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Optimization of the cold-rolling process to enhance service life of railway axles

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Abstract

Over the last years, deep rolling has been adopted to improve the fatigue strength of railway axles. In particular, recent researches between PoliMi and LucchiniRS have shown the possibility to greatly enhance the residual lifetime of axles in presence of defects from running in service by inhibiting the propagation of cracks under normal loading conditions and retarding the appearance of corrosion-fatigue phenomena. Therefore, the new automatic machining line for axles setup by LucchiniRS includes a modern cold-rolling machine as a finishing process for premium quality axles. This paper is devoted to discuss the optimization of the cold-rolling process considering all the relevant parameters (load, roller radius, pitch) through a novel model able to simulate the build-up of residual stresses. The model was validated by comparing the residual stress path with the experimental outcomes, showing a good agreement for the various combination of the adopted parameters. The exploitation of the model will enable the designer to optimize the cold-rolling process taking advantage of the increase of fatigue properties in the definition of a safe life maintenance plan.

Keywords: cold-rolling, residual stresses, crack propagation

1. Introduction

Railway axles are safety critical components, designed for infinite life, typically set in 30 years of service, whose failure may result in derailments, with serious damage for the rolling stock, the infrastructure, or even worst, to injuries to people. Despite these components are designed for an infinite life, EN 13103 (2001) and EN 13104 (2001), the design approach has been in the last years more and more complemented by the damage tolerant one, where the presence of defects arising from service is accepted, Grandt (2004); Zerbst et al. (2013); Cantini et al. (2011). Even if these defects can happen and grow, the safety of the axle is ensured, by this methodology, by the regular

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in-service inspections during the life of the train. For this reason, the resistance against failure in service is a key issue in designing the axle and in its related maintenance plan in service, to ensure high safety standards and, at the same time, to optimize life-cycle costs. More than a meticulous definition of the service inspection plan, any methodology able to increase the lifetime of a real axle subjected to service, with the possibility of damaging in line, is particularly appreciated. Among them, the presence of compressive residual stresses on the axle is one of the strategies for increasing lifetime by reducing the stress intensity factors (SIFs) experienced by an eventual crack. This paper will focus to the definition of an analytical tool for the calculation of the residual stresses in railway axle after the cold rolling procedure.

2. The adoption of cold rolling to enhanced service life of railway axle

The presence of a compressive residual stress field is always desirable for all the components which are designed for a very long life and are safety components, like railway axles are. While the quenching and tempering process can result in slightly compressive stresses under the surface, the reachable values and depths are not sufficient to effectively prevent the propagation of defects which can typically happen from the running in service, like impact from ballast, scratches or corrosion pitting.

Considering the railway axle sector, the technological process traditionally adopted by axle producers for the life extension is cold rolling. By this procedure, see Altenberger (2005), a roller translates along the whole surface of the axle, or just along those regions which are recognized as critical, inducing local plastic deformations which results at the end in compressive residual stresses.

The compressive residual stresses at the end of the cold rolling technological process typically stay in the first 3 mm in depth, having values in the range of -600 MPa along the longitudinal direction (the axis direction) and about -300 MPa along the circumferential one, as measured from previous work from the authors. Such a magnitude of residual stresses suggests an effective prospective action against crack propagation in full scale axles, where, usually, the maximum in-service stress amplitude is lower than 200 MPa.

Previously carried out tests, by Regazzi et al. (2014), have shown that, after cold rolling, notches up to 4 mm, which are supposed to be easily detectable during in-service inspections, propagates with very slow speed rate and only with load spectra higher than normal, increasing the lifetime of the axle or, alternatively, increasing the safety of the axle during its life.

The relevant technological parameters, depending on the desired magnitude of residual stresses and their maximum depth, are the geometry of the roller at the contact region, meaning basically its radius, the longitudinal feed (the step of advancement per turn along the axis) and the applied contact force, as shown for example in Altenberger (2005). The definition of such parameters is very important in the fine-tuning of the process, since the experimental evaluation of the residual stresses under the surface is a very long and costly process, requiring a huge amount of measurements by XRD methodology, which is typically beyond the scopes and the time availability of the production line.

For such reason, the development of an analytical model able to properly and quickly define the parameters of the process given the required amount of residual stresses and their depth, is very important in the optimization of the production process.

3. Modelling of residual stresses

The analytical model for the prediction of the residual stresses induced by cold rolling is based on the original model proposed by Guechichi et al. (1986) for predicting the residual stresses due to shot-peening.

The model assumes a periodic time dependent stress field as a linear combination of the elastic stress field and the residual stress field:

$$\boldsymbol{\sigma} = \boldsymbol{\sigma}^{el} + \boldsymbol{\sigma}^{r} \quad (1)$$