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Parametric Analysis of Deep Drawing Process for Hemisphere Dome Shape of Steel AISI 1023

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***Abstract:** Deep Drawing is a widely used sheet metal shape transformation process with material retention. From Automobile components to plumbing and sanitary ware, this process is used for mass production of industrial and domestic artifacts with the depth greater than corresponding diameter. Deep drawing process using a die-punch pair on a press induces radial stresses on flange region and compressive stresses on the center of a blank to provide a permanent shape change. The production quality and cost associated depend upon obtained thickness distribution and an accurate prediction of formability.*

This demands a coherent set of correlations between various parameters associated with deep drawing. This study reviews various theoretical and experimental attempts made to connect punching force, blank holding force, dome height, thickness of blank etc. with thickness distribution on final products. The focus is also drawn onto various modes of failures for hemispherical products and associated problems including creasing and wrinkling, crushing and cracking of sheet metal parts. Conclusions are drawn to suggest desired range of various parameters and impact of isolated deviation of one or more parameters on the resulted product.

1. INTRODUCTION

One of the important processes of forming of sheet metal parts is Deep drawing. Vita use of deep drawing process is in production of hollow shapes in the packing industry, automotive industry etc. According to the definition in DIN 8584, deep drawing is the tensile compressive forming of a sheet blank (or, depending on the material, also of foils or plates) to a hollow body open on one side or the forming of a pre-drawn hollow shape into another with a smaller cross-section without an intentional change in the sheet thickness. [19] The condition for the completing process is transmitting the force into the forming zone.

Figure 1 shows the different parts of deep drawing assembly and forces applied at various components. Deformation in the flange occurs due to the tangential compressive stress and radial tensile stress, when the sheet blank with diameter Do is drawn through the die to a cup with the punch diameter do. The blank holder force F_N prevents the formation of folds. Blank holder pressure is small compared to the radial and tangential stresses.

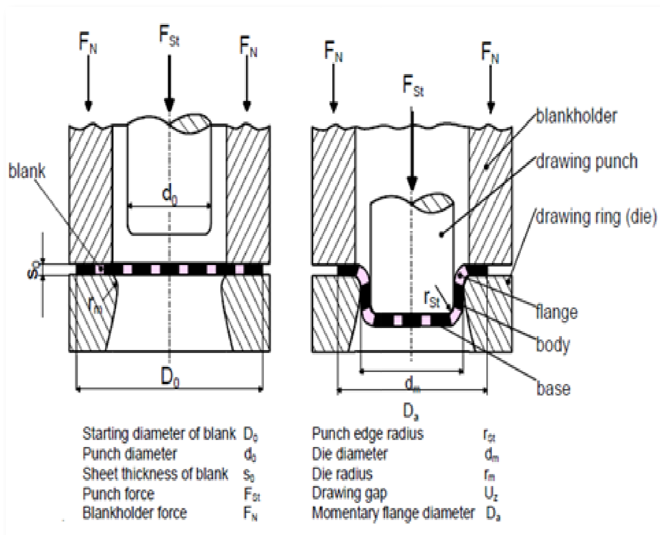

Fig. 1: Deep Drawing Process

For forming, drawing force is transmitted from the punch to the work-piece base and from there to the forming zone in the flange. The resulting limiting deformation in the force application zone has nothing to do with the depletion of the forming capacity of the material in the forming zone. The limits of the process are when the largest applied drawing force cannot be transmitted to the forming zone in the flange. It can be stated that, from this condition, one can derive the characteristic behavior of deep annealing step. Subdividing the whole process is into a number of drawing steps. The advantage it has, that the tensile force acting at the force application zone can be less.

There are four zones formed during the drawing process of the cylindrical cup as shown in Fig.2**,** with different state of stress and deformation. The forming zone is the sheet material between the flange outer edge and the outlet of the material to be formed from the drawing ring radius. The surface area of the drawn part is about the same as that of the starting blank. Consequently, the sheet thickness remains almost constant. The base of the drawn part is formed on the same principles that apply to mechanical Drawing.

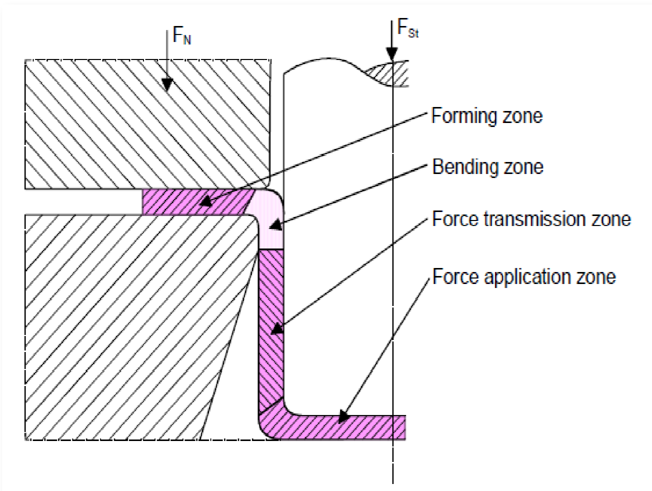

Fig. 2 Stress Zones During Deep Drawing

Application of Deep drawing process is for Closed Cylindrical shapes as Cans, pots and pans, Rectangular container of all shapes and sizes Shells, Cartridge cases, Automobile panel, Cylindrical parts, End automotive exhaust application, LPG bottles and Household goods.[2,7,16,18]

2. EFFECT OF PROCESS PARAMETERS

There are various process parameters used in deep drawing process like punch force, blank holding force, blank thickness, punch velocity, punch stroke, and co-efficient of friction, which are controllable. Effect of these parameters on blank is described in Table 1.

Table-1. Effect of parameters on blank

Sr. no.	Parameters	Effect of parameter on blank
1	Punch force	The cup height increases with an increase in punch force. So does the damage in lower edge corner, where stress concentration is observed.[6,9]
2	Blank holding force	a. Increasing blank holding force by using a blank holder of an appropriate size will ensure a reduction in wrinkling height.[8] b. A feedback based variable blank cushion ensures a uniform flow of metal.[3] c. Too rigid holding with a greater friction factor will induce tears in the cup region.[4]
3	Blank thickness	a. The average distribution of the blank thinning is increasing with increasing of the blank thickness.[11,16] b. The maximum percentage thinning however does not bear any independent relation to blank thickness.[14,17]
4	Punch velocity	a. Higher the values of punch velocity, greater are the chances of tear in the cup region.[18] b. Low to medium velocities result in a controlled metal flow rate and thus a uniform product.[20]
5	Punch stroke	a. Stroke length is controlled by the depth to be achieved.[10] b. A punch stroke should be minimized as longer strokes will result in a greater pull and greater probability of tear.[12] c. Blank thickness required increases with an increase in a punch stroke.[13,15]
6	Co-efficient of friction	a. Throughout the system, the coefficient of friction between blank and punch as well as blank and die along with blank and blank holder is required to be minimum to ensure the maximum metal flow.[5] b. Friction factor can also be used as a controlling factor to control the flow of metal from flange to cup region, wrinkling effect and percentage thinning.[1,7]

3. SIMULATION WORK OF STEEL (AISI 1023)

There is Solid work Simulation 3D Forming software used for simulation of steel AISI 1023.

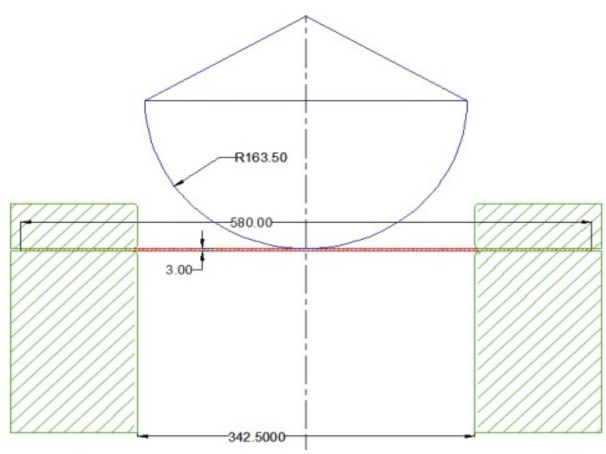

Fig. 3- Simulation Model

There is simulation model shown in fig.3. There are include components like punch, die, blank, and blank holder. The dimension of components of this assembly is as per experiment model.

3.1 Simulation work on 3mm steel blank

Table 2- Simulation work on 3mm steel sheet

Sr. No.	Height of dome in mm	Percentage of thinning
1	0-30	3.95%
2	31-60	7.9%
3	61-90	11.85%
4	91-120	15.8%
5	121-150	19.75%

There is shown in Table 2, percentage of thinning is increase with increase height of dome of 3mmsteel blank

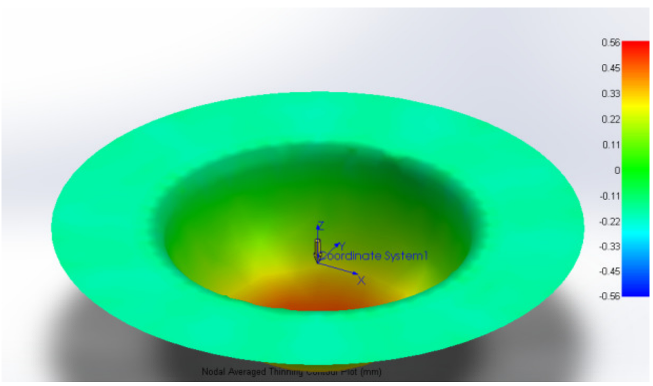

Fig. 4- Thickness distribution in 3mm blank

There is fig.4 shown of thickness distribution of 3mm blank. The maximum thinning in dome at center which is 18.6% and minimum thinning in dome at upper part of crown which is zero.

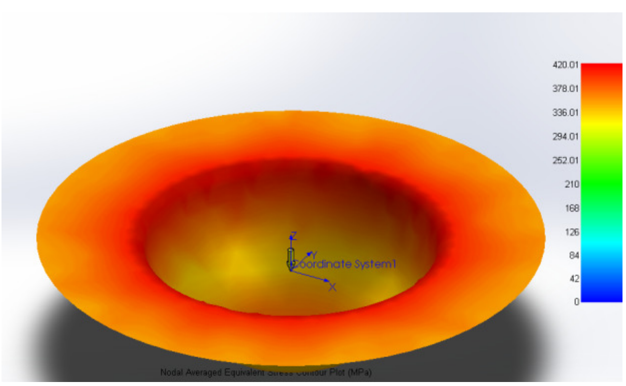

Fig. 5- Stress distribution in 3mm thickness blank

There is fig.5 shown of stress distribution in 3mm thickness blank. The maximum stress in dome at knuckle radius is 420.01 Mpa and minimum stress in dome at crown radius is 300.1 Mpa.

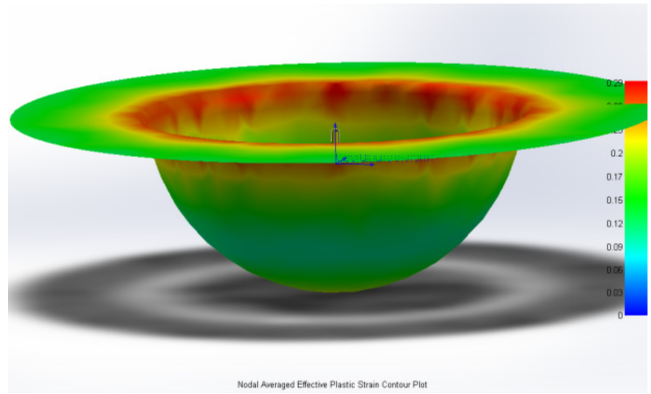

Fig. 6- Equivalent Plastic Strain in 3mm thickness blank

There is fig.6 shown of Equivalent Plastic Strain in 3mm thickness blank. The maximum equivalent plastic strain in dome at knuckle radius which is 0.29 and minimum equivalent plastic strain in dome at mid crown radius which is 0.09.

3.2 Simulation work on 4mm steel blank

Table 3- Simulation work on 4mm steel sheet results

Sr. No.	Height of dome in mm	Percentage thinning
1	0-32	3.72%
2	33-64	7.44%
3	65-96	11.86%
4	97-128	14.88%
5	129-160	18.6%

There is shown in Table 3, percentage of thinning is increase with increase height of dome of 4mm steel blank

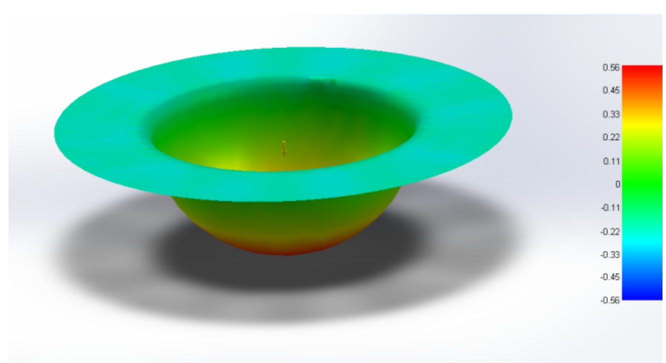

Fig. 7- Thickness distribution in 4mm blank

There is fig.7 shown of thickness distribution of 4mm blank. The maximum thinning in dome at center which is 13.95% and minimum thinning in dome at upper part of crown which is zero.

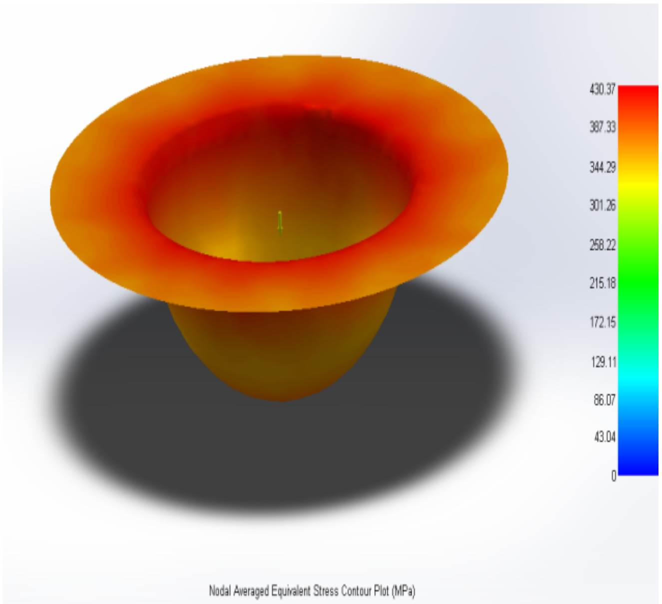

Fig. 8- Stress distribution in 4mm thickness blank

There is fig.8 shown of stress distribution in 4mm thickness blank. The maximum stress in dome at knuckle radius is 430.37 Mpa and minimum stress in dome at crown radius is 374.4 Mpa.

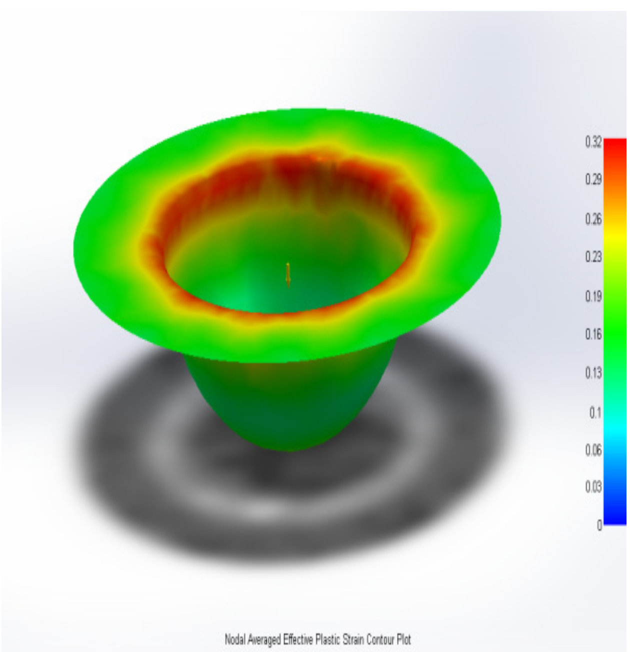

Fig. 9- Equivalent Plastic Strain in 4mm thickness blank

There is fig.9 shown of Equivalent Plastic Strain in 4mm thickness blank. The maximum equivalent plastic strain in dome at knuckle radius which is 0.32 and minimum equivalent plastic strain in dome at mid crown radius which is 0.176.

3.3 Simulation work on 5mm steel blank

Table 4- Simulation work on 5mm steel sheet

Sr. No.	Height of dome in mm	Percentage thinning
1	0-36	2.79%
2	37-72	5.58%
3	73-108	8.37%
4	108-144	11.16%
5	145-180	13.95%

There is shown in Table 4, percentage of thinning is increase with increase height of dome of 5mmsteel blank.

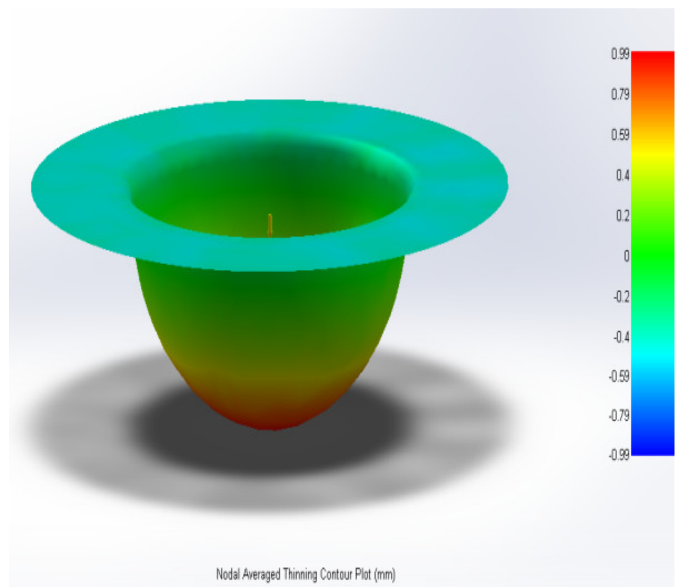

Fig. 10- Thickness distribution in 5mm blank

There is fig.10 shown of thickness distribution of 5mm blank. The maximum thinning in dome at center which is 19.75% and minimum thinning in dome at upper part of crown which is zero.

There is fig.11 shown of stress distribution in 5mm thickness blank. The maximum stress in dome at knuckle radius is 442.98 Mpa and minimum stress in dome at crown radius is 353.2Mpa.

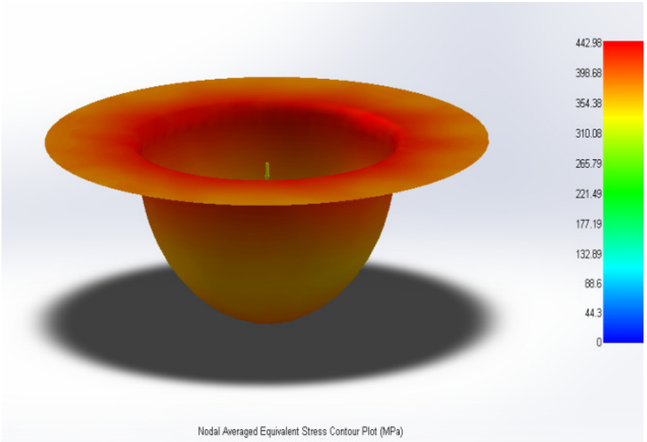

Fig. 11- Stress distribution in 5mm thickness blank

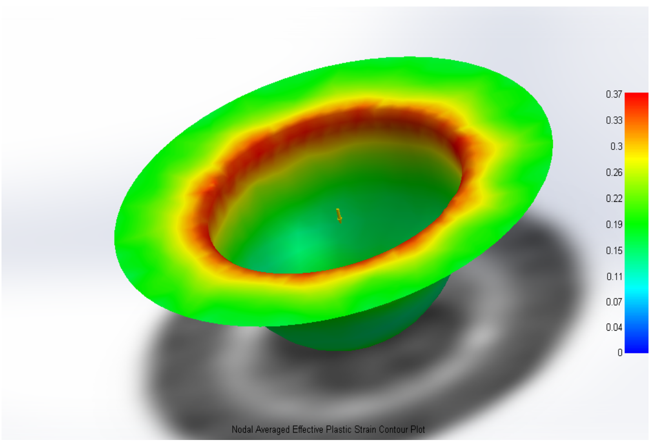

Fig. 12- Equivalent Plastic Strain in 5mm thickness blank

There is fig.12 shown of Equivalent Plastic Strain in 5mm thickness blank. The maximum equivalent plastic strain in dome at knuckle radius which is 0.37 and minimum equivalent plastic strain in dome at mid crown radius which is 0.2.

4. EXPERIMENTAL OF STEEL (AISI 1023)

Fig. 13- Experimental Set-up

Fig. 14- Experimental model of steel

4.1. Experimentation work on 3mm steel blanks

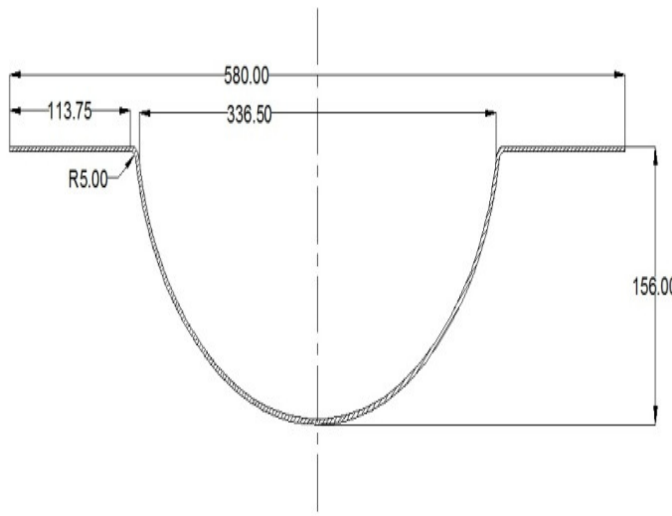

Fig. 15- Geometrical Model of 3mm steel

Fig.15 shows that Geometrical model of 3mm steel blank with the dimension of created dome

Table-5 Experimentation work on 3mm steel sheet

Sr. No.	Height of dome in mm	Change in Thickness	Percentage thinning
1	0-30	3	0%
2	31-60	2.83	5.67%
3	61-90	2.71	9.67%
4	91-120	2.66	11.33%
5	121-150	2.60	13.33%

As per Table-5 show that blank thickness at bottom is decreasing with increase of dome height

4.2. Experimentation work on 4mm steel blanks

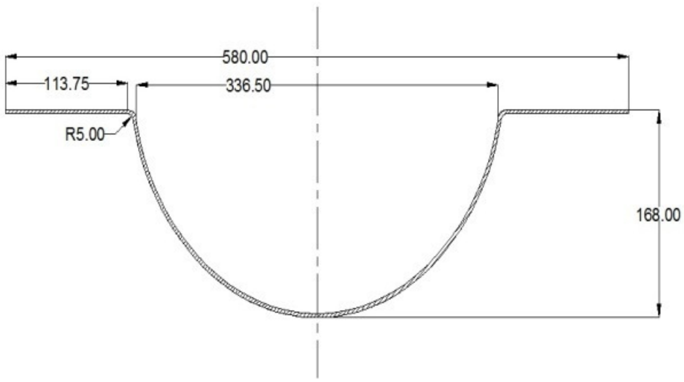

Fig. 16- Geometrical Model of 4mm steel

As shown in Fig.16, Geometrical model of 4mm steel blank with the dimension of created dome.

Table-6 Experimentation work on 4mm steel sheet

Sr. No.	Height of dome in mm	Change in Thickness	Percentage thinning
1	0-32	4	0%
2	33-64	3.85	3.75%
3	65-96	3.68	8%
4	97-128	3.54	11.5%
5	129-160	3.47	13.25%

As per Table-6 show that blank thickness at bottom is decreasing with increase of dome height

4.3. Experimentation work on 5mm steel blanks

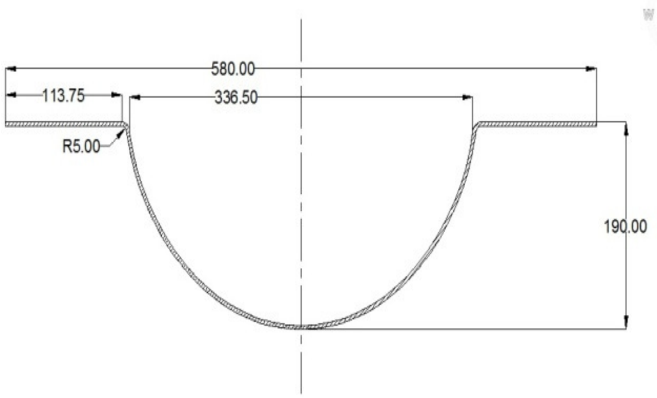

Fig. 17- Geometrical Model of 5mm steel

Fig.17 shows that Geometrical model of 3mm steel blank with the dimension of created dome

Table-7 Experimentation work on 5mm steel sheet

Sr. No.	Height of dome in mm	Change in Thickness	Percentage thinning
1	0-36	5	0%
2	37-72	4.81	3.8%
3	73-108	4.7	6%
4	108-144	4.47	10.6%
5	145-180	4.4	12%

As per Table-7 show that blank thickness at bottom is decreasing with increase of dome height

5. VALIDATION OF EXPERIMENT AND SIMULATION IN STEEL AISI 1023

5.1 Validation for 3mm thickness blank

Table 8- Validation for 3mm thickness blank

Sr.No.	Displacement (mm)	Experimental (Thinning percentage)	Simulation (Thinning percentage)
1	30	0%	3.95%
2	60	5.67%	7.90%
3	90	9.67%	11.85%
4	120	11.33%	15.80%
5	150	13.33%	19.75%

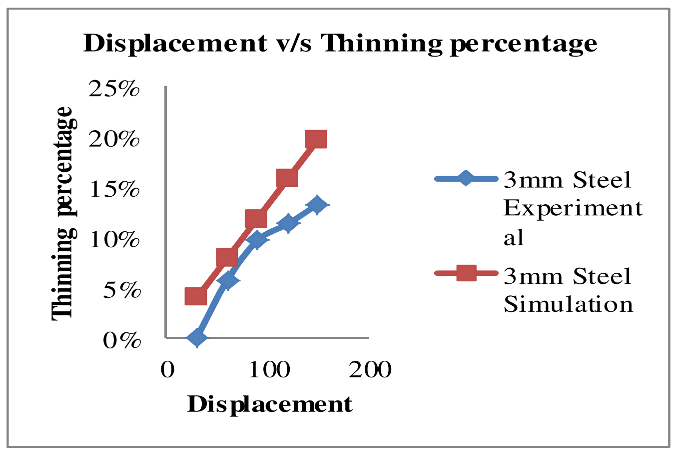

Fig. 18 Validation for 3mm thickness blank (Displacement v/s Thinning percentage)

As shown in fig.18 for validation for 3mm thickness blank (Displacement v/s Thinning percentage). Error between experimental and simulation is less, then 3mm thickness blank model is validated.

5.2 Validation for 4mm thickness blank

Table 9- Validation for 4mm thickness blank

Sr.No.	Displacement (mm)	Experimental (Thinning percentage)	Simulation (Thinning percentage)
1	32	0%	3.72%
2	64	3.75%	7.44%
3	96	8%	11.86%
4	128	11.50%	14.88%
5	160	13.25%	18.60%

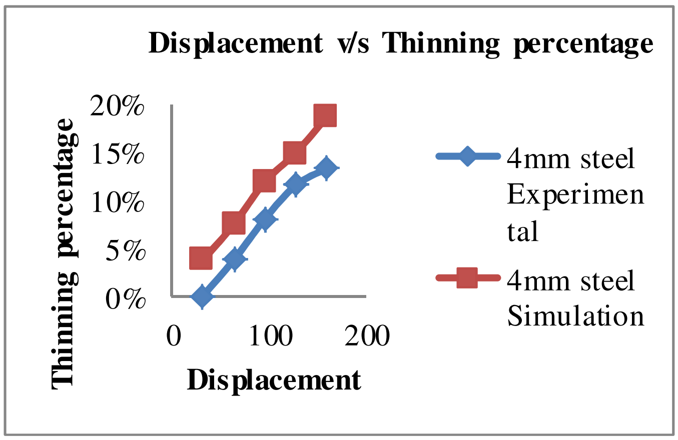

Fig. 19 Validation for 4mm thickness blank (Displacement v/s Thinning percentage)

As shown in fig.19 for validation for 4mm thickness blank (Displacement v/s Thinning percentage). Error between experimental and simulation is less, then 3mm thickness blank model is validated

5.3 Validation for 5mm thickness blank

Table 10- Validation for 5mm thickness blank

Sr.No.	Displacement (mm)	Experimental (Thinning percentage)	Simulation (Thinning percentage)
1	36	0%	2.79%
2	72	3.80%	5.58%
3	108	6%	8.37%
4	144	10.60%	11.16%
5	180	12%	13.95%

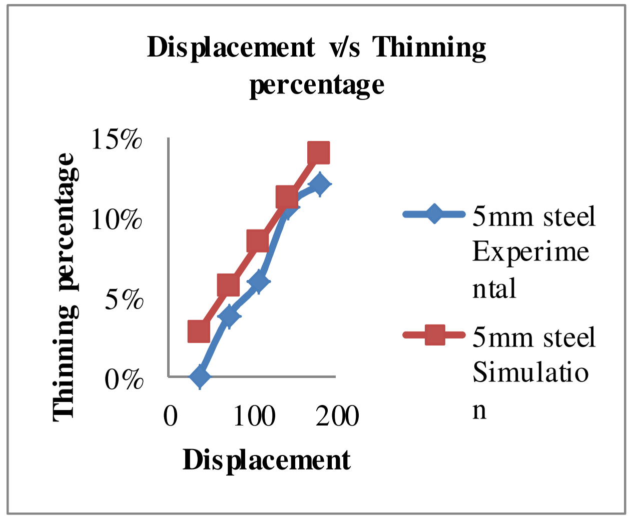

Fig. 20 Validation for 5mm thickness blank (Displacement v/s Thinning percentage)

As shown in fig.20 for validation for 5mm thickness blank (Displacement v/s Thinning percentage), Error between experimental and simulation is less than 3mm thickness blank model is validated.

6. CONCLUSION

As per the experimental and simulation carried, it is observed that, as the dome height increases, thickness of blank decreases and thinning of dome increases at bottom of blank. Percentage thinning for all the thickness of Steel AISI 1023 blank as observed in all experimental and simulation cases are very nearer. The defects like cracks, wrinkling, crushing and tearing are not observed within the stipulated dome height.

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