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Analysis of deformations and stresses in flat rolling of wire

C. Vallellano, P.A. Cabanillas, F.J. García-Lomas*

Departamento de Ingeniería Mecánica y de Materiales, Escuela Superior de Ingenieros, Universidad de Sevilla, Camino de los Descubrimientos s/n, 41092 Sevilla, Spain

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ABSTRACT

Flat rolling of wire is an industrial process used to manufacture electrical flat wire, medical catheters, springs and piston segments, among other products. This paper presents a 3D numerical analysis of the contact stress distributions prevailing in the roll-wire contact zone, as well as of residual stresses in the resulting flat wire, as a function of the deformation inhomogeneity induced in the material. Three different patterns in the contact pressure are clearly distinguished and discussed. As in slab-rolling process, a generalized parameter H^* is proposed to quantify the deformation inhomogeneity in wire rolling. This parameter allows the characterization and prediction of the morphology of the contact and residual stress distributions.

1. Introduction

Rolling of wire is a widely used industrial process for the production of wire with a specific cross-section. Rolling has some advantages over drawing through shaped dies that include more precise dimensional control of the end-product, an increased production rate and a decreased risk of breaking the wire—particularly when complex geometries or large reductions are involved.

The simplest wire rolling process uses flat rolls, which is known as "flat rolling of wire". The initial workpiece is usually a wire of circular cross-section. The final product is a flat wire with rounded edges due to the barrelling effect. This is usually a cold rolling process, which may involve one pass or as many as required to achieve the desired wire width and reduction. The quality of the wire depends primarily on two key factors, namely: the lateral spreading and the edge rounding. Occasionally, the process involves application of front or back tension or both in order to reduce the rolling force and facilitate control of widening. Flat wire is used to manufacture springs, piston segments, electrical flat wire and medical catheters, among other products. Very recently, the use of flat-wire electrodes in the conventional gas metal arc welding (GMAW) instead of the traditional round-wire electrodes has successfully increased the technical and practical capabilities of this process.

In mechanical terms, the flattening process involves a strongly inhomogeneous deformation dependent on the reduction applied to the wire. As in flat rolling of slabs, deformation inhomogeneity has a marked effect on the contact stress distribution, the force required to deform the material and residual stresses in the final product, all of which evolve in a way that departs markedly from that under homogenous deformation conditions. Their variation has a crucial effect on the service characteristics and integrity of the finished product.

Although the wire flattening process has been widely studied – particularly in the 1950s to 1980s – most of the ensuing

* *Corresponding author*. Tel.: +34 954 487 311; fax: +34 954 460 475.
E-mail address: carpofor@us.es (C. Vallellano).
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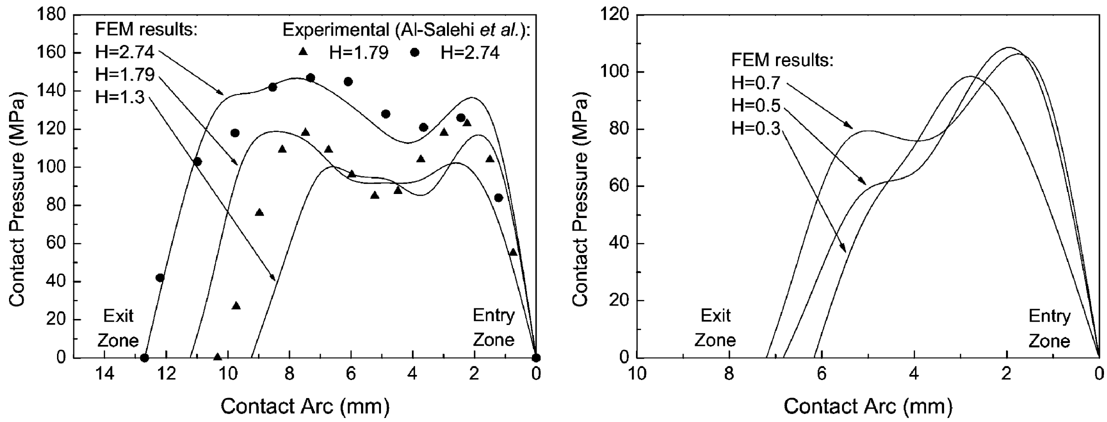

Fig. 1 – Variation of the contact pressure during flat rolling of slabs as a function of *H* (Fulgueira et al., 2004).

literature has been published in German or Japanese. More recently, the renewed interest in more efficient control of the process has promoted research involving numerical simulations based on the finite element method (FEM) and aimed at improving available knowledge on the process and its key variables (Carlsson and Lagergren, 1996; Carlsson, 1998; Utsunomiya et al., 2001). In this work, numerical techniques are used to examine changes in the contact stresses and the residual stresses in the end-product as a function of deformation inhomogeneity in the material. As in slab-rolling, a universal parameter to characterize the degree of homogeneity may be also defined in wire flat rolling that allows the shape of the contact and residual stresses distributions to be to predict and classified.

2. Stress evolution and deformation inhomogeneity in flat-rolling of slabs

Before analysing the wire flattening process, let us briefly review the key results of the well-know slab rolling process. The pioneering experimental work of MacGregor and Palme (MacGregor and Palme, 1959), and Al-Salehi et al. (Al-Salehi et al., 1973), revealed the presence of well-defined patterns in the contact pressure distribution dependent on the degree of deformation homogeneity in the material. Thus, under homogeneous deformation conditions, the stress exhibits a single maximum that coincides with the position of the neutral line. This pattern is consistent with the classical theories of flat rolling developed by Orowan (Orowan, 1943), and Bland and Ford (Bland and Ford, 1948), among other authors. However, as deformation homogeneity reduces, the contact pressure starts to exhibit a double peak distribution, one near the roll entry zone and the other near the roll exit zone. MacGregor and Palme (MacGregor and Palme, 1959) pointed out that the maximum in the entry zone is due to the yielding restriction imposed by the adjacent, more rigid, elastic regions. This was termed by Orowan "peening effect". On the other hand, the peak in the exit zone seemingly results from deformation hardening of the material (MacGregor and Palme, 1959). As deformation homogeneity continues to decrease, the peak in the exit zone gradually disappears and a single maximum in the entry zone is eventually observed at high enough deformation inhomogeneity levels (see Fig. 1). In this case, the

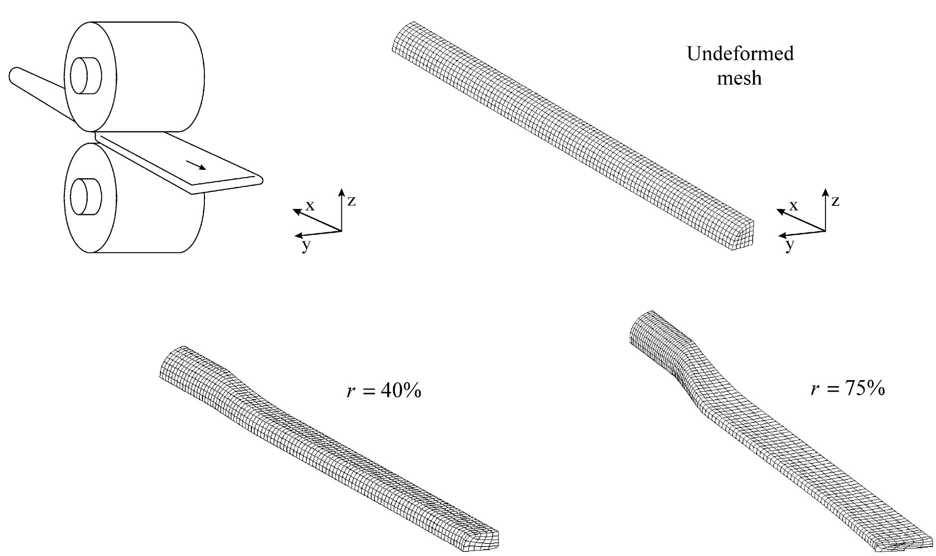

Fig. 2 – Schematic wire flattening process and FE mesh for 1/4 of the wire cross-section, both undeformed and deformed by 40 and 75% (different scales).