PERFORATED ALUMINIUM SHEET FORMING SIMULATION USING PAMSTAMP

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ABSTRACT: Sheet metal forming is a huge market with a major share going to the consumer and automobile sector. Sheet metal is normally formed and only then piercings if any are done. These piercings if on a complicated form are very difficult to perform and very expensive tooling with cams are needed. This study aims at studying the forming limit of different perforation sizes (diameter 6, 8 &10), open area % (5, 10 & 15) and ligament ratios (0.3, 0.4 & 0.5) on 1.0 mm commercially pure Aluminium sheet metal. The standard Limiting height dome test was used to determine the limiting dome height before the onset of the crack and the corresponding limiting minor and major strains and limiting minor and major stresses were found.

KEY WORDS: PAMSTAMP, perforated sheet metal forming FEA, Aluminium perforated sheet FEA.

1 INTRODUCTION

In sheet metal forming, a sheet blank that has a simple shape is plastically formed between punch and die, to obtain a part with relatively complex geometry with desired tolerances and properties. Sheet metal forming processes usually produce little scrap and generate the final part geometry in a very short time, usually in one stroke or a few strokes of a press. As a result, sheet forming offers potential savings in energy and material, especially in medium and large production quantities, where tool costs can be easily amortized.

The ever-increasing costs of material, energy and manpower require that sheet metal forming processes and tooling be designed and developed with minimum amount of trial and error with shortest possible lead times. Therefore, to remain competitive, the cost-effective application of computer-aided technologies, i.e. CAD, CAM, CAE, and especially finite element analysis (FEA), computer-based simulation is an absolute necessity.

Until recently, the design of metal forming tools was based mainly on knowledge gained through experience and expensive trial- and-error processes. However, today the metal forming industry is making use of finite-element methods even in the early stages of die and process design.

The emerging role of modelling and simulation can be explained by the growing competition in the world market that requires shorter lead times and cost-effective solutions while developing a new design of process and product.

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2 LITERATURE SURVEY

Sheet forming [1] comprises of deformation processes in which a metal blank is shaped by tools or dies, primarily under the action of tensile stresses. The design and control of such processes depend on the characteristics of the work piece material, the conditions at the tool / work piece interface, the mechanics of plastic deformation (metal flow), the equipment used and the finished product requirements. These factors influence the selection of tool geometry and material as well as processing conditions (work piece, tooling temperature, lubrication, etc.). Due to the complexity of many sheet forming operations, models of various types such as Analytics, physical or numerical models are often relied on to design such processes.

Ravikumar (2002) in his work [2], determined the Forming limit diagrams (FLD) by conducting punch stretching experiments on Aluminium killed extra deep drawing low carbon steel sheets of varying thickness. Venkatachalam et al (2010) [3], investigated the significance of 3 parameters namely, blank temperature, die arc radius and punch velocity on the deep drawing characteristics of Aluminium 7075 sheets. They concluded that the blank temperature had the most significant impact of the three factors.

Talic et al (2006) in their paper [4], studied the effects of friction on the deep drawing process. They concluded that the increase in friction coefficient between working surfaces of tool and the blank leads to the increase of the deformation force. PAMSTAMP was used successfully to simulate the deep drawing process effectively and accurately. Sivanandini et al (2012) in their paper [5], studied the effect of temperature and thickness of Magnesium alloy ZW41 sheets on the formability. They concluded that the formability improved with the increase in temperature.

Makinouchi (1996) in his paper [6], outlined broadly the use of finite element simulation as used in the industry. He stated that each industry has its own purpose of using the Finite element simulations such as prediction of wrinkle, prediction of surface defects, study of tearing limit conditions, determination of blank geometry, prediction of spring back, evaluation of sheet thickness and residual stress and so on. Piete et al (2010) in their paper [7], studied the spring back response on a stamped part, calculated by FEA.

Shridhar Kumar et al (2015) in their work [8], studied the explicit nonlinear behaviour of sheet metal forming utilizing the FEA software LSDYNA. Solfronk et al (2011) in their paper [9], studied the effect of blank holder force on the drawing of Aluminium alloys using PAMSTAMP 2G.

Farsi et al (2011) in their work [10], studied Bending force and spring back in V-bending of perforated sheet metal components. They studied about bending forces and spring back on two thicknesses of 0.75mm and 0.95mm Low carbon steel. Oblong holes were used as perforations. The influence of area of holes, die angles, die width and punch radius on the value of spring back and bending force was studied. Venkatachalam et al (2016) in their work [11], studied the forming behaviour of square holes in mild steel perforated sheet metal using the FEA software LSDYNA. They studied the effects of perforation parameters such as hole size, open area and thickness on the formability.

Venkachalam et al (2016) in their work [12], studied the influence of geometric parameters in drawing of perforated sheet metal. They investigated the effect of parameters such as hole size, shape and pattern, ligament ratio, thickness of blank, percentage of open area on the formability of the sheets. Elangovan et al (2010) in their work [13], used Taguchi approach to investigate the formability of perforated Al 8011 sheets. They used 1mm thick Al8011 sheets with varying diameter holes and ligament width to study the forming limit strains. Perforation diameters of 3, 4 and 5mm and ligament width of 5, 7.5 and 10mm were used.

Venkatachalam et al (2013) in their work [14], studied the forming limit diagrams of perforated Aluminium 1050A sheets. They studied the influence of percentage of open area, hole size and hole arrangement pattern on the FLD. Venkatachalam et al (2012) in their work [15] studied the spring back of V-bending of perforated sheet metal. They studied the influence of hole size, hole shape and hole pattern on spring back of a V-bending die.

Venkatachalam et al (2013) in their work [16], studied the forming limits for stretch forming of perforated Aluminium sheet metal. They used ANSYS to calculate the major strain, minor strain and failure load for both uniaxial stretching and biaxial stretching of perforated sheet metal. They studied the influence of hole shape on limiting major and minor strain.

AlaHijazi et al (2004) in their work [17], studied the forming limit diagram for Aluminium 2024 using the PAMSTAMP 2G software and compared the results with experimental simulations on a test rig. They used 0.8 and 1.25mm sheets and used different lubricating conditions.

3 METHODOLOGY

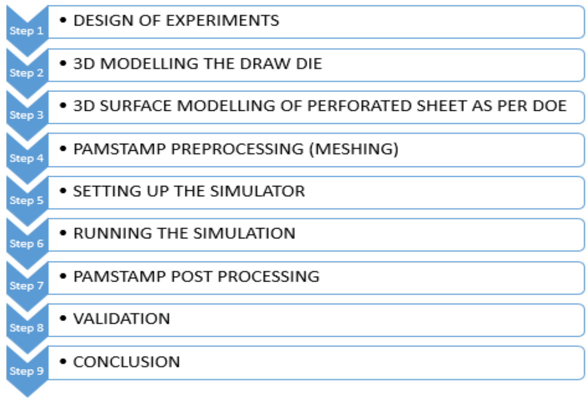

Figure 1. Process flow chart.

Figure 1 shows the methodology adopted in this work. Design of experiments (DOE) Taguchi L9 Array was used to formulate the experiments. Three factors namely, hole size, % open area and ligament ratio were used at 3 levels each as shown in table 1.

Table 1. Design of Experiments

Exp. No.	Hole Diameter	Open Area	Ligament Ratio
1	6	5	0.3
2	6	10	0.4
3	6	15	0.5
4	**8**	5	0.4
5	**8**	10	0.5
6	**8**	15	0.3
7	10	5	0.5
8	10	10	0.3
9	10	15	0.4

Perforated sheet metal and die modelling: SOLIDWORKS was used to model the 9 blanks as per the DOE. The blanks were modelled in 3D using surfaces. It is very important that we model using zero thickness surface, the thickness of the blank will be given as input in the PAMSTAMP 2G module. Similarly the draw die is also modelled as a zero thickness surface in SOLIDWORKS.

PROCESSING IN PAMSTAMP: The first step is to import the CAD geometry into the software and to mesh the same. A very fine mesh of 0.1mm was used to mesh the die and the perforated sheet. This was necessary since the holes were closely placed and the gap between them was also very less. The fine mesh was necessary to capture the small web more effectively.

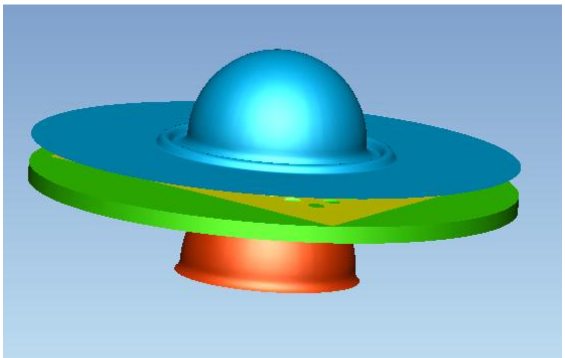

Figure 2. Setup of the case in PAMSTAMP

Sequence of operation:

- Import the cad surfaces in to the deck and mesh the surfaces.
- Identify, select and name the parts, namely, the component, the punch, the die and the blank holder and blank.
- Select the type of operation in our case it is - Single action Stamping.
- Indicate the direction of the placement of blank holder.
- Indicate stamping direction.
- Select the blank material and specify the properties.
- Specify the stroke of the punch.
- Specify the Draw force.
- Fire the case.
- Extract the results using the post processing tool.

3.1 Validation of Simulation

The work done by AlaHijazi [27] was used for validation of the Pamstamp simulation. 1.25mm thick Aluminium 2024-O sheet was used for the simulation in PAMSTAMP. Figure 3. shows the FLD plot for wax lubrication condition as simulated in PAMSTAMP 2G. Figure 4 shows the FLD plot for no lube dry condition as simulated in PAMSTAMP 2G. Figure 5 shows the FLD plot of (AlaHijazi [27]).

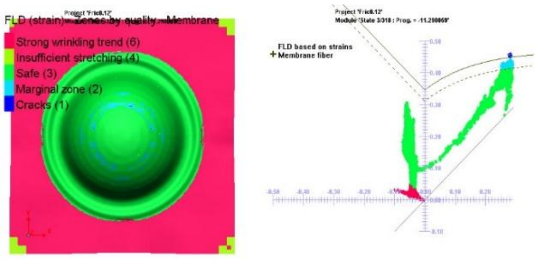

Figure 3. Validated FLD using PAMSTAMP (friction coefficient 0.12 – lubricated condition).

The results of wax lubricated forming FLD (blue plot) and the dry no lube forming plot (orange plot) match with the PAMSTAMP simulation. From this one can infer that the perforated hole simulations done on PAMSTAMP are validated. A full width specimen was used for the simulation.

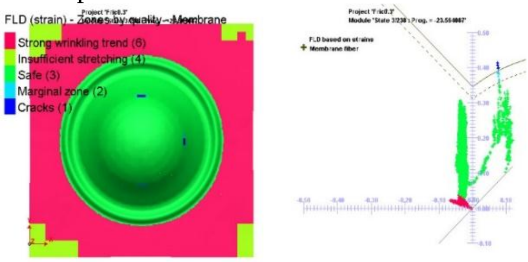

Figure 4. Validated FLD using PAMSTAMP (friction coefficient 0.3- dry condition)

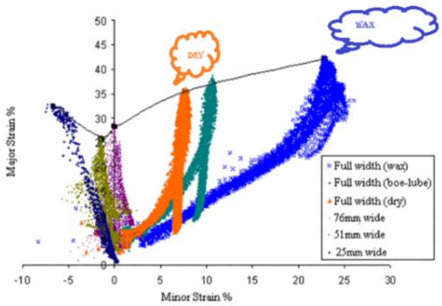

Figure 5. FLD used for validation from AlaHijazi et al 2004 [27] Experiment

4 RESULTS AND DISCUSSION

4.1 Pamstamp Results

4.1.1 FLD strain – zones by quality

Figures 6-14 show the FLD Strain plots for the 9 perforated sheets as per the DOE.

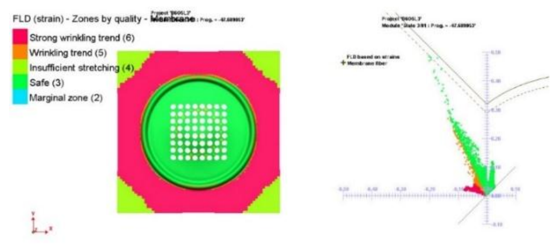

Figure 6. FLD Strain D6O5L0.3

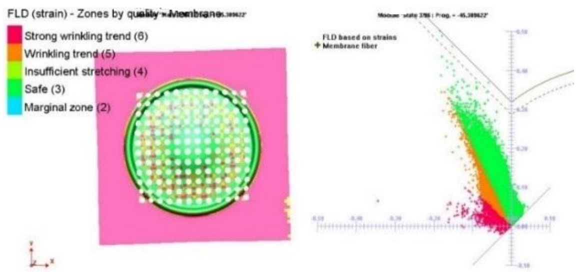

Figure 7. FLD Strain D6O10L0.4

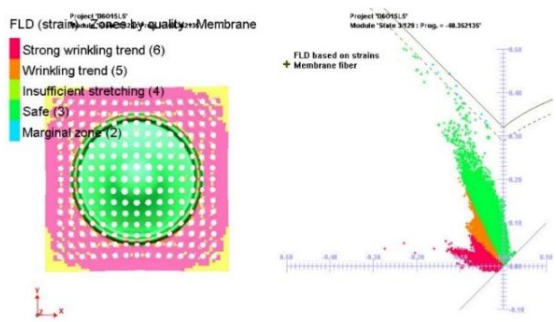

Figure 8. FLD Strain D6O15L0.5.

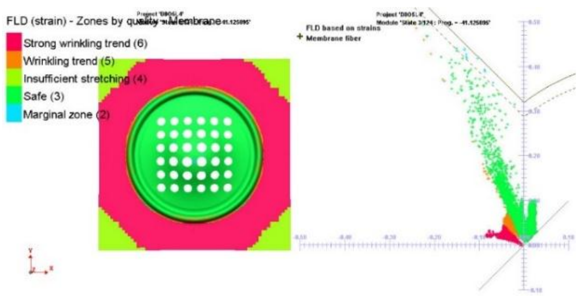

Figure 9. FLD Strain D8O5L0.4

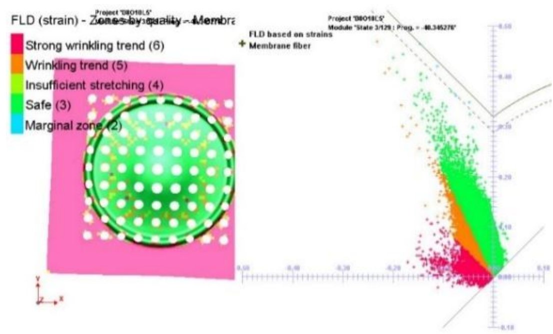

Figure 10. FLD Strain D8O10L0.5.

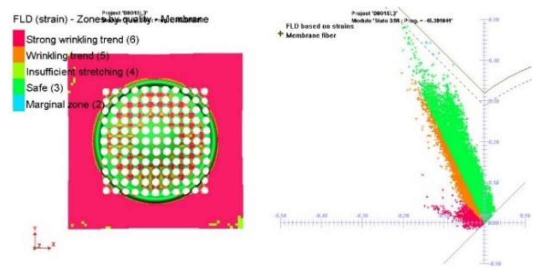

Figure 11. FLD Strain D8O15L0.3

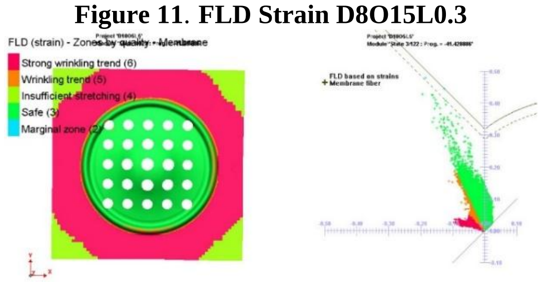

Figure 12. FLD Strain D10O5L0.5

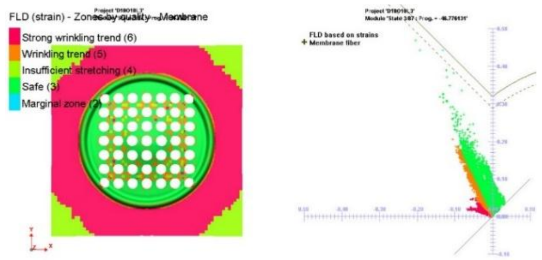

Figure 13. FLD Strain D10O10L0.3

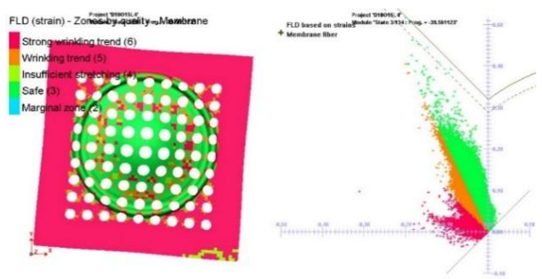

Figure 14. FLD Strain D10O15L0.4

4.1.2 Limiting dome height

Table 2. Limiting dome height.

Hole Diameter (mm)	Open Area %	Ligament Ratio	Limiting Dome Height (mm)
6	5	0.3	12.21
6	10	0.4	14.51
6	15	0.5	19.55
8	5	0.4	18.78
8	10	0.5	18.32
8	15	0.3	14.51
10	5	0.5	18.47
10	10	0.3	13.12
10	15	0.4	20.34

Table 2 lists out the limiting dome heights for the 9 samples. The hole diameter and the ligament ratio are the major factors influencing the limiting dome height. As the hole size increases so does the limiting dome height. Similarly as the ligament ratio increases so does the limiting dome height. For a larger open area the holes are seen to go out of the draw area and so don't seem to influence the limiting height when out of the draw dome area.

5 STASTICAL ANALYSIS AND PLOTS

5.1 Pamstamp Anova – Main Effects Plot

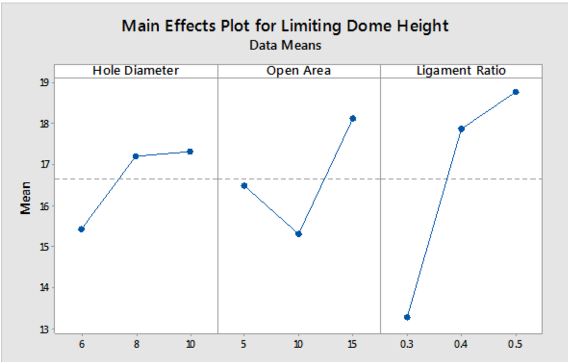

Figure 15. Main effects plot for limiting dome height

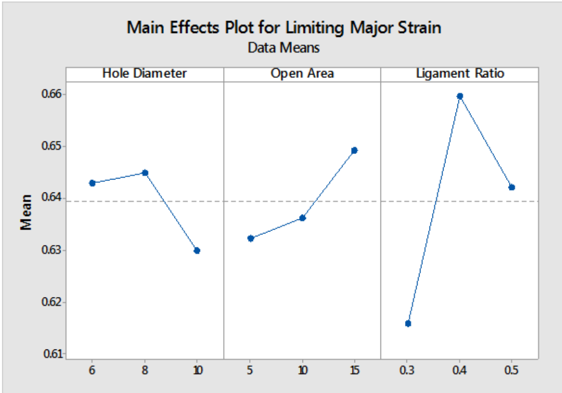

Figure 16. Main effects plot for limiting major strain

Diameter 6mm perforations are less likely to deform and allow stretching of the sheet 8mm and 10mm perforations allow more deformation. The Ligament ratio plays an important role, as the ligament ratio increases the forming depth also increases.

5.2 Regression Analysis

$$Limiting\ Minor\ Strain = 0.0393 - 0.00093\ Hole\ Diameter + 0.000002\ Open\ Area - 0.0033\ Ligament\ Ratio \quad (1)$$

$$Limiting\ Major\ Strain = 0.5959 - 0.00324\ Hole\ Diameter + 0.00168\ Open\ Area + 0.131\ Ligament\ Ratio \quad (2)$$

$$Limiting\ Minor\ Stress = 0.06281 + 0.000038\ Hole\ Diameter + 0.000468\ Open\ Area + 0.00986\ Ligament\ Ratio \quad (3)$$

$$Limiting\ Major\ Stress = 0.15215 - 0.000580\ Hole\ Diameter - 0.000171\ Open\ Area - 0.0073\ Ligament\ Ratio \quad (4)$$

$$Limiting\ Dome\ Height = 0.22 + 0.472\ Hole\ Diameter + 0.165\ Open\ Area + 27.50\ Ligament\ Ratio \quad (5)$$

Table 3. Error Calculation -1

Hole Diameter	Open Area	Ligament Ratio	Limiting Minor Strain	Regression	Error%	Limiting Major Strain	Regression	Error%	Limiting Minor Stress	Regression	Error%
6	5	0.3	0.027342	0.03472	-26.98	0.62849	0.62416	0.69	0.0675	0.068336	-1.24
6	10	0.4	0.043072	0.03506	18.60	0.65082	0.64566	0.79	0.07217	0.071662	0.70
6	15	0.5	0.027286	0.0354	-29.74	0.64972	0.66716	-2.68	0.07603	0.074988	1.37
8	5	0.4	0.029283	0.03319	-13.34	0.65243	0.63078	3.32	0.0702	0.069398	1.15
8	10	0.5	0.031534	0.03353	-6.33	0.66063	0.65228	1.26	0.07334	0.072724	0.84
8	15	0.3	0.029733	0.03288	-10.58	0.6219	0.63448	-2.02	0.07018	0.073092	-4.16
10	5	0.5	0.027722	0.03166	-14.21	0.6164	0.6374	-3.41	0.06829	0.07046	-3.19
10	10	0.3	0.031459	0.03101	1.43	0.59758	0.6196	-3.68	0.07407	0.070828	4.37
10	15	0.4	0.027375	0.03135	-14.52	0.67615	0.6411	5.18	0.07381	0.074154	-0.47

Table 4. Error Calculation -2

Hole Diameter	Open Area	Ligament Ratio	Limiting Minor Stress	Regression	Error%	Regression	Error%	Limiting Dome Height	Regression	Error%
6	5	0.3	0.0675	0.068336	-1.22	0.145625	1.44	12.21	12.127	0.68
6	10	0.4	0.072167	0.071662	0.70	0.14404	0.09	14.51	15.702	-7.59
6	15	0.5	0.076033	0.074988	1.39	0.142455	-0.91	19.55	19.277	1.41
8	5	0.4	0.070204	0.069398	1.16	0.143735	-0.37	18.78	15.821	18.67
8	10	0.5	0.073339	0.072724	0.85	0.14215	-1.26	18.32	19.396	-5.55
8	15	0.3	0.070175	0.073092	-3.99	0.142755	0.43	14.51	14.721	-1.43
10	5	0.5	0.068285	0.07046	-3.09	0.141845	1.06	18.47	19.515	-5.35
10	10	0.3	0.074068	0.070828	4.57	0.14245	-3.04	13.12	14.84	-11.59
10	15	0.4	0.073808	0.074154	-0.47	0.140865	2.67	20.34	18.415	10.45

Regression equations were derived from the values for individual limiting stresses and strains. The individual regression was calculated from the same and the error for each was also calculated. The error deviations were at the acceptable level. Hence our regression analysis is valid.

6 RESULTS AND DISCUSSION

PAMSTAMP is a widely used software for FEA forming simulation of sheet metals. Several leading car manufacturers such as Nissan, Renault as well as numerous other suppliers of consumer and electronic equipment's are using PAMSTAMP for the FEA of sheet metal parts. This study shows that PAMSTAMP can be successfully used to simulate even perforated sheet metal parts. As the hole size decreases and the ligament ratio decreases the ability of the sheet metal to deform decreases. Diameter 6mm perforations deform to smaller depths than the diameter 8 and 10mm perforations. As the ligament ratio increases so does the amount of material in the adjoining vicinity of the holes hence the stretching is also more. More the ligament ratio more the stretching.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

►[1] Makinouchi A (2001) Recent developments in sheet metal forming simulation. In: Mori K (ed) NUMIFORM 2001, AA Balkema, Toyohashi, Japan
►[2] S. L. Semiatin, *ASM Handbook Vol. 14b: Metalworking: Sheet Forming*, vol. 14. 2006.
►[3] D. Ravi Kumar, "Formability analysis of extra-deep drawing steel," *J. Mater. Process. Technol.*, vol. 130–131, pp. 31–41, 2002.
►[4] G. Venkateswarlu, M. J. Davidson, and G. R. N. Tagore, "Influence of process parameters on the cup drawing of aluminium 7075 sheet," *Int. J. Eng. Sci. Technol.*, vol. 2, no. 11, pp. 41–49, 2010.
►[5] M. S. Amra, "Simulation of Fricton Ratios At Deep-Drawing Process," pp. 1335–1338, 2006.
►[6] M. Sivanandini, S. S. Dhami, and B. S. Pabla, "Formability of magnesium alloys," *Int. Journel Mod. Eng. Res.*, vol. 2, no. 4, pp. 2464–2471, 2012.
►[7] "1996. Makinouchi. Sheet metal forming simulation in industry.pdf."
►[8] Del Prete, T. Primo, and M. Strano, "The use of FEA packages in the simulation of a drawing operation with springback, in the presence of random uncertainty," *Finite Elem. Anal. Des.*, vol. 46, no. 7, pp. 527–534, 2010.
►[9] M. Engineering and K. L. E. M. S. Sheshgiri, "Finite Element Simulation of Sheet Metal Deep Drawing Using Explicit Code and Result Validation," pp. 1080–1086, 2015.
►[10] P. Solfronk and J. Sobotka, "Utilization of forming tool with variable blankholder force for drawing of Al alloys," *Phys. Procedia*, vol. 22, pp. 233–238, 2011.
►[11] M. A. Farsi and B. Arezoo, "Bending force and spring-back in v-die-bending of perforated sheet-metal components," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 33, no. 1, pp. 45–51, 2011.

►[12] G. Venkatachalam, J. Nishanth, M. Mukesh, and D. S. Pavan Kumar, “Study of Forming Behaviour of Square Hole Mild Steel Perforated Sheet Metal,” *Appl. Mech. Mater.*, vol. 852, pp. 218–228, 2016.

►[13] G. Venkatachalam, J. Nishanth, M. Mukesh, and D. S. Pavan Kumar, “Investigations on Influence of Geometric Parameters in Drawing of Perforated Sheet Metals,” *Appl. Mech. Mater.*, vol. 852, pp. 229–235, 2016.

►[14] K. Elangovan and C. S. Narayanan, “Application of Taguchi approach on investigation of formability for perforated Al 8011 sheets,” vol. 2, no. 5, pp. 300–309, 2010.

►[15] G. Venkatachalam, S. v Nilay, D. Mishra, S. Singh, Y. Choudhary, and S. Narayanan, “Determination of forming limit diagram for perforated aluminium 1050A sheets,” *Int. J. Mech. Mechatronics Eng.*, vol. 13, no. 1, pp. 37–39, 2013.

►[16] S. Narayanan, “Influence Of Hole Size , Hole Shape And Hole Pattern On Spring-Back Effect In Perforated Sheet Metals Using FEM,” vol. 4, no. 06, pp. 2636–2640, 2012.

►[17] G. Venkatachalam, V. Kumar, and S. Narayanan, “Finite element analysis of forming limits for stretch forming of perforated aluminium sheet metals,” *ARPN J. Eng. Appl. Sci.*, vol. 8, no. 8, pp. 652–655, 2013.

►[18] Hijazi, A., Yardi, N. & Madhavan, V., “Determination of forming limit curves using 3d digital image correlation and in-situ.” Proceedings of SAMPE, May, 2004.