-5].

The Oliver-Pharr method (eq. 1) is standardized for methods using optical microscopy. The Vickers hardness is given by the maximum force (P_{max}) divided by the four-sided pyramidal contact area (S) and ε is geometrical constant. This is evaluated by measuring diagonals of residual indentation [5-6]

$$H_d = \varepsilon \frac{P_{max}}{S} \tag{1}$$

Depth sensing indenters measure total imprint into the sample – both elastic and plastic deformation are measured. For accurate hardness measurement it is needed to subtract elastic deformation. Resulting hardness is given by the maximum force divided by the true projected contact area considering pile-up and sink-in.

For hardness calculated employing the depth of indent the equation (1) must be adjusted to (2) where h_c is contact depth of indentation [5].

$$H = \frac{P_{max}}{24.5 * (h_c)^2} \tag{2}$$

Hardness tests by IIT were performed on AIS3000HD by Frontics Co., Ltd. Testing depth was 50 μm The indentation curve of hardness testing is in the **Figure *2***. Vickers indenter was employed in the test. Comparation tests for standard Vickers hardness were performed using Qness 60 A+EVO hardness tester. Tests were performed in lines from the centre of the axle to its outer surface.

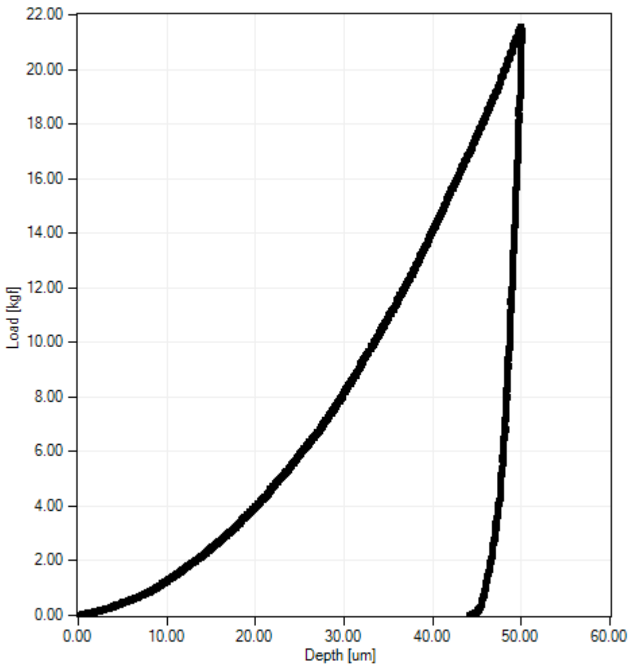

Figure 2 Indentation curve of hardness testing done by AIS3000HD

2.3. Tensile properties evaluation

Tensile properties were measured by AIS 3000HD. Theoretical background of IIT can be found in [6][9].

AIS was attached to the railway axle. Spherical tungsten carbide indenter with a diameter of 500 μm was used for measurements. Multiple sets of tests from the centre of an axle to its outer surface were performed. Each indentation test consists of 15 loading and partially unloading cycles with 50% unload ratio. The maximum depth was 150 μm. **Figure 3** shows the load-depth curve of the tensile testing by AIS3000HD.

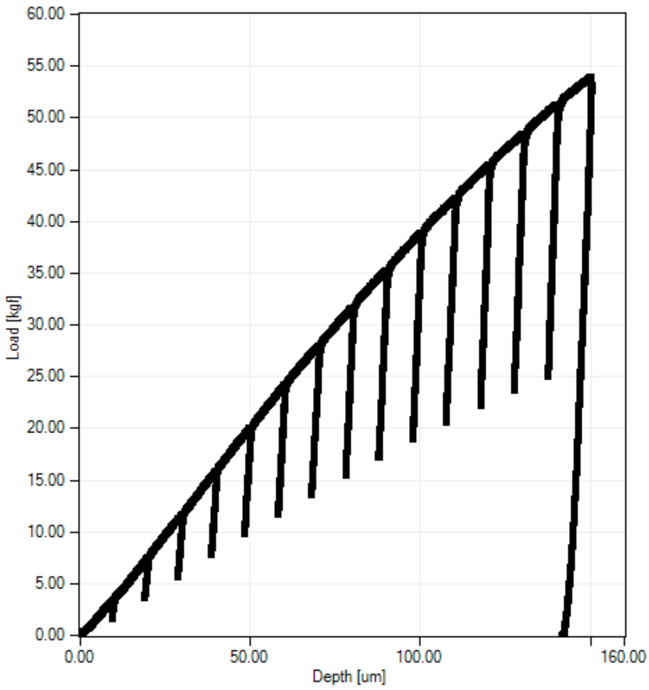

Figure 3 Load depth curve of tensile testing by AIS3000HD

3. RESULTS AND DISCUSSION

Results of hardness testing are presented in the **Figure 4**.

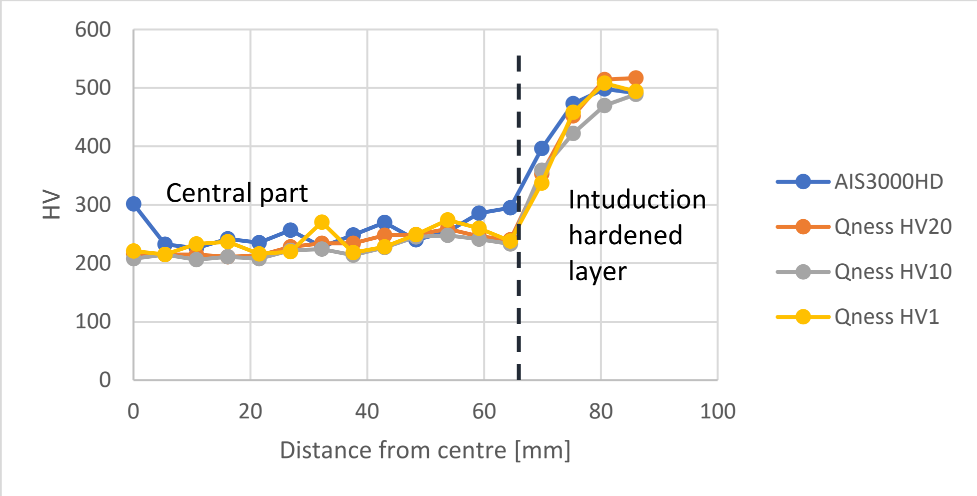

Figure 4 Vickers hardness comparation of tests conducted by AIS3000HD with standardized HV20, HV10 and HV1 acquired by Qness hardness tester.

The results of the hardness obtained by IIT and standard hardness testing are in good agreement. Results by the AIS3000HD follow same trend as the results acquired by Qness and values differ by less 10% in general. The steep gradient at 65 mm indicates transition into induction hardened layer near surface. The IIT hardness cannot be attributed to any normative values of standard hardness tests, such as HV10 or HV20, because in the case of IIT the maximum depth is the setting parameter instead of the maximum load.

Results of 3 sets composed of 8 tests of tensile properties are shown in the **Figure 5**. Note that the graph does not include tensile tests from induction hardened layer.

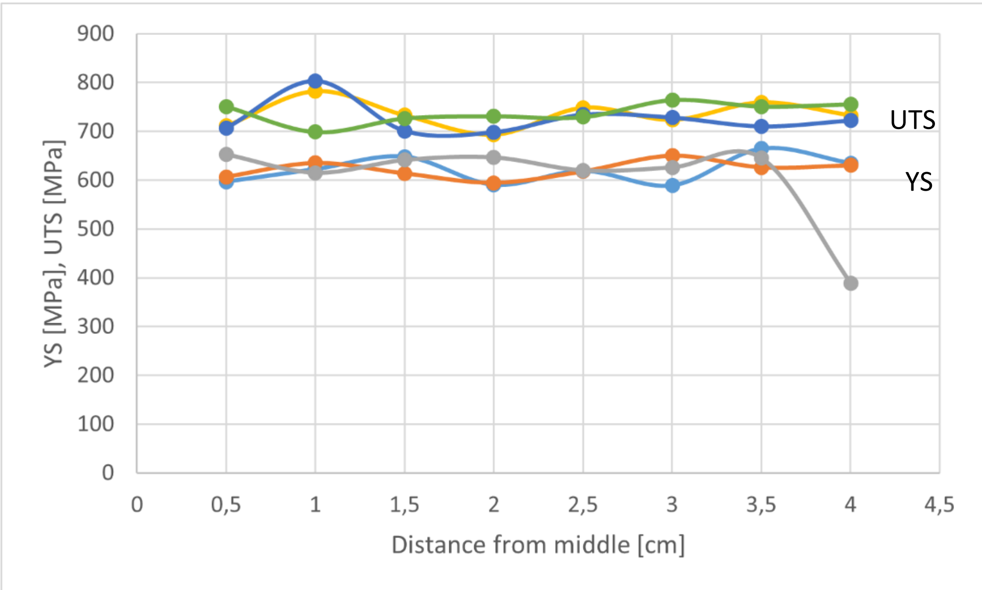

Figure 5 YS and UTS measured by IIT from the middle to the outer layer of the axle

The standard EN 13261 [10] states properties of the EA4T steel in following way: YS≥420 MPa and UTS∈⟨650-800⟩. It can be seen that the results fit well with the values stated in EN 13261 [10].

The hardness results from both methods were in good agreement. Consequently, the results of hardness measurement were used for the estimation of the tensile properties. According to standard ASTM A370 tensile properties can be approximated based on hardness [11]. The trend of UTS measured by IIT and approximated using the correlation stated in ASTM A370 match well. The correlation between hardness and UTS is presented in **Figure 6**.

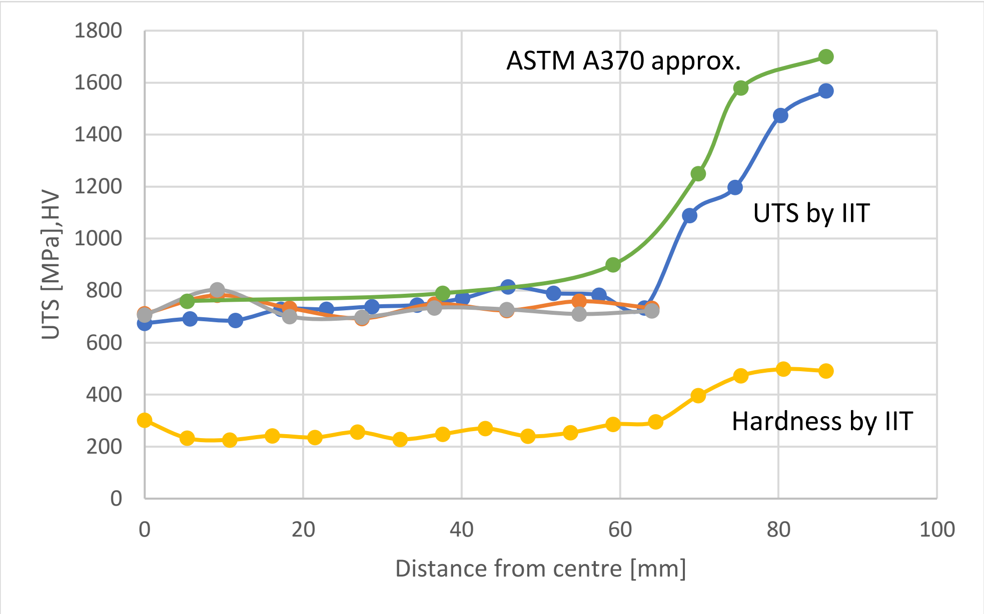

Figure 6 Correlation between HV and UTS by IIT

At the lover values of hardness, measured UTS match well with the values estimated from the hardness testing. However, at higher values of hardness UTS estimated from the hardness testing is higher about 130 MPa (up to 10%) in average compared to the values measured by IIT. The difference may be a consequence of the limit load of AIS 3000HD that was reached in the induction hardened layer due to its high hardness, and consequently, the maximum depth of the measurement had to be lowered. The results could be affected by lower depth of the measurement. The fact that the standard ASTM A370 is an approximation and not the exact measured value has to be taken into consideration as well.

4. CONCLUSION

In this paper evaluating of hardness tests by the IIT were done and compared to conventional Vickers hardness. Furthermore, tensile properties tests using IIT were also performed, and its results were discussed against literature data. Comparing standard hardness tests with instrumented indentation suggests that IIT is viable substitute for hardness measurement. The tensile properties tests are in good agreement with the values stated in EN 13261 standard. The correlation between Vickers hardness and tensile properties is in good agreement considering the approximation found in the standard ASTM A370.

ACKNOWLEDGEMENTS

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