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Influence of the yielding criterion on total forming force in metallic junctions using elastomers

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Abstract

The production of metallic junctions employing elastomers is an unconventional technique that has been in development in the last 20 years. The forming process gets successfull just if a simultaneous compression between the elastomers and the tube takes place. Exact solutions for problems involving forming with elastomers are quite difficult to determine. However, the upper-bound theory can be used in order to predict the necessary load for junctions forming. Thus, it is necessary to develop a model capable to provide an estimate of the total forming force, which is useful to set-up tools and equipments required for the process. In this work, Von Mises, Hill's 1948 and Hill's 1979 associated yielding theories, and the Hosford's theory (1979) as well, were used in order to study the anisotropic behaviour on total forming force of junctions using elastomers, insuring the functionality of the proposed model.

Keywords: Junctions; Elastomers; Yielding criterion; Anisotropy; Forming

1. Introduction

Despite metal forming processes differ widely with respect to speed, temperature, and in the way by which forces are applied, all processes possess a similar characteristic in terms of its physical parts of interest: tools under loading, plastic zones, interface between the material plastically deformed and the rigid tools, and also elastic–plastic transition regions in the material.

Among the forming processes, arises the forming of thin-walled tube junctions using elastomer (Marreco and Al-Qureshi [1], Moreira Filho and Al-Qureshi [2], Moreira Filho [3] and Foli et al. [4]).

This last forming process shows a considerable number of variables, as for instance: the definition of the necessary relationship between the dome feed formed and the developed pressure in the elastomer, the friction and lubricating conditions during the junction forming, the role of the anisotropy and the material strain-hardening, so as the influence of the strain-rate in the forming process and the definition of the maximum force to form the junctions.

Nowadays, the applications of tube forming technologies are spreading continually out, especially in automotive, aeronautic and nuclear industries. Some applications of this technology are based on the possibility of generating thin-walled tubes with complex geometry. The principal advantages of the elastomer metal forming are, e.g. low weight and high strength of the part.

The assumption that every material remains isotropic during the deformation process is weak, since when individual crystalline grains are elongated in the higher tensile strain direction, the sample texture acquires a preferential direction, Hosford and Caddell [5]. In metals, the main reason for anisotropic plastic properties is this preferential direction, which arises due to grain rotation during sliding or twinning deformation.

Generally, the normal plastic anisotropy coefficient, R, is shown to be more significant, for that is often more discussed upon plastic flow behaviour analysis of anisotropic materials. Regarding that, Menezes and Hartley [6], reinterpreting data previously published in literature reinforced the role of the strain-hardening index n and the normal plastic anisotropy coefficient R and, particularly, they demonstrated that the anisotropy increases the deformation capability of an anisotropic sheet, for both regions of the forming limiting curve (drawing and stretching), a fact confirmed recently by Itikava [7]. As a consequence of this anisotropy, the shape of the yield locus is substantially affected requiring that a yield function of anisotropic materials must include parameters that characterise the anisotropy, Hill [8].

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Hill [8] put forward the first yield criterion for anisotropic materials with orthotropic symmetry. A quadratic function, that is reduced to the Von Mises yield criterion for isotropic materials, when the anisotropy is neglected, is expressed as:

$$2\phi(\sigma_{ij}) = F(\sigma_y - \sigma_z)^2 + G(\sigma_z - \sigma_x)^2 + H(\sigma_x - \sigma_y)^2 + 2L\sigma_{yz}^2 + 2M'\sigma_{zx}^2 + 2N\sigma_{xy}^2 = 1, \quad (1)$$

where the coefficients F, G, H, L, M' and N are characteristic parameters of the anisotropy state present.

In the case of thin-walled metal tubes, the anisotropy is characterised, for simplicity, starting from three orthogonal planes of symmetry to each other that lead to the principal anisotropy axes. Such axes are the reference axes in the theoretical analyses, and they are referred in relation to the longitudinal (z), the circumferential (θ) and the radial (r) directions. Thus, in Eq. (1), when are only considered the principal anisotropy axes, introducing the normal plastic anisotropy coefficient R, effective stress representative of the stress state of the anisotropic material σ_a, and condition of the plane stress (membrane), it leads to the equation:

$$\sigma_a^2(R+1) = (R+1)\sigma_z^2 - 2R\sigma_z\sigma_\theta + (R+1)\sigma_\theta^2, \quad (2)$$

that the form is more common for quadratic representation.

Quadratic form of Eq. (2) is repeatedly used in applications, usually showing a satisfactory prediction of sheet metals behaviour with $R \geq 1$ (Wu et al. [9]). However, for the case of $R < 1$, the anisotropic behaviour was observed by Pearce [10] and Woodthorpe and Pearce [11] for commercially pure aluminium sheets. In this case, the stress–strain experimental curves in balanced biaxial tension present larger stress values than the ones for the simple tension curves, being that the Hill's yield quadratic criterion does not get to predict this behaviour. Dillamore's [12] arguement based on crystals plasticity that the Hill's yield theory for anisotropic materials presents reasonable agreement between theory and experiments for R-values between 1 and 2.

For accommodating the anisotropic behaviour, Hill [13] has proposed a number of possible quadratic yield function generalisations and established four simplified forms considering the planar isotropy of metallic sheets, starting from the following non-quadratic form:

$$F|\sigma_2 - \sigma_3|^M + G|\sigma_3 - \sigma_1|^M + H|\sigma_1 - \sigma_2|^M + L|2\sigma_1 - \sigma_2 - \sigma_3|^M + M'|2\sigma_2 - \sigma_3 - \sigma_1|^M + N|2\sigma_3 - \sigma_1 - \sigma_2|^M = Y^M, \quad (3)$$

where the six coefficients, F, G, H, L, M', N characterise the anisotropy, Y is the yield stress, and $M > 1$ is to assure the convexity.

- Case I: $L = M' = H = 0$, $F = G$.
- Case II: $L = M'$, $N = F = G = 0$.
- Case III: $L = M'$, $F = G$, $N = H = 0$.
- Case IV: $L = M' = F = G = 0$.

All these four forms are adequate to describe the anisotropic behaviour.

If a M value is fixed, it can cause a discrepancy between the predict yield surface and the experimental, showing that the fourth form of the yield function established by Hill is the one more indicated to represent the anisotropic behaviour of metal sheets and tubes.

Eq. (4) shows the Case IV of the Hill's generalised criterion, already considering that the material exhibits solely normal anisotropy, with orthogonal symmetry for condition of plane stress, or be:

$$2(1+R)\phi^M = (1+2R)|\sigma_1 - \sigma_2|^M + |\sigma_1 + \sigma_2|^M, \quad (4)$$

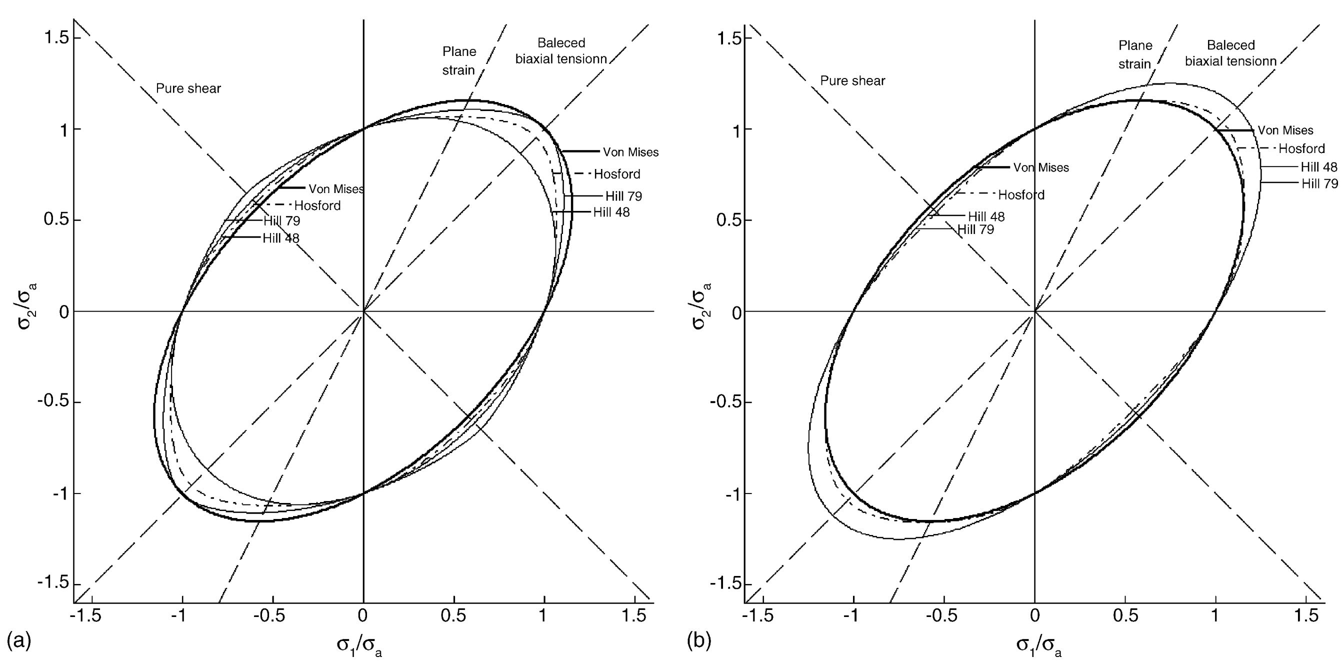

Fig. 1. Initial yield surface using Von Mises, Hill's 1948, Hill's 1979 and Hosford' criteria: (a) $R < 1$ and (b) $R > 1$.