Multi-Level Cavity Forming Analysis Using Fluid Forming Technique

E. Hazya, Dr.S.Gajanana, M. Mallareddy, V.Raviteja
Mechanical Engineering Department, M.V.S.R. Engineering College, Nadergul, Hyderabad, Telangana, India
corresponding Email: g_saparey@rediffmail.com

Abstract: Liquid hammer is a pressure surge or wave caused when a fluid (usually a liquid but sometimes also a gas) in motion is forced to stop or change direction suddenly which also involves a momentum change. This process generates shock waves which reach the sheet metal kept at a lower part of the cylinder and deform it to the shape of the die placed below the sheet metal.The process variables that were considered which affect deformation are the thickness of the specimen, height of drop hammer, number of blows and weight of the drop hammer.In this work Response Surface Methodology(RSM) is used as a tool for optimization of process parameters using Design Expert Software.Further force and strain analysis are performed for the deformed specimens.

Keywords: **liquid hammer, Response Surface Methodology (RSM), designexpert, ANOVA, Optimization, Finite Element Analysis (FEA)**

I. Introduction

Liquid hammer process of forming is a simple high energy rate forming technique. The liquid hammer method of forming sheet metals is a simple, safe and inexpensive technique in which the necessary high energy is obtained from the shock waves generated in a liquid column by the impact of a falling weight transmitted through a plunger. The plunger works inside a cylinder containing the hydraulic fluid that generates shock waves which reach the sheet metal kept at the lower part of cylinder and deforms it to the shape of the die placed below the sheet metal. Therefore, there is a considerable scope for a process in which sheet metal can be formed by safer and convenient equipment. Forming by means of water hammer offers such an alternative.

Principle of water hammer

The method uses the principle of generation of liquid hammer waves by dropping the weight in cylindrical cavity filled with the liquid column.Water can be considered as a homogeneous fluid incapable of supporting any shear; this implies that if the water is loaded impulsively its volume is able to readjust by means of flow through any boundary displacements caused by the loading. Change in the pressure results in change in volume. In this way pressure suddenly applied locally will be transmitted to other points in the fluid as an “elastic wave of disturbance” which will travel at the velocity of sound in the liquid.

. **Parameters affecting the deformation of the specimen**

1. Thickness of the specimen
2. Height of the drop hammer
3. Weight of drop hammer

II Methodology:

Response surface methodology (RSM) is a collection of experimental strategies, mathematical methods and statistical inference which enable an experimenter to make efficient empirical exploration of the system of interest.

Many times these procedures are used to optimize a process. For example, we may wish to maximize yield of a chemical process by controlling temperature, pressure and amount of catalyst.

The basic strategy has four steps:

1. Procedures to move into the optimum region.
2. Behaviour of the response in the optimum region.
3. Estimation of the optimum conditions.
4. Verification.

The main objectives of RSM are

- RSM is a collection of mathematical and statistical techniques that are useful for modeling and analysis in applications where a response of interest is influenced by several variables and the objective is to optimize the response.
- Optimize →maximize, minimize, or getting to a target.
- Or, where a nonlinear model is warranted when there is significant curvature in the response.

Here, in this Experimentation, the outputs obtained are to be incorporated into the historical data of RSM in Design Experts Software and the optimum value of the outputs for the suggested model is to be obtained.

III.Experimentation:

The equipment is arranged on a circular concrete base. A wooden block is placed over the concrete base so as to absorb the shock load without damaging the system; die holder is kept on the wooden block. Suitable die is selected and placed in the die holder over which the sheet metal (work piece) is located in the shallow counter sunk bore, of the same diameter as the specimen, on the die face. Venting is provided both in the die and the die holder, to prevent spring back of the specimen due to compressing of trapped air. Now the cylinder with two ‘O’ rings are fixed in order to prevent leakage of the working fluid. Cylinder flange and guide bush are mounted on the cylinders in such a way that it is fixed with an m-10 Allen screw. Two swing bolts are used to clamp the cylinder flange and hold the cylinder in position. Plunger along with ‘O’ ring fixed on it is inserted through the guide bush into the cylinder. The mating faces of plunger and cylinder were grinded for smooth movement. Wall bracket is fixed in the wall to support the guide mechanism. The guide mechanism comprises of a pulley for lifting the weight. The set of three guide wires are provided to guide the falling weight. The weights are fixed on a disc carrying a one end thread inside the disc and other end locked to the rope by means of an eye end. The die holder is placed on the wooden block. The surface of the die should be free from dust, dirt and other foreign materials to provide good forming. The die is placed in the holder. The specimen is located in the shallow counter sunk bore between the die face and the cylinder. The cylinder cavity is filled with the fluid up to desired height by removing the necessary tap screws. Cylinder flange along with the guide bush is located by means of bolts. The plunger is inserted into the cylinder with the ‘O’ rings in position, up to the liquid level. Predetermined weight is raised to the required height manually by means of the rope over the pulley. Then it is released suddenly. The deformation of the work piece takes place by the shock waves in the liquid generated by the impact of the freely falling weights. The swing bolt is unfastened. The wire fixed of the cylinder flange lifts the cylinder along with the plunger, guide and guide bush. The formed specimen is removed from the shallow counter sunk bore and replaced by the new specimen. The cyclic process can be repeated by varying loads, energy input and water column heights.

Table 1- Process parameters and their working ranges

Process Parameters	Range	
	Minimum	Maximum
Thickness of the Specimen(mm)	0.5	1.0
Height of the Hammer Blow(cm)	140	190
Weight on the drop Hammer(kg)	5	7

IV Analysis:

In the analysis, the response data values are entered in the design expert software and the following steps are performed to analyse and optimise the results,and then theoretical analysis to find out volume leakage and finite element analysis are carried out on the specimens to know deformations and strain values.

1. Transformation: Select response node and choose transformation.
2. Fit summary: Use this to evaluate models.
3. Model: choose model order and desired terms from list.
4. Analysis of variance (ANOVA): Analyze the chosen model and view results.
5. Diagnostics: Evaluate model fit and transformation choice with graphs.

The second part of analysis is done using Finite Element Analysis(FEA) and the deformations on the specimens are analysed and results are presented.

Table 2- Thickness of sheet at mid-point of cavity,deformation and strain

S NO	Initial Sheet Thickness (t)(mm)	Final sheet thickness (t_f) (mm)	Change in thickness (t_f-t)	STRAIN (t_f-t/t)	DEFORMATION (mm)
1	1.00	0.38	0.62	0.620	4.91
2	0.71	0.17	0.54	0.760	5.27
3	0.71	0.22	0.49	0.690	5.24
4	1.17	0.63	0.54	0.461	4.89
5	0.71	0.35	0.36	0.507	5.24
6	0.5	0.28	0.22	0.440	5.23
7	0.5	0.20	0.3	0.600	5.25
8	0.71	0.39	0.32	0.450	5.26
9	0.71	0.5	0.21	0.295	5.25
10	1.00	0.82	0.18	0.180	4.81
11	0.71	0.34	0.37	0.521	5.24
12	0.5	0.28	0.22	0.440	5.27
13	1.17	0.93	0.24	0.205	4.64
14	1.00	0.38	0.62	0.620	4.81
15	0.5	0.3	0.2	0.400	5.34

Table 3-Analysis tables for 1ST set of trails

	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	0.1026		0.1846	-0.2136	Suggested
2FI	0.4632		0.1705	-1.2495	
Quadratic	0.2783		0.2534	-1.9916	
Cubic	0.0001		0.9586	-1.8832	Aliased

ISSN:2319-6890)(online),2347-5013(print)
11-12 Feb. 2016

Table 4-ANOVA table for 1st set of trials

Response –Deformation					
Analysis of variance table [Partial sum of squares - Type III]					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob> F
Model	0.48	9	0.053	1.72	0.2059
A-Thickness	0.11	1	0.11	3.46	0.0923
B-Height	1.604E-004	1	1.604E-003	5.210E-003	0.9439
C-Weight	0.14	1	0.14	4.51	0.0598
AB	2.113E-003	1	2.113E-003	0.069	0.7987
AC	0.035	1	0.035	1.14	0.3107
BC	0.056	1	0.056	1.82	0.2068
A^2	0.045	1	0.045	1.48	0.2524
B^2	0.10	1	0.10	3.34	0.0977
C^2	3.436E-004	1	3.436-004	0.011	0.9180
Residual	0.31	10	0.031		
Lack of Fit	0.31	5	0.062		
Pure Error	0.000	5	0.000		
Cor Total	0.78	19			

Table 5-Final Equation in terms of Actual Factors

Final Equation in Terms of Actual Factors	
deformation	=
+3.57748	
+3.01310	* thickness
+0.026293	* height
-0.39618	* weight
-2.60000E-003	* thickness * height
-0.26500	* thickness * weight
+3.35000E-003	*height* weight
-0.89837	* $thickness^2$
-1.35092E-004	* $height^2$
-4.88312E-003	* $weight^2$

Table 6- Solutions for 1st set of trials

Solutions				
Number	thickness	height	weight	deformation
1	0.73	170.58	5.36	5.29095
2	0.58	171.03	5.63	5.28532
3	0.81	187.51	5.75	5.15093
4	0.93	176.99	6.25	5.09245
5	0.65	154.29	6.53	5.1919
6	0.54	151.03	6.90	5.15709
7	0.77	159.63	6.51	5.16873
8	0.53	178.01	5.00	5.2546
9	0.63	189.57	6.06	5.19555
10	0.72	156.07	6.63	5.16228
11	0.73	183.36	6.60	5.17664
12	0.75	174.80	5.81	5.24053
13	067	142.10	5.45	5.27569
14	0.81	140.51	5.38	5.26517
15	0.74	145.43	5.44	5.28602
16	0.93	173.24	6.07	5.12409
17	0.58	187.76	6.92	5.22793
18	0.56	167.94	6.29	5.26442
19	0.58	183.41	6.32	5.23668
20	0.97	168.13	6.06	5.10779
21	0.93	170.76	6.61	5.0632
22	0.84	172.71	6.48	5.14173
23	0.74	180.22	6.90	5.16355
24	0.69	169.69	6.56	5.2183
25	0.61	177.19	6.36	5.24798
26	0.88	143.01	5.81	5.16593
27	0.75	176.17	5.44	5.25633
28	0.79	163.22	6.40	5.17619
29	0.77	162.91	6.02	5.23014
30	0.52	180.8	6.49	5.25542

Finite Element Analysis (FEA)

An FEA model of the sheet metal is created and the change in thickness and the Von-Mises stresses are enumerated. This is a basic simulation done in the "SOLIDWORKS SimulationXpress". The respective loads acting on the sheet metal during the operation of liquid hammer forming are applied on the metal plate model having the same properties as the specimen which has been used in the experimentation. The overall change in the thickness of the sheet metal plate is analysed and also the Von-Mises stresses at the critical points are found out.

The basic steps followed in the model development and analysis is:

- A 123mm diameter circle is created using the sketcher tool and the same is extruded through 1.17mm, 1mm, 0.71mm and 1.628mm as per the specimen defined.
- 56mm diameter circles are sketched over the surface of the plate and extruded through 6mm.
- A circle of diameter 36mm is sketched on the other surface of the plate and extruded through 6mm which ends up the basic designing of specimen.
- Fixtures are applied on the bottom surface excluding the circles of diameter 56mm and 36mm.

Pressure of 4.7841N/mm^2 is applied on the top surface of sheet excluding the 56mm and 36mm diameter circle. This

ISSN:2319-6890)(online),2347-5013(print)
11-12 Feb. 2016

load is offered by the combine weight of cylinder and the cover.
The above steps are common to every specimen and the pressure is applied on the 72mm circle bounding surface which is different for each specimen.The material of the specimen is selected either from the list of materials or a custom material is generated by added the required fields such as thermal properties, Young's modulus, yield strength, ultimate tensile strength, etc. For the present study, Aluminium 19000 (AA1100 or Al-99.0) is the specimen material having the below properties:

Elastic Modulus = 7e+010 N/mm^2
Poisson's Ratio = 0.33
Mass Density = 2710 Kg/mm^3
Tensile Strength = 123.2 MPa
Yield Strength = 105 MPa
Thermal Conductivity = 218 W/m-K.

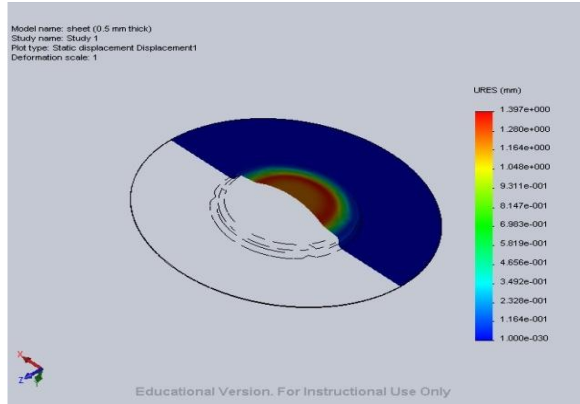
In the final stage the simulation is run to generate automatic mesh for the given solid and the required results are displayed.

In the above analysis it is assumed that there are no constraints established at the region of cavities formation, .i.e., there is no die constraint below the cavities portion. Thus the material is free to flow with the applied pressure to the maximum possible limit. The maximum force concentration will be at the mid-point of the cavity, so the resulting shape will be a hemispherical shape. Since the required shape of cavity is a hemispherical one, so the stated procedure is considered for the analysis of specimens.

Table 7- strains from FEA models

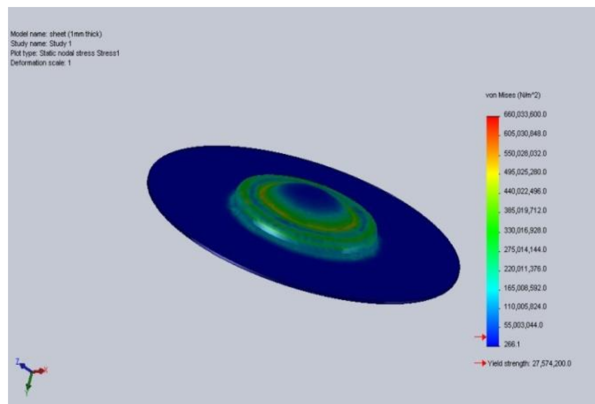
Specimen No.	Thickness of plate, t (mm)	Change in Thickness , dt (mm)	Strain ($\frac{dt}{t}$)
1	1.00	0.474	0.474
2	0.71	0.056	0.0788
3	0.71	0.017	0.0.39
4	1.17	0.239	0.2042
5	0.71	0.2076	0.2924
6	0.5	0.203	0.406
7	0.5	0.058	0.116
8	0.71	0.166	0.234
9	0.71	0.184	0.2591
10	1.00	0.098	0.098
11	0.71	0.0735	0.1035
12	0.5	0.2029	0.4058
13	1.17	0.165	0.1410
14	1.00	0.0113	0.0113
15	0.5	0.14989	0.2998

FEA model deformed specimens



At t = 1.17mm, h = 165cm, w = 6kg, P = 3.497MPa
Thickness at the mid-point of cavity =0.931mm

Von-Mises stress in the deformed specimens-FEA analysis



Deformed Specimens having multi-level cavities

Fabricated die

IV.Conclusion

The efficiency of liquid hammer process is defined as the ratio of kinetic energy of the drop weight at impact with the piston to the energy absorbed in plastic deformation of the work piece. Efficiencies are typically in between 40% to 50%, which is high compared with the 10% or so obtained or attained in explosive and electro hydraulic forming. The reason for the improvement is that in the liquid hammer process the energy is propagated directly towards the work piece, where as in other systems the energy is radiated in all directions from a point source, and only a small portion impinges directly on the work piece.The die has been designed of multilevel-cavity shape as shown and the outer cavity is of 55mm dia,inner cavity is of 36 dia and fillets of radius 2 mm is used everywhere.

The die is of EN8 steel alloyed material. Metal sheets of 123mm diameter of Aluminium19000 are used of different gauges like 18,20and 22. Experimentation is carried out,strains and deformations are determined and force analysis and simulation is to be done to know the parameters effects on deformation.

The major outcomes from the observations are:

1. The pressures calculated considering a leak-proof apparatus and a leakage factor taken apparatus has shown variations in the pressures produced inside the cylinder. The leakage is a theoretically calculated value which affects the pressure as the spilled water from cylinder is confined beneath the column increasing the cross sectional area and volume. Thus it exhibits more pressure than a leak-proof apparatus which is impractical. The stress or the internal resistance produced at the mid-point of the cavities is greater than the external pressure applied through the water column.

2. The maximum deformation of 5.35mm is obtained with optimal values of parameters. The force of impact produced by the water hammer with these conditions is 8353.603N and the strain in the sheet at the mid-point of cavities is 0.400.

3. When the maximum and minimum impact force cases are considered for comparison, the strain and final thickness values from the FEA and theoretical analysis are as below:

Table 8- comparison of strains and final thickness

Specimen No.	Impact Force (N)	Strain ($\frac{dt}{t_i}$)		Final Thickness (mm)	
		Theoretical Analysis	FEA	Theoretical Analysis	FEA
5	5864.218 (Minimum Impact force)	0.507	0.2924	0.35	0.5024
1	11387 (Maximum Impact force)	0.620	0.474	0.38	0.526

V. References

i. ***Lingaraju. D , Ch. Ramesh Babu , K.Ramji*** *: "Studies on Water Hammer Forming on Sheet Metal Works", Published in International Journal of Applied Engineering Research, Dindigul, Volume 2, No.1, 2011.*

ii. ***Ravinder Kumar, Ashish Kumar Sharma:*** *"Analysis of Water Hammer Forming on the Sheet Metal"***,** *Journal of Information Engineering and Applications, Vol 2, No.1, 2012.*

iii. ***Gajanana.S****, (2002): "Development of Mathematical Model for Maximum Punch Force"Proceeding of National Conference on Advanced Trends in ME Research andDevelopment, JNTU College of Engineering, Anantapur, 21st Dec, 2002.*

iv. ***Gajanana.S****, "Optimization of Process Parameters for Hero Honda Exhaust Valve using Design of Experiments" Proceeding of National Conference on Recent Advances in Computer Aided Engineering, Osmania University, Hyderabad, March 3rd & 4th , 2006.*

v. ***Gajanana.S****, (2007): "Development of Mathematical Model for EDM Using Two Factorial Design of Experiments" XXIII National Convention of Mechanical Engineers and National Seminar on 'Emerging Trends in Manufacturing Systems and Technologies', Hyderabad, September 10-12, 2007.*

vi. ***Davis, R.*** *and* ***Austin, E.R.,*** *"Developments in High Speed Metal Forming", Industrial Press Inc, 1970.*

vii. ***Grieve, R.J.*** *and* ***Wambugu, N.W.****, "Some aspects of sheet-metal forming using impact loading through water columns", Experimental mechanics, August 1981, 302-308.*

viii. ***Adler, Y.P., Markova, E.V. and Gromovsky, Y.V.****, "The design of experiments to fin optimum conditions", Mir Publishers, Moscow, 1975.*

ix. ***Dr. Gajanana S and Ravikumar B****, "Development of Model for Deformation in Water Hammer Forming Proces", Manufacturing Technology Today, Vol.12, No. 4, April 2013, 22-26.*

x. ***Montgomery, D.C****., "Design and Analysis of Experiments", John Wiley and Sons, 2003.*