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State of the art of Deep Rolling

P. Delgado, I.I. Cuesta*, J.M. Alegre, A. Díaz

Structural Integrity Group, Escuela Politécnica Superior, Avda. Cantabria s/n, 09006 Burgos, Spain

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ABSTRACT

It is vital to control fatigue life in different industrial sectors, and to improve this, surface treatments are usually used. Some of the most important surface treatments are Shot Peening (SP), Laser Shock Peening (LSP) or Deep Rolling (DR), which are used to improve the surface properties and resistance to cyclic loading of the components. The idea of this article is to focus on Deep Rolling and revise the state of its development at the present time, with a particular emphasis on implementation and changes in materials. A comparison of Deep Rolling versus other surface has been made, and different processes that can improve the effects of Deep Rolling, such as heat treatments, are shown. It can be concluded that the pressure of the tool during the process is the most important control parameter for Deep Rolling and that the residual stresses and strain hardening have the greatest influence in terms of fatigue life. Moreover, selecting the correct values of the other control parameters for DR, depending on the material on which DR is to be done, allows increased compressive residual stresses, a hardened layer near the surface and lower surface roughness, all of which produce an improvement in fatigue life.

Contents

* Corresponding author. Fax: +34 947258922.
E-mail address: iicuesta@ubu.es (I.I. Cuesta).

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1. Introduction

The behaviour of metallic components regarding cyclic loading, and therefore against fatigue phenomena of components operating in industries such as the aerospace (Sticchi et al., 2015; Klocke and Mader, 2005), power generation (Ma et al., 2015), or automotive industries (Matlock et al., 2009), is very important because in many cases their useful life is determined by cyclic performance. The industrial sectors, where fatigue is of great importance, are always in a process of continuous evolution with the aim of improving the fatigue life of their components. One of the most common ways to increase the useful life against cyclic phenomena is the realization of surface treatments on the components.

Surface treatments are a set of processes by which residual compressive stresses are attained on the surface of components to increase their life against cyclic phenomena (Sticchi et al., 2015; Manouchehrifar and Alasvand, 2009; Perenda et al., 2015; Altenberger, 2005a). The most commonly used surface treatments include Shot Peening (SP), Laser Shock Peening (LSP) and Deep Rolling (DR).

Laser Shock Peening is based on the action of one or several short high-energy laser pulse on the surface of the material, so that strain hardening and the introduction of residual stresses occur there. Shot Peening is the bombardment of the surface by small diameter spherical particles with sufficient force to cause plastic deformation and the introduction of residual stresses.

Deep Rolling is a process by which a mechanically or hydraulically (Klocke and Mader, 2005) controlled ball or roller applies a specific pressure on the surface of a component, causing plastic deformation of the surface and subsurface area and introducing a layer (1–2 mm) of compressive residual stresses. Besides these residual stresses, two beneficial phenomena for increasing fatigue life are produced: strain hardening and lower surface roughness (Groche et al., 2012). The influence of these effects on the crack growth and propagation is shown in Table 1 (Wagner, 1999).

However, both residual stresses as well as strain hardening can decrease over the life of the component, either due to the effect of temperature, the effect of mechanical stresses from fatigue (Michaud et al., 2006) or a combination of both (Juijerm and Altenberger, 2007a). Therefore, studies of the relaxation of the values of residual stresses and strain hardening are needed (Altenberger et al., 2012; Juijerm and Altenberger, 2007b).

The parameters for Deep Rolling – pressure, speed, number of passes, etc. – directly influence the state of residual stresses, strain hardening and the final roughness, so their correct determination, depending on the material, is a key to maximizing the benefits of DR (Manouchehrifar and Alasvand, 2009; Abrão et al., 2014a). Numerical simulation offers the possibility to study the optimal configuration of DR parameters, eliminating the need to test various operating conditions (Manouchehrifar and Alasvand, 2009; Perenda et al., 2015; Yen et al., 2005; Balland et al., 2013a; Bouzid Saï and Saï, 2004; Balland et al., 2013b).

The aim of this article is to review the state of DR nowadays. First, different procedures for the execution of the DR, as well as parameters that control the process and the influence on material parameters such as microstructure, surface hardness or yield strength are presented. Then, the numerical simulation of DR is addressed, and the materials most commonly subjected to this treatment and their industrial applications are reviewed. Finally, new procedures for the implementation of DR, especially related to DR at high and low temperatures, as well as a comparison between DR and the most common surface treatments are presented.

2. Deep Rolling process

2.1. The process of Deep Rolling

The process of DR can be carried out in different ways, mainly depending on the shape of the element on which it is to be performed. For components with axial symmetry, it is often carried out by a DR machine consisting of three balls equally spaced at 120° around the axis of the workpiece. The component undergoes a rotation about its longitudinal axis and a displacement in the direction of this axis, while the three balls of the DR machine don't move at all. This way, DR is produced by subjecting the workpiece to a certain pressure exerted by the balls on the workpiece due to the movement of the latter (Perenda et al., 2015; Wagner, 1999; Abrão et al., 2014b).

In elements without axial symmetry, for example planar elements or with more complex geometries (Altenberger et al., 2012; Wong et al., 2014; Nikitin et al., 2004; Nikitin and Altenberger, 2007), applying pressure is performed by a ball or roller whose required pressure is transmitted hydraulically or mechanically, while moving along the surface (Fig. 1). In order to prevent thin elements from bending, DR might be accomplished by two opposed rolling tools (Klocke and Mader, 2005). DR on more complex geometries can be applied in a similar way, designing tools with special shapes adapted to the geometry of the component and attaching them to another tool to provide the movement, such as a robotic arm (Wong et al., 2014).

2.2. Measurable parameters

Measurable parameters are those material variables or properties that undergo changes due to DR. Their values condition the component behaviour during its lifetime.

2.2.1. Residual stresses

They are one of the most important parameters caused by DR. Residual stresses are often measured by X-ray diffraction (XRD) (Achmus et al., 1997; Galzy et al., 2005) (e.g. $\sin^2\psi$ method with CrKα radiation for steels). Another way to measure residual stresses is the use of the Central Hole Drilling (CHD) method (Wong et al., 2014; Nau et al., 2014). CHD measures the near surface residual stresses by strain release corresponding to a small shallow drilled