Journal of Manufacturing Processes 31 (2018) 703–711

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Stability and instability analysis of the substrate supported panels in the forming process based on perturbation growth and bifurcation threshold models

Asghar Zajkani*, Ali Bandizaki

Department of Mechanical Engineering, Imam Khomeini International University, Qazvin, Iran

A R T I C L E I N F O

Article history:
Received 5 January 2017
Received in revised form
22 December 2017
Accepted 29 December 2017

Keywords:
Plastic stability and instability
Linear perturbation
Vertex theory
Elastomeric layer
Neo-hookean reinforce layer

A B S T R A C T

It is highly appreciated the using reinforced layers in supporting metallic parts due to increased performance and formability of the sheets. Firstly, the effect of reinforcing layer will be investigated on the expanding of rings as a benchmark stability problem and then considered when the composite panels undergo the axial and biaxial stretches near instability threshold. In the ring expanding case; process will be explored by the wavelength and wave number changes through the linear perturbation analysis. The linear perturbation or linear stability is established on the elastic-visco-plastic fragmentation of the rings that includes the effect of significant deformation, geometric softening and hydrostatic pressure. Alternately, the vertex model will be used in prediction of localized necking instability that, considers the discontinuity of stress and strain rates inside the neck band. Here, the DYC-angle and quadratic Hill yield criterion help us to predict the localized necking band and consider the anisotropy effect, respectively. Also, the forming limit diagrams will be used for presenting the vertex analysis results. In the vertex theory, the non-linear reinforced layer will be considered among the neo-Hookean materials. Results will be validated with the other theoretical and experimental data available in the literature.

1. Introduction

In recent years, it is strongly considered the study and investigation of the reinforce layer effects on the metals to obtain a more formability. Because it may enhance the performance of the forming limits in the metals under different conditions that can be more important on the costly process and expensive industries. The mentioned structure through damping of vibration, more dissipation of absorbed energy, increase of the surface quality and resistance to scratch and heat can be efficient in the more performance of the structure. In the necking phenomenon, it plays an important role the reinforce - layer and delaying the plastic instability. For example, in the thin metallic sheets which are supported by elastomeric layers, the localized necking occurs in the large strains against the freestanding metal layer. Also, The uniaxial tensile experiments show that a freestanding thin metal film usually bursts at a small strain [10]. By contrast, the plastic-supported thin metal films can sustain a tensile strain, up to 50% before rupture [11]. It is mainly the value of thickness ratio and material properties ratio of metallic sheet and elastomer on the analysis of the metal elastomer structure. Recently, there were studies for investigation of the reinforce - layer effect under different conditions. Xue and Hutchinson studied the roles of the elastomer module as well as the strength and rate of stretching to obtain the necking retardation [12]. Since the polymer-coated metal layers have a necessary ability to undergo the significant plastic deformation before rupture; thus, they hold a potential energy absorbed in the structural elements when being subjected to the high-intensity impulsive loads. Amini and Nemat-Nasser explored the experimental results in the steel plates reinforced with the polyurea to investigate the micromechanical ductile damage [13]. Amirkhizi et al. [14] studied the temperature and rate/ pressure-sensitive constitutive model through the experimental results of the polyuria. Zajkani et al. investigated the reinforce layer effects on the diffuse and localized necking of pre-strained metallic thin sheets [1].

In the investigation of necking phenomenon with the statically loading, the plastic strain analysis is considered. The categories of mentioned studies are based on the preliminary definitions which are presented by considére [2]. Swift, used the considére's assumptions for prediction of the diffuse necking and stated that, in the stability and instability deformations, it has the primary role the strain hardening and decrease of the cross-section, respectively [3].

* Corresponding author.
E-mail address: zajkani@eng.ikiu.ac.ir (A. Zajkani).

https://doi.org/10.1016/j.jmapro.2017.12.026
1526-6125/

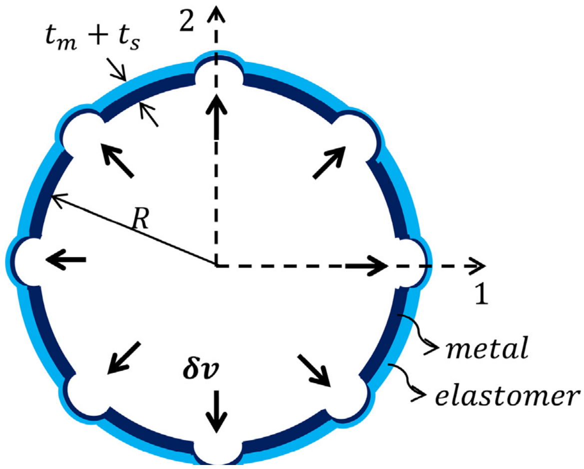

Fig. 1. Fragmentation of the reinforced – supported metal layerwise ring under internal impact loading.

Then, Hora et al. presented the MMFC through the extent of Swift model that includes the best accuracy against the previous models [4]. The diffuse necking is a volumetric deformation. While, in the localized necking, plastic deformation occurs in the thin band of the sheet. The neck gradually develops as the significant extension is still possible after the onset of diffuse necking. Finally, a particular condition will be reached where a sharply localized necking starts to form. In practical cases, the width of the localized necking is an order of the sheet thickness. The first localized necking model has been proposed by Hill [5] based on the assumption that the necking occurs in the direction of layers without extension. Then, Marciniak and Kuczynski [6] introduced the M-K model through experimental studies about the localized strains for the specimen which have initial imperfections under biaxial tensile tests. The M-K model has been based on the thickness reduction and developed by a fundamental defect. Due to an initial fault of the depth, the evolution of the different equivalent plastic strains can be found in the flawless and incomplete zones. Marciniak [7] made a thorough analysis of the strain localization phenomenon from the right-hand-side of the FLD and extended his initial model to cover this area. The M-K model was extended to a negative range of the FLD by Hutchinson and Neale (H–N model) [8]. Stören and Rice [9] described the localized necking through the assumptions that the difference between nominal stress rate components in inside and outside of the necking band is zero. They presented a Vertex model based on J_2 deformation theory of plasticity in the necking band. They used a Hill zeros extension relation for obtaining the necking band angle in left-hand-side of FLD's. Accordingly, the necking band angle is only dependent on the strain ratio. In that study, they assumed that the necking band angle is zero in the right-hand-side of FLD.

Another category of necking exploration that is related to impact loading is named linear perturbation or linear stability [10]. It is usually based on an elastoplastic analysis that is used in the investigation of fragmentation of the ring expansion [10] or other hands, prediction of the necking onset. The linear perturbation is analyzed by creating a small perturb and using the initial and boundary conditions. Indeed, the results are presented as an investigation of wavelength and wave number and the strains and strains rate being related to the initial value. The mentioned model includes the triaxiality and hydrostatic stresses and considers the geometrical softening and material viscoplasticity. Recently, the linear stability was studied as widely for the plane strain and biaxial tensions by Jouve [11,12].

The main target of the present study is investigating the reinforce layers effects on the metallic materials and exploring the stability and instability behaviors at the composite structures under different conditions. It Will be considered the exponential behavior of reinforce - layer as the neo-Hookean elastomers. The effect of strengthening layer will be explored on the ring expansion and tension of sheets. The linear perturbation analysis is used for the development of the rings with the viscoplastic behavior related to impact loading. The mentioned procedure can help us in understanding the perturbation growth rate and the required wave number for the instability or rapture. In the tension of sheets, it is used the vertex model or instability predictor that is based on the discontinuity of strain and stress rates against the continuity of stress and strain on the localized necking band. The DYC-angle will help us in the prediction of the necking bond angle that includes the anisotropy, rate, yield function and other effects. Finally, the results of the vertex theory will be presented by using the forming limit diagrams. In the substrate supported metal layers, it is considered the incompressibility of deformation being regardless of the delamination.

2. Problem formulation

The plastic instability occurs in the more considerable strains at the reinforce-metal structure. Here, it will be investigated the supported metal with the reinforce - layers that have a small elastic modulus of the metal layers. The mentioned structure will be studied for both fragmentations of the ring expansion and localized necking. For more discussion about the composite structure of the metal- elastomer, we can point out that this structure can be used as another application for dilatation of the plastic instability through a supporting layer for the following reasons:

- Raising surface quality as a primary parameter in the metals that are exposed to tension. This case can potentially cause the fracture accelerating by connecting the first surface voids. So, the elastomeric layers are capable of the filling the initial voids being on the metal surface.
- Scratch resistance.
- Larger dissipating energy of the structures.

Therefore, selecting the material type along with layer thickness will be significant. For the reinforced metal layer that is studied in this work, it is assumed the equality of the metal and elastomer strains and the incompressible deformation. Also, the delamination is disregarded.

2.1. Linear perturbation analysis

The fragmentation is an important material failure mode in high-velocity impacts. In the investigation of fragmentation, it will be assumed that the ring expansion is equal to the tension of a bar. According to the Fig. 1, for the bilayer ring with radius R and thickness, we can be assumed the bar with cross-section and length as $A_0 = \pi r_0^2$, $L = 2\pi R$. In the ring expansion analysis through linear perturbation, it is considered that the impact is equivalent to the small perturbation as δv. Namely, all the mechanical variables are functions of the Lagrangian coordinate X along the bar and of time. So, the true strain is given by:

$$\varepsilon(X, t) = ln\left(\frac{\partial x}{\partial X}\right)_t \quad (1)$$