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A FINITE ELEMENT METHOD BASED FORMABILITY ANALYSIS OF TRIANGULAR PATTERN OF SQUARE HOLE PERFORATED COMMERCIAL PURE ALUMINIUM SHEETS

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ABSTRACT

Limiting strain is the strain at the onset of fracture / necking in a sheet metal. This limiting strain varies with respect to the material / condition of the material, strain condition in geometrical features of a sheet metal. In conventional sheet forming, the solid sheets posses higher limiting strain compared to that of perforated sheets. Perforated sheets find increased applications due to their reduced weight, versatility and aesthetic appearances. In this work, triangular pattern – square holed, perforated commercial aluminium sheets of various thicknesses are considered for the study. The limiting strain for the above sheet metals is predicted using Finite Element Analysis. It is found that the limiting strain is influenced by percentage of open area, ligament ratio, hole size and thickness.

Key words: Finite element aanlysis, Ligament ratio, Open area, Thickness and hole size.

1. INTRODUCTION

The attractiveness and versatility, in both form and function of perforated sheet metals increase their use in engineering applications. Some of the components made from perforated sheet metals are ceilings, walls, conduits, stairways, acoustical surfaces, electrical apparatus, furniture (IPA hand book, 1993) and the rapid growth in the use of perforated sheet metals materials, both in industrial and domestic, lead the researchers to study their formability. Perforated sheet metals, made from Aluminium, are very versatile because of their light weight construction.

Forming Limit Diagram (FLD) is used in sheet metal forming for studying forming behaviour of sheet metal. The prediction of the FLD of sheet metals is of great importance especially for analyzing the plastic instabilities and determining the limits of possible deformations in component design. The FLD, firstly introduced by Keeler (1965) and Goodwin (1968), represents the local limit strains of the sheet metal in the principal strain coordinates. In industrial practice, different tests like Erichsen, Nakazima tests are used to predict the FLD. There are many factors which govern these tests. Since the interpretation of these tests are complex, tensile tests on sheet specimens have been reported in the literature to study the negative minor strain region of the FLD (Kleemola and Kumpulainen, 1980, Priadi et al., 1992 and Holmberg et al., 2004). Priadi et al. (1992) studied the FLD through testing procedures that avoid any friction problem and it was found that central necking in some specimens is obtained for strain values that are well below the standard FLD used in industrial practice. Holmberg et al. (2004) outlined a test procedure for determining the complete left-hand side of the Forming Limit Curve (FLC) by tensile tests. Lian and Baudelet (1987) focussed on the analysis of Hill's zero-extension direction and re-examined the FLD in the negative minor strain region.

The proper design and manufacture of perforated sheet metals require its characterization of the plastic deformation. Chen (1993) 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. Venkatachalam et al. (2011) 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. Baik et al. (1995) have proposed a model which can predict apparent limit strains of the perforated sheets of varied hole size along thickness direction. The FLD of the perforated sheet calculated by the model gives a reasonable lower bound solution of the forming limits. Baik et al. (1997) proposed a yield criterion of sheets with a uniform triangular pattern of round holes in the whole range of ligament efficiencies. Baik et al. (2000) proposed a yield criterion for sheets with slot-type holes used in shadow mask under biaxial loading in terms of apparent stresses and confirmed it by FEM. Lee and Chen (2000) investigated the plastic behavior of perforated sheet with round holes in a triangular pattern with low ligament ratio and proposed a yield criterion for the perforated sheets in terms of apparent stresses by employing the equivalent-continuum approach. Elangovan et al. (2010) studied the forming limits of commercial pure aluminium perforated sheets with round holes of triangular pattern. They developed a model based on Artificial Neural Network which uses the different geometric features. Venkatachalam et al. (2012)

investigated the limiting strains for (square pattern) square hole perforated commercial pure aluminium sheets. Ghazali et al. (2007) studied the plastic deformation of aluminium A2124 and A6092 alloys. Gunawan (2011) proposed a new method to indentify the parameters of a simple viscoelastic model and the method was based on coupling of finite element analysis and inverse analysis. Ali et al. (2011) used the finite element method to evaluate charpy impact signals using power spectrum densities and measured the strain on the striker. Fadhil (2012) developed a 3D finite element model for ballistic impact on ceramic targets with three different thicknesses. In all the works discussed above, limiting strains have been predicted or found out experimentally for different strain conditions. An attempt is made in this work to study the influence of open area, ligament ratio, hole size and thickness on limiting strain using Finite Element Method.

Perforated sheet metals with square holes are used in many applications such as balustrade infill, acoustics, security screens, air-condition units, radiator covers, screening, and display units and hence perforated sheets, made of commercial pure aluminium, with square holes in triangular pattern are considered for the analysis. In this work, uniaxial tensile test on perforated sheet is carried out and hence the work is focussed to predict the limiting strain of perforated sheet under this condition. Finite Element Method is used for the analysis and commercial finite element analysis software ABAQUS is used for the same. The parameters, considered here, are percentage of open area, ligament ratio, hole sizes and thickness of the sheets. The analysis was carried out varying one parameter and keeping other parameters same.

2. MODELING

Perforated sheets of 200 mm x 200 mm, 200 mm x 180 mm, 200 mm x 160 mm and 200 mm x 140 mm were taken for the analysis the sample of which is shown in figure 1(a). The commercial pure aluminium was considered and its Young's modulus and Poisson's ratio are 70GPa and 0.33 respectively. 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 values of K and n are 173.79 MPa and 0.304 respectively. Uniaxial tensile load was applied on the specimen. 8-node linear brick element was used. Minor and major strains were found out and from that limiting strains were plotted in the negative minor strain region. Experiment was also conducted to validate the results obtained from Finite Element Analysis. Uniaxial tension test was conducted using electronic tensometer for different open areas to find the failure strain. ASTM-E8 standard was used for the same. The setup for the same is shown in Figure 2.

Firstly perforated sheets, triangular pattern of square holes, were modeled based on varying open areas. The ligament ratio, thickness and hole sizes were maintained as 0.375, 1.6 mm and 10 mm, respectively. The open areas considered were 0%, 5%, 10%, 15%, 20% and 25%. The second set of models was drawn based on varying ligament ratio. Ligament ratios of 0.375, 0.444, 0.5 and 0.546 were taken for the analysis. The thickness, hole sizes and open area were maintained as 1.6 mm, 10 mm and 15% respectively. In the third set of modeling, hole size was varied. The hole sizes taken for the modeling were 10 mm, 16 mm and 20 mm. The thickness, ligament ratio and open area were kept as 1.6 mm, 0.2 and 15% respectively. Thickness was varied in the last set of modeling from 0.8 mm to 2 mm. The hole size, ligament ratio and open area were kept as 10 mm, 0.5 and 15%, respectively.

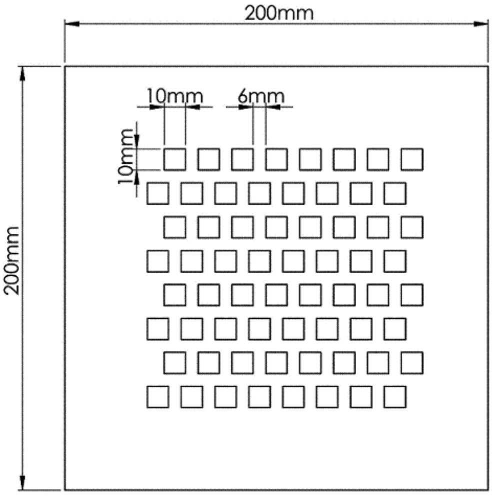

Figure 1(a) Commercial pure Aluminium sheet with 10 mm square hole, 0.5 µ, 15% open area and 1.6 mm thickness.

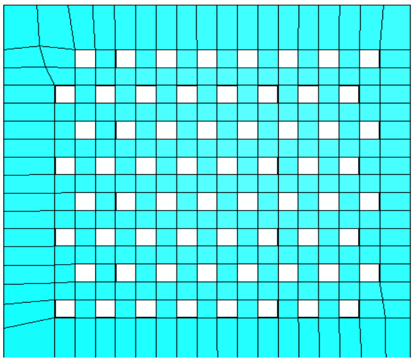

Figure 1(b) Finite element meshing.

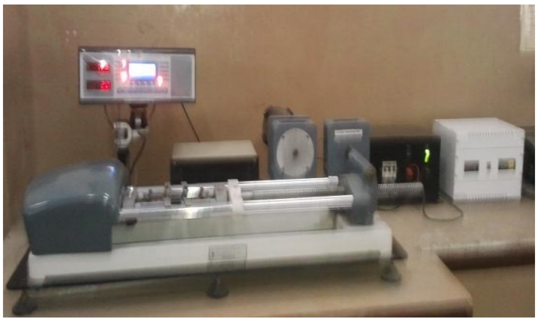

Figure 2 Electronic tensometer used for uniaxial tension test.

3. RESULTS & DISCUSSION

Figure 1 (b) shows the finite element meshing of the perforated sheet metal shown in figure 1(a). 8 node linear brick element is used which accommodates 3 degrees of freedom. There are 684 nodes and 242 elements used in this model. Mesh optimization study was done to find the optimum size of the mesh.

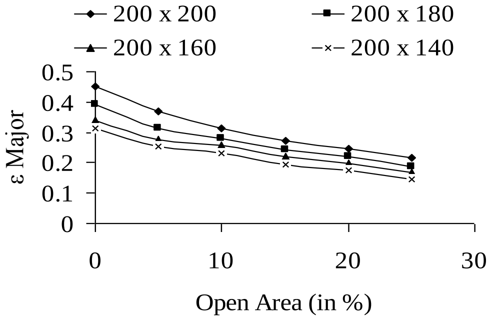

Figure 3(a) Limiting major strain vs open area.

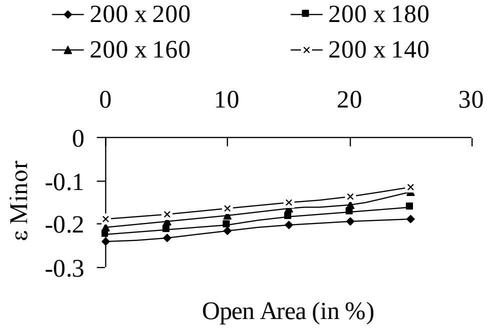

Figure 3(b) Limiting minor strain vs open area.

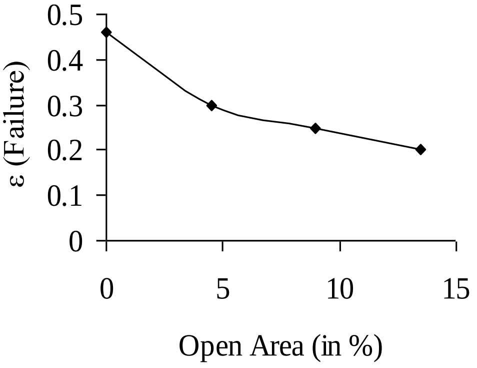

Figure 3(c) Failure strain vs open area.

Figure 3(a) gives the limiting major strains of sheet metals for different open areas. 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. 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. But the difference in the limiting strains of sheets with holes is modest. The same behaviour is observed in figure 3(c). The figure 3(c) presents failure strain for different open areas under uniaxial tension test conducted using electronic tensometer. Figures 3(a) and 3(c) compare the results obtained from finite element analysis and experimental analysis. The influence of holes on limiting minor strains is shown in figure 3(b). Figures 3(a) and 3(b) are results from finite element analysis and figure 3(c) is the experimental analysis.

Figures 4(a) and 4(b) present the influence of ligament ratio on limiting major and minor strains respectively. Ligament ratio is the ratio of ligament width to perforation pitch. Ligament width is the distance between the boundaries of two successive holes where as the perforation pitch is the distance between centre points of two successive holes. As the hole size is kept constant, the distance between boundaries of two successive holes increases with an increase in ligament ratio. The sheets with higher ligament width contracts more than the sheets with lower ligament width along the transverse direction under uniaxial tension which in turn reduces the limiting strain for sheets with high ligament ratio. Hence the limiting strain decreases when the ligament ratio increases. The influence of the ligament ratio in the findings of limiting strain is in accordance with Baik et al. (1996).

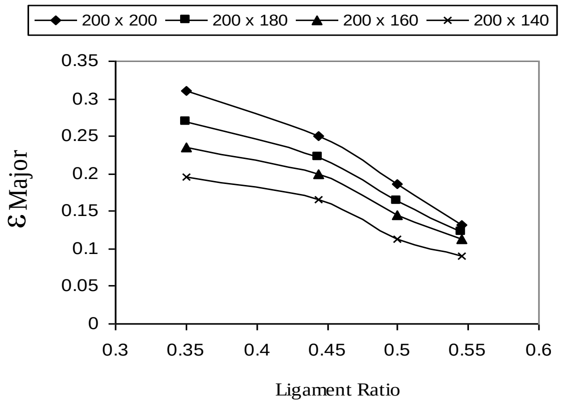

Figure 4(a) Influence of ligament ratio on limiting major strain.

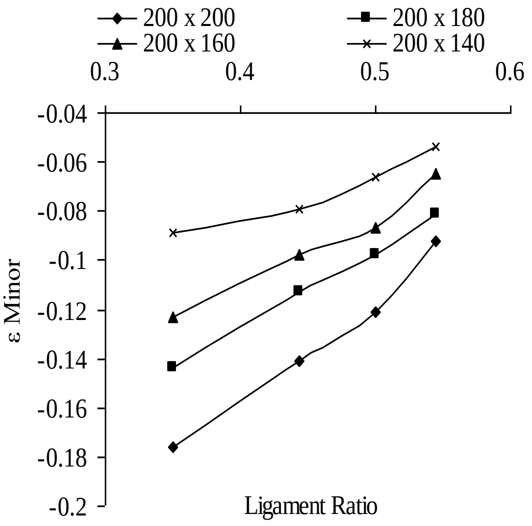

Figure 4(b) Influence of ligament ratio on limiting minor strain.

Figures 5(a) and 5(b) provide the control of hole size on limiting strain. As the percentage of open area is kept constant, sheets with smaller size holes has more number of holes than that of sheets with larger size holes. Presence of more number of holes in sheets with smaller size holes decreases its effective strength and hence the limiting strain decreases with hole sizes. Perforated sheets of smaller holes will reach the unsafe (failure) zones faster than that of larger holes. Figures 6(a) and 6(b) give the limiting strains by varying the thickness of perforated sheet metals. It is evident from figures that limiting strain decreases when sheet thickness decreases. Higher the thickness, then higher limiting strains.

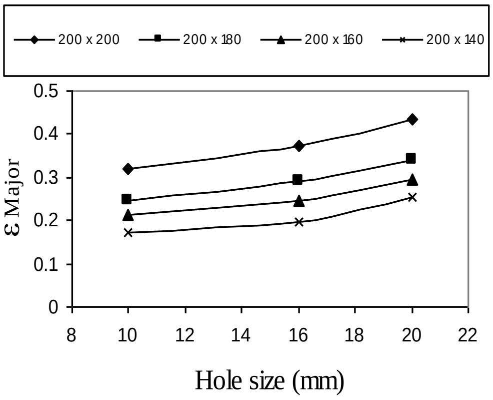

Figure 5(a) Limiting major strain vs hole size.

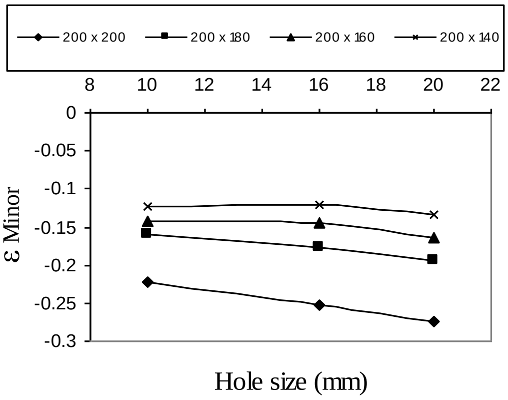

Figure 5(b) Limiting minor strain vs hole size.

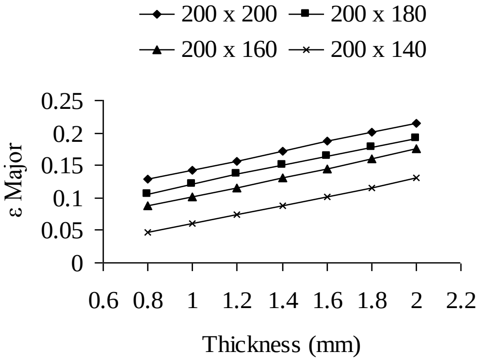

Figure 6(a) Influence of thickness on limiting major strain.

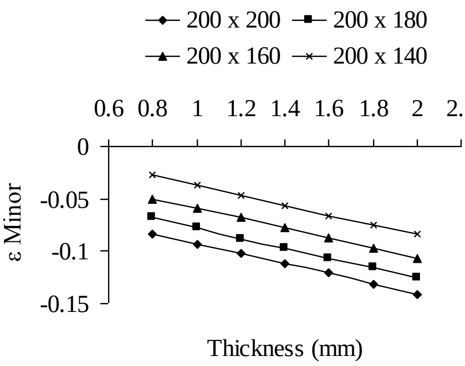

Figure 6(b) Influence of thickness on limiting minor strain.

4. CONCLUSION

Commercial pure Aluminium perforated sheets of square holes with triangular pattern were modeled in this work. Limiting strains of these sheets were found out using Finite Element Analysis. The influence of open area, ligament ratio, hole size and thickness of sheets on limiting strains are studied. In the case of open area, the results obtained from FE analysis is confirmed with experimental results. It has also been found that limiting strain decreases when open area and ligament ratio increase whereas it increases when hole size and thickness increase. The results obtained in this work are very useful in the design of perforated sheet metals. Also the results are useful for the perforated sheet metal forming industry working aluminium sheets.

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