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# Metallurgical characterization and computational simulation of a screw spike aiming to improve its performance in railways

Geraldo Lúcio de Faria, Leonardo Barbosa Godefroid, Luiz Cláudio Cândido, Thayene Oliveira Silotti

*Department of Material and Metallurgical Engineering, Universidade Federal de Ouro Preto, Ouro Preto, Minas Gerais, Brazil*

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ABSTRACT

The screw spike is an important structural component of railroads. It is a fixation component responsible for supporting the plat fixation on the sleeper and guarantees the railroad stability. This component is commonly produced by hot forming processing of low carbon steels. In Brazil, this component has been often failing in service due to the increase in the transported loads by trains in last years. This work investigated the stress concentration susceptibility of this component in order to understand the effects of screw threads on the mechanical behavior of the screw spike. Chemical and microstructural analyses were performed using optical emission spectrometry and optical microscopy; tensile and hardness tests were also executed. Computational models of static loading were used to determine the stress distribution along the actual geometry of the studied screw and to understand the main causes of recurrent failures. The use of appropriate relations of Mechanics of Materials associated with computational simulations allowed the proposal of some changes in the screw spike original project aiming to improve its performance in service.

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## 1. Introduction

Economic development depends heavily on the advance of transportation means. Decreasing transportation costs while increasing efficiency and reliability may grow the flow of goods and the level of national trade, and consequently, international competitiveness [1–3].

The growth of railways is directly related to the investments in high performance engineering materials, training people, workshops, telecommunication/signaling, and especially in the superstructure of the permanent way [1–5].

According to many authors, one of the most common problems in the permanent way, besides fatigue rail failures, is the loosening and the fracture of the fixation system components, which requires urgently their tightening or replacing. Many derailment accidents may have been caused by either bad or insufficient fixation. The failure of the permanent way components is responsible for 50% of the railway accidents, and the fasteners, such as screw spikes, are included in this context [3–7].

The fracture of screw spikes has become a recurrent problem in Brazilian railroads due to the increase in the transported load in the last years. The screw failures occur mainly in two situations: overload during the component installation, or in service after many hours submitted to cyclic loading. In Brazilian railroads, the second situation is the most recurrent and serious. When it happens and is not quickly detected, all the structures may be unstable and the rail lifetime decreases strongly [6]. Fig. 1 shows one perfect screw spike and thirteen of them failed in service. It was observed that, in general, the screw breaks down in the 2nd thread region.

Currently, screw spikes are produced by forging and hot rolling SAE1015 carbon steel bars, in accordance to the NBR 8497:08/2008 standard. This standard establishes the conditions for manufacturing, supplying and receiving raw materials, as well as the required mechanical characteristics for the screw spike acceptance [8,9]. However, even following the technical standard criteria, the Brazilian concessionaries have reported the increase of the failure occurrence on this fixation element.

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**Fig. 1.** In service failure of screw spikes.

In this context, this work has as main objective to apply computational simulation as well as chemical, metallurgical and mechanical characterizations of screw spikes to understand the failure's main causes and to propose improvements in the screw manufacturing process in order to extend its lifetime without changes in steel chemical composition for economic feasibility purposes.

## 2. Materials and methods

The structural, chemical and mechanical experimental procedures were performed in new screw spikes supplied by the same manufacturer of the failed screws used in the railroad (Fig. 2).

The chemical analysis was performed by optical emission spectroscopy. The microstructural characterization was done in an optical microscope. The tensile tests were executed at room temperature in a universal machine with $10^{-3}$ $s^{-1}$ strain rate. Bars of SAE1015 steel were drawn until different final strains (5, 10, 15, 20 and 25%). The strained samples were machined and submitted to tensile tests in similar conditions. The yield and tensile strengths, as well as the area reduction and the total elongation were determined for each pre-strained sample. Applying these results, a strain hardening curve was built. A torsion test was also performed aiming to determine the material shear yield strength.

Subsequently, the finite element technique was applied, using the ANSYS 14.5 software, to determine the stress distribution along the actual screw spike when loaded.

The characterization results were used as input data to the computational model. Then, the stress distribution on the screw spike subjected to a regular static load of 15 kN [4,8,9] was simulated for three different geometries: the current (to understand the recurrent failures) and two new proposed designs.

The two new geometries were proposed based on calculation models of the stress concentration factor $K_t$ proposed by Neuber [10–20]. The determination of the stress concentration factor under normal stress loading, considering a geometry with a single thread, was performed using Eq. (1), where **t** is thread height, and **r** is the thread root radius [10–12].

$$\mathbf{K_t} = 1 + 2\sqrt{\frac{\mathbf{t}}{\mathbf{r}}}. \tag{1}$$

The screw spike has a sequence of identical and equally spaced threads. Due to that, according to models based on Mechanical of Materials, a stress relief occurs at the stress concentration points. Neuber's model was used to determine the relief load coefficient ($\boldsymbol{\gamma}$) by using Eq. (2) either for the actual and proposed geometries. In those models, this coefficient is a correction factor used to calculate the geometrical stress concentration ($\mathbf{K_t}$) in a screw with multiples and sequential threads, where $\mathbf{t}$ = thread height; $\mathbf{P}$ = distance between two threads (pitch) (Eq. (3)) [10–15].

$$\boldsymbol{\gamma} = \left(\frac{\mathbf{P}}{\pi t}\right) Tgh\left(\frac{\pi t}{\mathbf{P}}\right) \tag{2}$$

$$\mathbf{K_t} = 1 + 2\left(\frac{\mathbf{t}\boldsymbol{\gamma}}{\mathbf{r}}\right)^{\frac{1}{2}}. \tag{3}$$


**Fig. 2.** Screw spike.

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