VOL. 8, NO. 8, AUGUST 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

FINITE ELEMENT ANALYSIS OF FORMING LIMITS FOR STRETCH FORMING OF PERFORATED ALUMINIUM SHEET METALS

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ABSTRACT

Stretch forming is one of the sheet metal forming process in which sheets are stretched to get the required shape. Formability of sheet metal is its ability to form when it is subjected to cold working process. Formability of a sheet metal is measured by Forming Limit Diagram (FLD/FLC). The limiting or failure strains in sheet metal forming are best represented by a forming limit curve which indicates the onset of necking over all possible combinations of strains in the plane. An attempt is made here to simulate the stretch forming of perforated sheet metals thereby studying its limiting strain. The uniaxial stretching and biaxial stretching are performed to get forming limit diagram. The influence of open area, and hole shape on FLD are studied. Perforated sheet is modelled with finite element method by using commercial FEA software ANSYS to calculate the major strain, minor strain and failure load for both uniaxial stretching and biaxial stretching of perforated sheet metal. It has been found that increasing in open area reduces the limiting major and minor strain. It has also been studied the influence of hole shape and punch shape on limiting major and minor strain.

Keywords: forming limit diagram, FEA, limiting strain, perforated sheet metal and open area.

INTRODUCTION

Stretch forming is a process of forming sheets and profiles by application of both tensile and bending forces. As the punch is pushed into the sheet, tensile forces are generated at the centre. Stretch forming operations are extensively used for aerospace industry and train skin parts. A stretch part has shape control because the metal has undergone strain hardening. The main advantage of this process is that there will not lie any wrinkling or spring backs.

Perforated sheet metals find its applications in various fields due to its versatile and ease in handling. They play major role in industry, architecture, designing, acoustic etc. because of its aesthetic features. The limiting strains for perforated sheets depend on hole size, hole shape, hole pattern, ligament ratio, open area, material properties, tool geometry and type of loading. Plastic behaviour of perforated sheet depends mainly on hole size, hole shape and hole arrangement. The concept of equivalent solid material is widely used for design analyses of perforated materials. The formability of the perforated sheet metal is defined by the curve known as forming limit curve (FLC/FLD). Forming limit diagrams indicate the limiting strains that sheet metal can sustain over a wide range of major to minor strains.

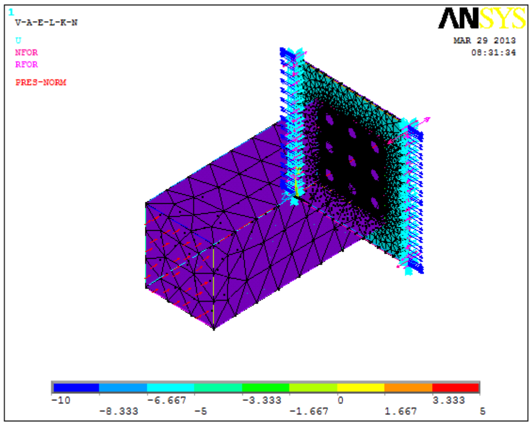
Literature review

The origin of analysis of forming limit was started in 1940s. The first presentation was similar to forming limit diagram published by Gansamer [1] in 1946. Swift [2] and Hill [3] have predicted the onset of diffuse and localized necks, respectively, by means of elementary theories. The forming limit diagram which is known today was developed by Keeler [4] in 1964. Keeler was the first who realised the possibility to show FLC for sheet metals in coordinate system of two main strains. But it was only limited for right side of contemporary known FLD. Later Goodwin [5] at the end of 1960s completed the diagram in the left side. Marciniak and Kuczynski (M-K) [6] have introduced pre-existing in homogeneity in the sheet and enabled the calculation of the development of a localized neck in stretching region. At the beginning of 1990s, the FEA practical application was introduced for solving problems of sheet metal forming. Takuda *et al.* [7] investigated a criterion for ductile fracture to predict the limit strains in biaxial stretching combined with finite element simulation. Chen and Lee [8] analyzed the plastic deformation of perforated sheets with non-uniform circular holes in thickness direction arranged in triangular pattern by equivalent continuum approach. Chen [9] investigated the plastic deformation of sheet metals with circular perforations in a hexagonal pattern. In this investigation, the equivalent-continuum approach has been employed to develop a theoretical model for the global analysis, which includes defining a yield criterion and the associated flow rules in terms of apparent stresses and apparent strains. Baik *et al.* [10] proposed a model which can predict apparent limit strains of the perforated sheets of varied hole size along thickness direction. Venkatachalam *et al.* [11] probed stress strain relations in the plastic zone and also investigated the effective yield stress and effective stiffness of perforated sheet metals with square and hexagonal holes using finite element method (FEM). Venkatachalam *et al.* [12] studied the limiting strain for the circular holes which are arranged in square and triangular pattern. Limiting strains of these sheets were found out using Finite Element Analysis. Elangovan *et al.* [13] predicted the forming limit diagram of perforated sheets by employing artificial neural network (ANN) technique. Venkatachalam *et al.* [14] proposed the forming limits for perforated sheets by calculating negative minor strain based on ductile fracture criterion. Venkatachalam *et al.* [15] studied the formability of triangular pattern of square hole perforated commercial pure aluminium sheets by using finite element method. Venkatachalam *et al*. [16] proposed the limiting strains for square pattern with square hole for perforated aluminium sheets. Venkatachalam *et al*. [17] probed forming limit diagram for perforated Aluminium 1050A sheets by drawing process with experimental set-up.

Modelling

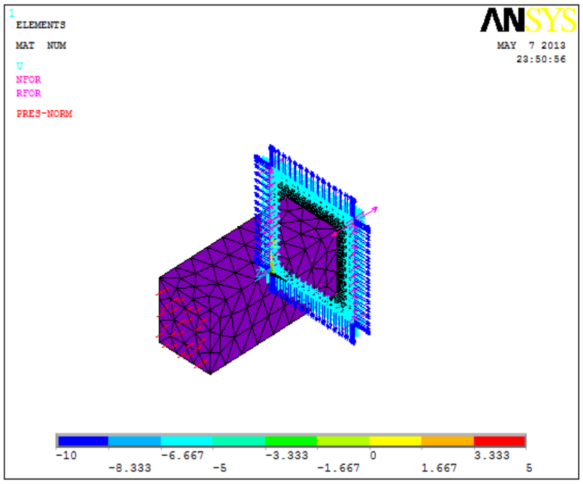
A perforated sheet of aluminium with dimension 100 mm*100 mm*1.5 mm is taken for the analysis. First set of analysis deals the sheets with circular holes of different open areas. The open areas considered here are 0%, 1.57%, 3.14%, 4.71% and 7.06%. Different hole shapes are considered in the second set. There are three types of hole shapes i.e., circular holes, triangular holes, and slot holes are considered in this paper. Influence of punch shape is considered in the third set of analysis. Square punch, elliptical punch and hemispherical punch are taken for the analysis. For uniaxial stretching, a tensile load is applied to stretch the sheet metal in longitudinal direction. For biaxial stretching, tensile loads in both longitudinal and transverse direction are applied. For designing of sheet metal, element Solid 185 is used which has three degree of freedom and for designing of punch brick 8 node Solid 45 is used. The plastic property of the material follows the power law flow rule i.e., $\sigma = K\varepsilon^n$ where σ, K, ε and n are stress developed, strength coefficient, strain and strain hardening exponent respectively. The value of strength coefficient and strain hardening exponent are 173.79 MPa and 0.304, respectively. The surface to surface flexible contact is given between sheet and punch. The CONTA 174 and TARGE 170 are used to define the surface to surface contact.

RESULTS AND DISCUSSIONS



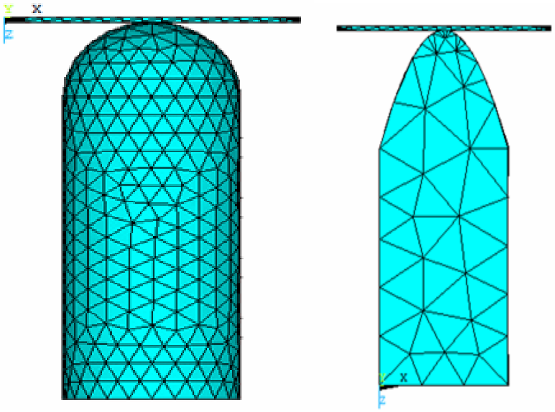
(a)

Figure-1 (a). Loading and boundary conditions for uniaxial stretching with square punch.



(b)

Figure-1 (b). Loading and boundary conditions for biaxial stretching with square punch.



(a) (b)

Figure-2 (a) and (b). Meshing of hemispherical and elliptical punch with sheet.

Figures 1 (a) and (b) show the boundary and loading conditions for the uniaxial stretching and biaxial stretching of sheet metal with square punch. The load is applied on the square punch due to which the sheet metals deform. The limiting major and minor strains are calculated for uniaxial stretching and biaxial stretching of sheet metals. Figure-3 presents comparison of the failure load versus open area for uniaxial stretching with square punch with the circular, slot and triangular holes shapes. The effective strength of the material is reduced by the presence of holes in perforated sheet metals. When the percentage of open area increases, the effective strength decreases. Figures 4 and 5 show the comparison of major strain and minor strain versus open area for circular, slot and triangular holes for uniaxial stretching of sheet with square punch. The decrease in the effective strength of sheet metals, because of the presence of holes, decreases the limiting strains. There is a large difference in the values of limiting strains between continuum sheet metal (i.e., 0% open area) and perforated sheet metals. Stress concentration is more in case of triangular hole perforated sheets. This is because of the presence of sharp corners in triangular holes. Hence the major and minor strains for triangular holes are less compared to circular and slot holes. Figures 6 and 7 illustrate the major and minor strains versus punch shape for uniaxial stretching of sheet with circular holes with open area of 3.14%. Same load is applied on all types of punches used i.e., square, elliptical and hemispherical. During the initial period, square, elliptical and hemispherical punches will have surface, line and point contacts with sheet metals respectively. Because of the surface contact with sheet metal, limiting strain is more for square punches as the load is distributed, Figure-8 shows the major strain versus minor strain for different percentage of open area and with different dimension of sheets. Both uniaxial and biaxial stretch forming is simulated for the same. It gives the forming limit diagram (FLD) for perforated aluminium sheet metals. The height of the forming limit curve is more for less percentage of open area with large sheet dimensions. The height of the forming limit curve decreases when percentage of open area increases.

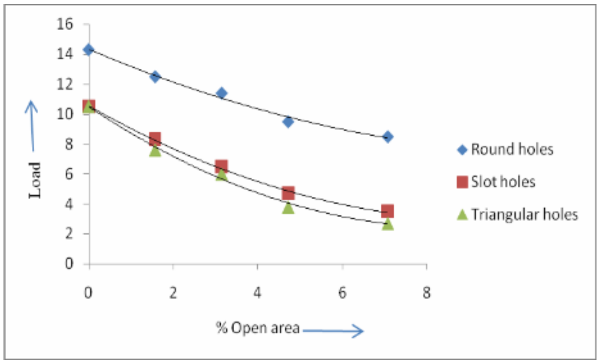


Figure-3. Failure load versus open area for uniaxial stretching with square punch with the circular, slot and triangular holes shapes.

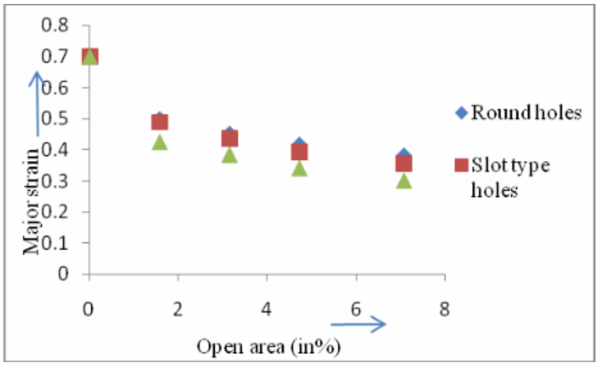


Figure-4. Major strains versus open area for circular, slot, and triangular holes for uniaxial stretching of sheet with square punch.

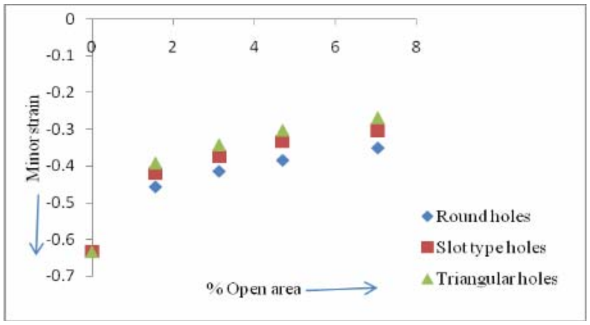


Figure-5. Minor strains versus open area for circular, slot, and triangular holes for uniaxial stretching of sheet with square punch.

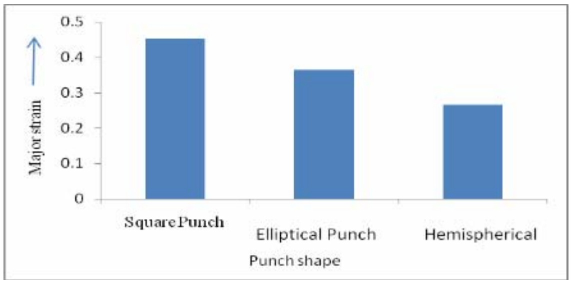


Figure-6. Major strains versus punch shape for uniaxial stretching of sheet with circular holes and constant open area (3.14%).

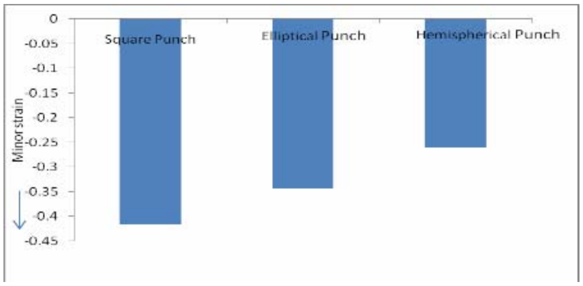


Figure-7. Minor strains versus punch shape for uniaxial stretching of sheet with circular holes and constant open area (3.14%).

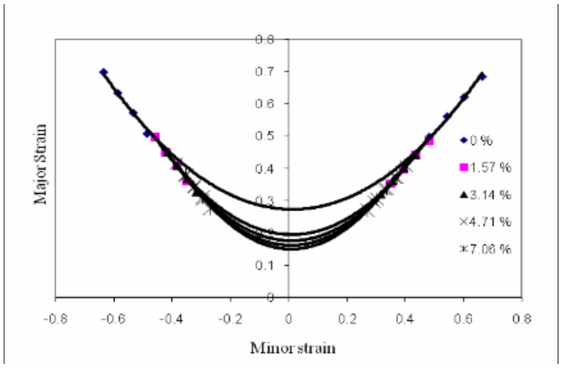


Figure-8. Major strains versus minor strains (FLD) for different percentage of open areas under uniaxial and biaxial stretching of circular holes sheet.

CONCLUSIONS

Aluminium perforated sheets of circular, triangular, and slot type holes with straight line pattern are modelled in this work. The limiting major and minor strains are calculated for stretch forming of perforated sheets for different open areas. It has been found that limiting strain decreases when open area increases. The sheets with circular holes exhibit more major and minor strains compared to triangular and slot type holes. The hemispherical punch produced more stresses as compared to square punch and elliptical punch shape and hence its limiting strains are less compared to the square punch and elliptical punch. The FLD is drawn for different open areas. The formability decreases when sheet area decreases. The results obtained in this work would be very useful in the design of perforated sheet metals undergoing stretch forming operations.

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