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# Experimental characterization of the mechanical properties of railway wheels manufactured using class B material

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**Abstract**

The railway system has an important role in developed countries, it is possible to see, nowadays, passenger trains crossing the Old Continent and achieving impressive speeds in the East; at the same time, cargo wagons are hitting load-by-axle records in North America. Railway wheels are a critical component to this system, as any failure can lead to derailment, potentially causing financial loss and/or fatal accidents. The present work aims to analyze the mechanical properties of forged wheels manufactured according to the American standard AAR Class B (produced at the MWL Brasil facility), usually applied in passenger cars due its chemical composition (around the eutectoid point) which achieves high mechanical resistance combined with moderated toughness. The mechanical tests to evaluate the mechanical strength, ductility, fracture toughness and hardness were performed in accordance with the European standard BS EN 13262 (location of sample and method test), as follows: tensile tests, impact tests, toughness tests and hardness Brinell tests (hardness survey/hardness map). The results are in accordance with the microstructure and chemical composition, and will be employed in future investigations for the numerical validation of the mechanical behavior for multiaxial fatigue conditions and for failure analysis reports.


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*Keywords:* Railway wheels, Mechanical properties, Forged product, Case study, Experimental techniques.

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## 1. Introduction

The railway system has an important role in developed countries: it is possible to see, nowadays, passenger trains crossing the Old Continent and achieving impressive speeds in the East; at the same time, cargo wagons are hitting load-by-axle records in North America, Zucarelli (2013).

In this contest, railway wheels are an important safety item in the both railway transport sector: passengers and cargo.

In the AAR M-107 standard, the railway wheels are in four classes of application, as presented in Table 1. Depending on the application, these traditional railway wheels are made by using steel with high or medium carbon contents.

Table 1 - Specifications Classes L, A, B, C, and D, AAR M-107 (2011).

| Class | Carbon (%) | Brinell Hardness | Type of application |
|---|---|---|---|
| L | 0.47 máx. | 197 – 277 | High-speed service with more severe braking conditions than other classes and light wheel loads. |
| A | 0.47 – 0.57 | 255 – 321 | High-speed service with severe braking conditions, but with moderate wheel loads. |
| B | 0.57 – 0.67 | 302 – 341 | High-speed service with severe braking conditions and heavier wheel loads. |
| C | 0.67 – 0.77 | 321 - 363 | Service with light braking conditions and heavy wheel loads and service with heavier braking conditions where off-tread brakes are employed. |
| D | 0.67 – 0.77 | 341 - 415 | Low speeds, braking legal conditions and high loads. |

The aim of this work is to perform the mechanical characterization of a wheel steel whose chemical composition complies with the Class B of standard AAR M-107, following to the European standard BS EN 13262 (2004).

These railway wheels were wrought and thermally treated following the manufacturing process of MWL Brazil. MWL company has large experience on the manufacturing of axle and railway wheels. Mechanical testing and metallographic were conducted and the achieved results were compared with historical values of the class B material in the standard AAR M-107

## 2. Theoretical Background

In general, when structural and machine components are working, they are subjected to multiaxial stress states mainly due to geometric form and/or complex loading. The lifetime prevision due to the fatigue of these components is extremely important, Reis (2004), once it is related to safety operating conditions.

Therefore, the railway wheels are projected to operating during a large lifetime, in general, around one million of kilometers before showing any problem. Afterwards, they are replaced in its maximum wear, Santos (1992).

They always need to be replaced due to wear and almost never due to other type of faulty issue. However, due to different working conditions and events related to its manufacturing process, some defects can occur in its use, consequently forcing a reprofiling or scrap operation, Zucarelli (2013).

Depending on the depth at which the fatigue process develops, it is possible to determine the related issue. When issues begin at higher depths, they are usually related to inclusions, porosity or internal voids in the steel. The superficial issues in the tread and flange are in general due to fatigue conditions that are presented in three forms: thermal (because braking), mechanical (because load) or both Villas Bôas *et al* (2010). These issues may also occur due to meteorological conditions, as instance, snow, rain, high humidity, as well as the presence of abrasive (sand) that directly affects the wear, Zakharov (2001). Such superficial issues in the tread and flange forces the railway wheels to be removed for re-machining in order to eliminate them.

The wear in the railway wheels can be minimized by correct wheel alignment, flange lubrication, similar materials employed on rail and railway manufacturing and by keeping components in good mechanical conditions. All the effort should be made to avoid excessive loss of material in the tread due to thermal cracking and shelling Clarke (2008) and Zucarelli (2013).

Nevertheless, the resistance (yield strength and tensile strength) and the hardness are considered as indicators of the railway wheels performance during its operation, since yield stress has higher influence on the damage response caused by contact fatigue of the bearing and wear resistance is associated with hardness increase of material, Constable et al (2004). The profile of a railway wheel and its nomenclature are presented in the Figure 1.

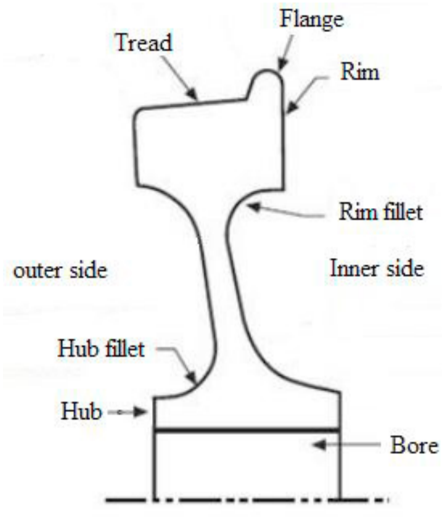


Figure 1. Designations of each part of a solid railway wheel.

This work conducts an investigation by using numerical simulation based on Finite Element Method (FEM) to simulate the mechanic behavior when subjected to multiaxial fatigue of the class B material of railway application.

## 3. Materials and methods

Two railway wheels were chosen in a manufactured lot and cut by oxyfuel, as illustrated in Figure 2. Then, specimens were removed to be used in the microstructural characterization and mechanical testing of the material (hardness, tensile, impact and fracture toughness). A fully machined railway wheel was considered, this means that the exceeding metal that should be removed during the machining was safety discounted in the specimens, then avoiding issues due to the thermal delivery of cut operation.

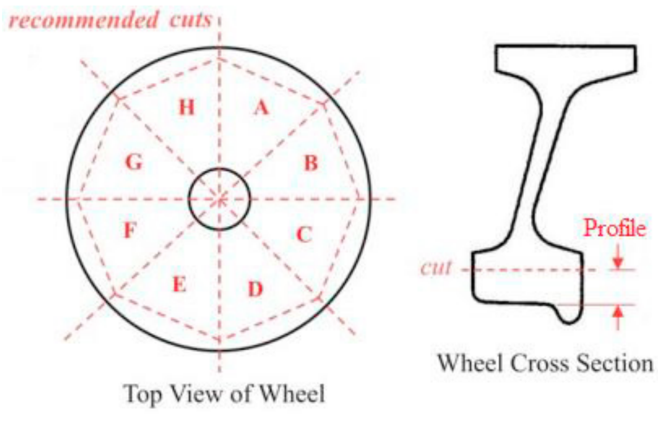


Figure 2. Front view and railway wheel profile with cut recommendation.

All the locations of the specimens used for the mechanical tests removed according to the standard EN 13262 (2004) are shown in the Figure 3. The tensile and hardness tests were performed according to the standard ASTM A-370, the Charpy impact testing (U-notch) according to the standard ASTM E-23 and the fracture toughness according to the ASTM E-399.

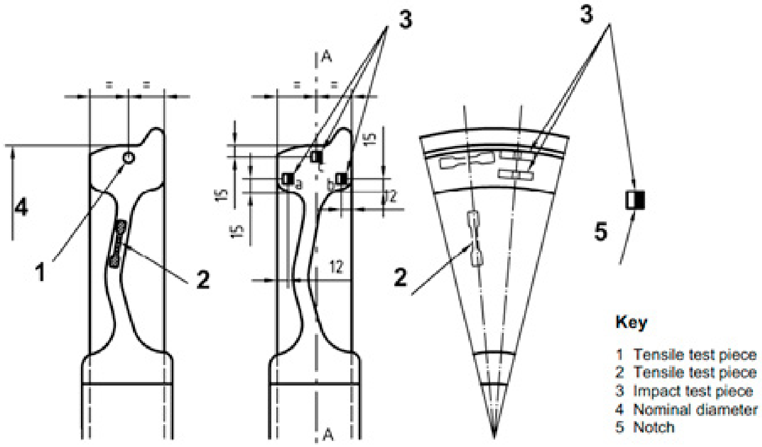


Figura 3. Location of test pieces, BS EN 13262 (2004).

## 4. Results obtained

### *4.1. Microstructure*

Table 2 presents the chemical composition of the class B Material by EDS Spectroscopy (Energy-Disperse X-Ray Spectroscopy). As expected, the carbon content is within the defined range for the Class B material in the standard AAR M-107. The present nitrogen was measured by parts per million and its value is 110,6 ppm. In Figure 4, the optical microscopy images (OM) can be observed.

Table 2 - Chemical composition of the class B material (percentage weight)

| C | Mn | Si | P | S | Cr | Ni | Mo | Al | Cu | V | Ti | B | Sn | Nb | Co |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.631 | 0.748 | 0.343 | 0.0193 | 0.0193 | 0.171 | 0.06 | 0.02 | 0.002 | 0.128 | 0.0065 | 0.0018 | 0.0001 | 0.0064 | 0.0026 | 0.0079 |

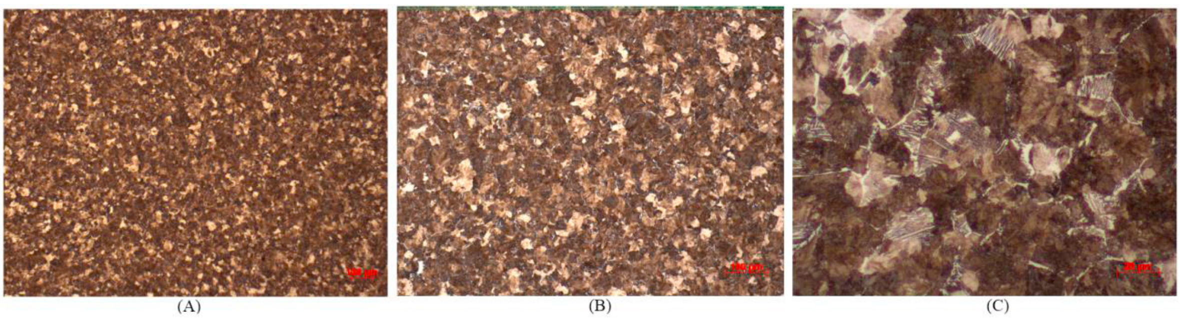


Figure 4. Optical microscopy (OM) - (A) 50x (B) 100x (C) 500x.

By enlarging the images as (A) 50x, (B) 100x and (C) 500x, evidence of pearlitic structure is clearly observed. Cementite (Fe3C) and ferrite appear too such as expected. due to the chemical composition which is close to the eutectoid point and due to high cooling rate on the rim caused by the tempering heat treatment.

### *4.2. Brinell and Rockwell c Hardness*

The Brinell hardness testing results and the measurement points of Rockwell C hardness of the profile of the studied railway wheel are presented in the Figure 5: first line at 15 mm, second line at 25 mm and third line at 35 mm from the bearing surface. The values of Rockwell C hardness per point are presented in Table 3. By comparing the Brinell hardness testing results (standard AAR M-107 for the class B material), on Table 4, with the achieved experimental results (341BHN maximum e 321BNH minimum), it is evident that the class B material is in comply with the American standard specifications.

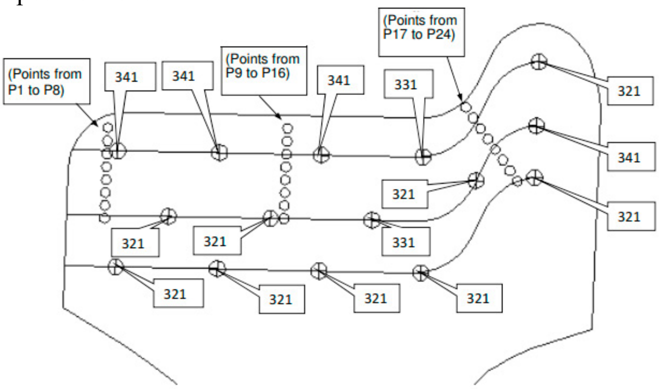


Figure 5. Brinell hardness results and Rockwell C Hardness points of the rim profile of the Railway Wheel.

Table 3. Rockwell C Hardness Points Result

| Table of points - HARDNESS HRc | | |
|---|---|---|
| P1 = 36 | P9 = 35 | P17 = 36 |
| P2 = 37 | P10 = 36 | P18 = 35 |
| P3 = 35 | P11 = 36 | P19 = 37 |
| P4 = 36 | P12 = 38 | P20 = 34 |
| P5 = 37 | P13 = 37 | P21 = 36 |
| P6 = 34 | P14 = 37 | P22 = 35 |
| P7 = 35 | P15 = 35 | P23 = 34 |
| P8 = 35 | P16 = 36 | P24 = 35 |

Table 4. Brinell hardness of rim, AAR M-107 (2011).

| Class | Minimum Hardness | Maximum Hardness |
|---|---|---|
| L | 197 BHN | 277 BHN |
| A | 255 BHN | 321 BHN |
| B | 302 BHN | 341 BHN |
| C | 321 BHN | 363 BHN |
| D | 341 BHN | 415 BHN |

### 4.3. Tensile test

Table 5 presents the results that are related to the yield strength ($\sigma_e$), endurance limit ($\sigma_{máx}$), percentage elongation ($A_p$) and percentage reduction in area (φ), for the railway wheels conformed with class B material, in the environment temperature in the rim area and wheel disk. According to the previously illustrated Figure 3, the tensile specimens of the rim were removed from the region that is directly affected by thermal treatment, thus justifying the increase of mechanical strength values and reduced ductility. The results are compatible to the hardness values previously presented. Figure 6 presents the tensile testing result and Stress (MPa) versus Displacement (mm) chart, respectively.

Table 5. Tensile Testing Results

| Zone | $\sigma_e$(Mpa) | $\sigma_{max}$(MPa) | Ap(%) | ϕ(%) |
|---|---|---|---|---|
| Rim | 733.1 | 1103.6 | 12.76 | 29.83 |
| Disk | 429.7 | 876.8 | 12.56 | 23.66 |

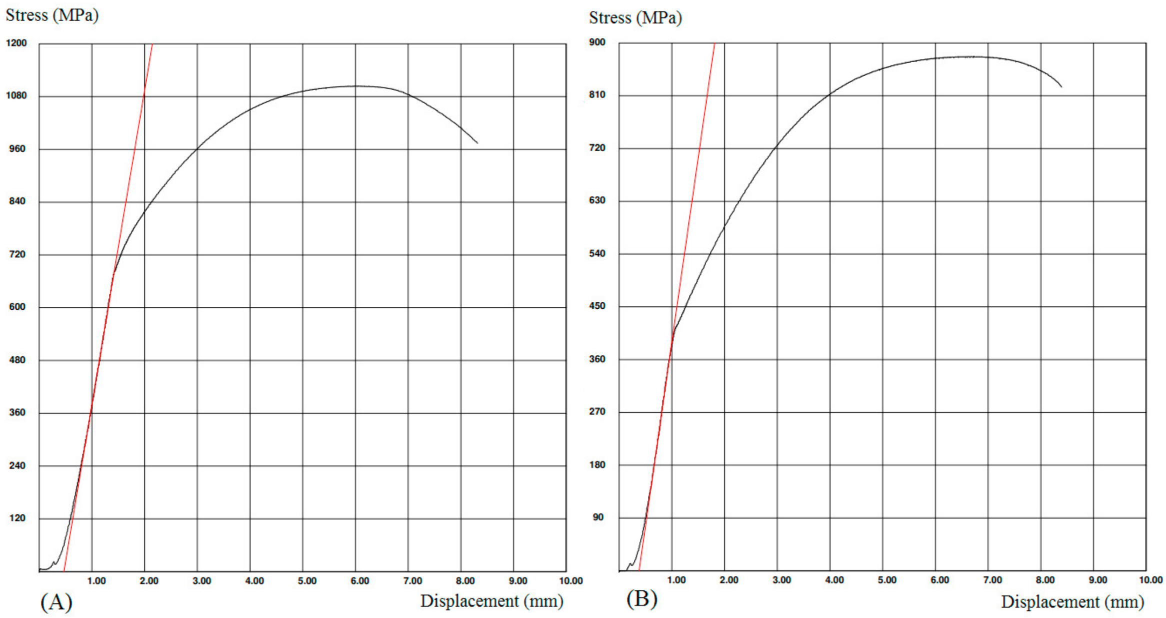


Figure 6. Tensile testing result - (A) Rim and (B) Wheel Disk Stress (MPa) versus Displacement (mm)

### 4.4. Impact test

The impact testing results of the class B material are presented in the Table 6.

Table 6. Impact testing results - specimens A, B and C.

| Impact Charpy - Joule (J) | |
|---|---|
| A | 13J |
| B | 12J |
| C | 15J |

By analyzing the achieved results, it is evident the inverse relation of mechanical strength (as proved by the hardness and tensile testing) with the impact resistance capability (ductility).

### *4.5. Fracture toughness*

The relation (1) was used to verify the $K_{IC}$ of the specimens A, B and C, Garcia (2008):

$$(t),(a) \geq 2.5\left(\frac{K_{IC}}{\sigma_e}\right)^2 \quad (1)$$

Table 7 shows the fracture toughness results for the specimens A, B and C.

Table 7. Fracture toughness testing results.

| C(T) | $K_{IC}$ (MPa.m$^{1/2}$) | Kq (MPa.m$^{1/2}$) |
|---|---|---|
| A | 58,6 | - |
| B | 57,23 | - |
| C | - | 48,25 |
| Average | 54,69 | |

Regarding Eq. (1), only the specimens A and B were validated for which $K_q$ is a valid $K_{IC}$; on the other side, for the specimen C, the $K_q$ value was not able to be considered a valid $K_{IC}$. The validation of the specimen C could not be achieved due to some parameter error, such as during the machining of samples and/or of the pre-crack (a).

## 5. Final remarks

The obtained results are in accordance with the microstructure and chemical composition.

The mechanical testing results for the Class B material were satisfactory and comply with the historic of standard AAR M-107 (2011) as well as the standard EN 13262 (2004) in terms of position of removing of the specimens and mechanical testing.

The results of this study will serve as groundwork for a future database for numerical simulations based on finite element method in multiaxial fatigue of the class B material for a railway wheel project.

## Acknowledgements

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