



THICKNESS DISTRIBUTION AND NUMERICAL MODELLING OF CONVENTIONAL SUPERPLASTIC FORMING IN AA2024 ALLOY

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Abstract: Super plastic Forming (SPF) is a close net-shape Forming process which gives numerous points of interest over ordinary shaping tasks including low Forming pressure because of low Flow Stress, low Die cost, more prominent Design flexibility, and the capacity to shape hard metals and shape complex shapes. The present work is going to focus on forming of aluminum sheet metal into cup using Super plastic forming technique. In order to optimise the superplastic forming processes, it is necessary to control the strain-rate and temperature induced in the material. The experimental work will be carried out in two stages. In the first stage heating of sheet metal will take place using furnace. Then in the second stage forming the sheet metal into desired shape will take place using blow forming process. The sheet was formed till 14.1 mm there after sheet was cracked. The thickness distribution of sheet metal after forming was analyzed. It is found that the thickness around the cracked surface is very less when compared to other formed portions of the sheet. The analysis of sheet metal formation was done in ABAQUS 6.12, and the analysis results were compared with experimental results.

Key words: Sheet metal forming, super plastic forming, Numerical modeling, experimental.

1. INTRODUCTION

Sheet metal Forming includes an extensive variety of procedures that make parts for a huge measure of purposes, both seen and concealed. Sheet metal alludes to metal that has a high surface territory to volume proportion. Sheet metal work stock, utilized for sheet metal procedures, is normally shaped by rolling and comes in loops. It works upon the hypothesis of super plasticity, which implies that capacity that a few materials need to experience substantial uniform elongation before necking and Fracture Tension". The task depends on the way that some combinations can be gradually extended well past their typical restrictions at hoisted temperatures.

The higher temperatures mean the flow stress of the sheet material is much lower than at typical temps. This trademark enables profound shaping strategies to be utilized that would regularly crack parts. Super plastic amalgams can be extended at higher temperatures by a few times of their underlying length without breaking. Super plastic Forming can deliver complex shapes with solidifying edges and other basic highlights too. "It was seen in paper [1] has investigated the plastic distortion conduct of the sheet amid Blow-Forming a superplastic utilizing "DEFORM" to do the recreations and figure the pressurization profile. In paper [2] it was seen that the superplastic tensile behavior of 5083 Al (Nominally Al/4.6% Mg) compounds from two distinct sources have been analyzed. It is discovered that for about a similar grain measure, one of the compounds (Alloy A) has marginally lower strain-rate affectability. It was seen in paper [3] a two-organize SPF process has been created and exhibited in shaping preliminaries utilizing a superplastic aluminum sheet combination. He proposed a preform has been intended to enhance the shaping of an intricate segment by giving a better thickness profile as thought about than an ordinary single stage forming cycle utilizing Finite component examination to control the plan of the preform depression since the preforming surface was not instinctive and could cause wrinkling in the last part. It was seen in paper [4] Superplastic Forming includes the forming of metal sheets by gas weight at hoisted temperatures. It depends on the way that fine-grained metals can display high sensitivities of flow worry to strain rate, yet this generally just happens at very moderate strain rates. Therefore, the procedure is much slower than customary squeezing tasks. It was seen in paper [5] in numerous super plastically shaped aviation segments, just a specific locale experiences superplastic forming. He proposed,

AZ31B magnesium amalgam is picked, and Friction Stir Processing is performed by fluctuating the procedure parameters, for example, as tool axial force, tool traversing speed and tool rotational speed. It is discovered that the strain rate affectability for the rubbing blend handled part has expanded, when contrasted with the base metal. It was seen in paper [6] in request to streamline the superplastic forming procedures, it is important to control the strain-rate instigated in the material by the weight gas. The test movement was completed utilizing a Pb-Sn-based metallic compound. An investigation in a paper [7] the endeavor was made to break down the Ti-6Al-4V composite sheet utilizing a ventured rectangular bite the dust by superplastic blow Forming procedure. This amalgam is most reasonable material for delivering complex shapes utilizing superplastic Forming techniques. An investigation in a paper [8] the laser welding microstructure of the fine-grained 5083 Al compound was considered. The fine equiaxed grains with 1.5 μm in focus zone of weld were seen by transmission electron magnifying lens. Malleable tests demonstrate that extreme elasticity of the welded example is about 91% that of the base metal at 500 °C. The present investigation confirms the attainability of the preparing techniques for the multi-sheet structures of an aluminum compound. The creator was addressed in paper, [9-23] an examination on ANSYS limited component code is utilized and an efficient methodology was produced to do the shaping investigation at consistent strain rate. Uniaxial pressure and profound illustration forms for 2024 Al. amalgam sheet". Super plastic shaping is one of the offers a scope of imperative advantages, from both the structure and creation points. In the first place there is the capacity to frame segments with twofold ebb and flow and smooth shapes from single sheet in one activity, with remarkable dimensional exactness and surface wrap up. So super plastic shaping is useful than other Forming procedures. The primary target of this examination is to frame the 1 mm sheet metal into wanted shape. The framed AA2024 sheet metal will be examined for thickness dispersion all through the shaped surface was finished up [18-23]. The main objectives are forming the sheet metal into desired shape. Forming of sheet metal at different temperatures and thickness distribution of sheet metal around the surface of the formed sheet metal.

2. EXPERIMENTAL PROCEDURE

In this chapter the experimental procedure was explained in detail. The design and fabrication were prepared and the process parameters and experimental conditions are explained. The sheet metal forming procedure with reference to different temperatures is also explained and is as follows.

2.1. Design of dies

The die design and fabrication is important as the female die gives shape while the male die gives passage for pressurized air to enter and form the sheet metal into desired shape.

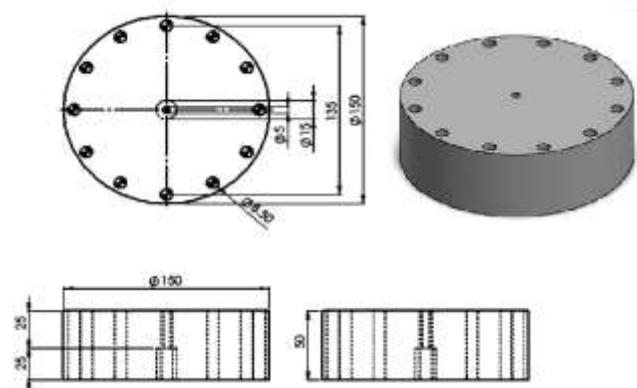


Fig. 1. Top, Isometric, Front, Top View of Male Die setup

Figure 1, shows the Male Die setup the drafting was done in Solid works software. The center hole will be used to send the pressurized gas, which falls on the sheet metal.

2.2 Design of Female Die

Female die will be having forming shape as shown in the figure 2, center hole will use to know the forming limit of the sheet metal and also to know the sheet metal temperature.

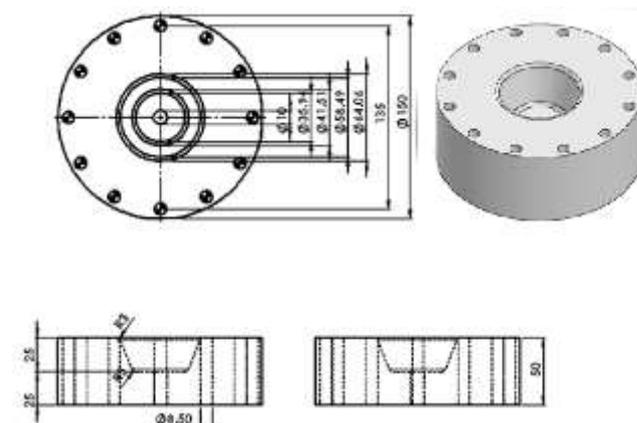


Fig. 2. Top, Isometric, Front, Top View of female Die setup

2.3. Fabrication of male die

The male die fabrication was done in CNC machines. The thickness of die is 50mm and is fabricated according to the cup shape shown in figure 3. In the center 5mm through hole is provided for allowing pressurized gas. On the top surface twelve 8.5mm diameter holes are drilled at 135mm pitch circle diameter and at angle of 30° between each hole.



Fig. 3. Fabricated male die



Fig. 4. 3/8th BSP Hole of Male Die

2.4. Fabrication of female die

The female die fabrication was done in CNC machines. 12 Slots will help to tightly fix the sheet metal in between male and female dies shown in figure 5. The through holes will be used to assemble the two dies along with the sheet in between them. Bolts and nuts were used to assemble the dies. The center hole was used to know the formation of die height. Female die will be placed on the top of the assembly and it allows sheet metal to form in desired shape. The thickness distribution can be measured through the hole provided at the top of the die. The female die consists of the sheet metal forming profile. The fabrication was carried out based on the design shown in figure 7. Slots were fabricated to align with male die slots. Holes were provided at 135 mm pitch circle diameter and at an angle of 30° between holes. The holes were drilled with 8.5mm dia. The specimen will be formed exactly at the center of the die. The pressurized gas will be allowed to fall on the specimen directly. A hole is provided at the bottom of male die to measure the thickness distribution of sheet metal. The temperature is also measured by sending probe into the hole provided at the bottom.

2.5 Specimen preparation

The sheet metal was cut 150mm dia. The 8.5mm holes were drilled at 135mm P.C.D and at an angle of 30° between each circle.



Fig. 5. Female Die



Fig. 6. Aluminum Sheet specimen



Fig. 7. Assembly of Dies with Sheet metal

The holes should match to the male and female die holes, so that while assembling sheet metal with dies there should not be any problem.

The assembly of dies with sheet was shown in the figure 6. The sheet will be placed in between male and female dies. The sheet has 9mm diameter holes in order to match holes of female and male die. Assembling will be done by fixing dies with sheet metal.

The sheet will be placed at the middle of the dies and fixed with bolts and nuts. Washers are provided in order to prevent the air leakage. The male die and female die will be placed at the bottom and top accordingly as shown in figure 7. The bottom of male die will be fixed with hydraulic pipe. The male die will be placed on the burner, so direct heat will be induced in the die as well as to hose pipe connection. The predicted temperature will always be high than the temperature measured. All the bolts and nuts should be fixed tightly as the air leakage is major problem in the superplastic forming. If there is air leakage taking place, we have to tightly tight the bolts and nuts. So that air leakage will be stopped and experiment can be done. Assembling of dies and sheet metal plays key role.

2.6 Experimental setup

The schematic diagram shown in figure 8 gives information about the experimental setup.

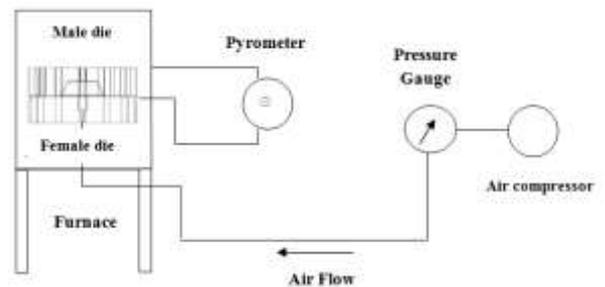


Fig. 8. Schematic Diagram of Experimental Setup

Cylindrical furnace dies burner, Pyrometer, Probes, Compressor, Pressure gauge are used in the experimental to get the formed cup. The experimental setup was shown in the figure 9. The dies are used to form the sheet to required shape and to allow the pressurized gas exactly fall on sheet metal at the time of forming. The burner is used to heat the dies and sheet metal up to the required temperature. Pyrometer is used to know the surface and internal temperatures of die and sheet metal.



Fig. 9. Experimental Setup of Superplastic Forming



Fig. 10. Heating of Dies and Sheet metal

After the air leakage test, the experiment work will take place. The dies will be placed on the burner and the dies will be covered with furnace as shown in figure 9. The hydraulic pipe which is connected to the female die at one end will be connected to air compressor at the other end. Then the heating process will be started. Surface probe which is connected to the pyrometer will be used to detect the surface temperature of dies shown in figure 10. Point probe is used to detect the inner temperature of dies as well as sheet metal temperature. After the temperature reaches pressurized air is allowed from the compressor at constant rate.



Fig. 11. Temperature Measuring with Pyrometer

By using depth micrometer to find the formation length of sheet metal. At the same time temperature should be noted at regular intervals in order to trace the formation of sheet metal at different temperatures shown in figure 11. After the sheet reaches maximum formation limit, turn off the burner and wait until the sheet metal and dies comes to the room temperature. After the dies and sheet metal reaches the room temperature, disassemble the dies and sheet metal. After disassembling check the sheet metal thoroughly for any cracks. Then analyze the sheet metal thickness at different areas. The constant pressure will be sending through compressor with 7bar.

2.7 Air leakages test

Air leakage test is one of the important tests in superplastic forming process. Air leakage is major problem in this process. Hydraulic hose pipe is connected in between dies and air compressor. The dies are completely immersed in water and 3.5bar air is allowed from the compressor. If we get any air bubbles in the bucket, then there is leakage of air in dies. Fixing of dies with sheet metal tightly can reduce the leakage. If there are no bubbles, there is no air leakage as shown in figure 12.



Fig. 12. Air Leakage Test



Fig. 13. Constant Pressure Gauge at 3.5bar

2.7.1. Experiment No 1

The experiment was conducted at varying temperature which is shown in the table given below. A constant Pressure of 7 bar was allowed from the air compressor shown in figure 14. The chamber temperature and mould temperature are noted at regular intervals as shown in the below table 1. The sheet metal has melted in some places and has cracked drastically in some places. The sheet metal was stuck to the die slots due to rapid melting. The temperature has been raised drastically, which results in melting of sheet metal shown in figure 15.

Table 1. Temperature distribution of die

Sl.no	Time (min)	Chamber temperature (°C)	Mold temperature (°C)
1	0	38	38
2	15	220	194
3	30	300	220
4	45	370	295
5	60	525	470



Fig. 14. Sheet Metal Formation

2.7.2. Experiment No 2

The experiment was conducted at varying temperature which is shown in the table given below. A constant Pressure of 7 bar was allowed from the air compressor. The chamber temperature and mould temperature are noted at regular intervals as shown in the below table 2. The temperature distribution was tabulated in the table. At different time intervals, mould temperature is noted and Vernier reading is also noted at a time to know the expansion of sheet metal. The forming distance of sheet metal will be noted and tabulated. The surface temperature distribution and mould temperature will be noted simultaneously. The mould temperature and surface temperature will be noted simultaneously with point and surface probes respectively. The table 2 gives the values of different temperatures and sheet forming. The sheet metal was formed up to 14.1mm, and then suddenly air leakage has taken place. The sheet was cracked and from female die air leakage has taken place. The burner was stopped suddenly at 348°C.

Table 2. Surface temperature distribution of die

S.N.	Time (min)	Mould temperature (°c)	Vernier reading (mm)	Difference (mm)
1	0	37	48.80	0.00
2	20	100	48.50	0.30
3	5	124	46.80	0.10
4	5	165	46.50	0.15
5	20	240	46.00	0.40
6	15	287	44.70	0.35
7	15	320	34.70	8.10
8	5	348	30.00	4.70



Fig. 15. Aluminum Sheet Metal Forming

The experiment was conducted for the span of 85minutes. The constant air pressure was allowed inside the die and made it to fall on sheet directly which is shown in figure 15.

The crack was formed on the sheet and air leakage has taken place. The burner was turned off after the air leakage has taken place. The cracked portion was shown in figure 16. The crack was formed exactly at the middle of the sheet metal.



Fig. 16. Crack on Formed Aluminum Sheet Metal

3. RESULTS AND DISCUSSIONS

The experimental results will be calculated and plotted on the graph. The thickness distribution around the surface of the formed sheet metal was tabulated and plotted in the graph.

3.1. Results

The obtained results are as follows:

1. Projected diameter of *sheetmetal* = 60mm ;
2. Projected area of *sheetmetal* = $(\pi D^2) / 4 = 2827 \text{ mm}^2$;
3. Area of *hemisphere* = $2\pi r^2 = 22619.46 \text{ mm}^2$.

3.2. Thickness distribution of the sheet

The formed sheet was cut into two pieces. In order to measure the sheet thickness distribution throughout the entire formed shape, the sheet was cut into two pieces. The cutting will be exactly at the center of the sheet shown in figure 17. Later the thickness distribution of both the sheets will be measured.

Table 3. Left side thickness distribution of the sheet after forming

Position	at Y ₁	at Y ₂	at Y ₃
1	0.86	0.86	-
2	0.74	0.79	-
3	0.69	0.68	0.75
4	0.54	0.62	0.74
5	0.49	0.58	0.71
6	0.60	0.6	0.73
7	0.72	0.68	0.79
8	0.82	0.85	-



Fig. 17. Left (L) and Right(R) Portions of Formed Sheet Metal

The sheet was cut exactly at the middle of the axis. The right side(R) and left side (L) sheet thickness distribution will be measured separately. The thickness distribution was tabulated and graph was plotted.

3.3. Left Side Thickness Distribution of the Sheet

The left side thickness distribution of the sheet was measured with Thickness micrometer. Points were marked on the sheet at different positions to measure the thickness. This allows finding the thickness distribution on maximum portion of the sheet as shown in figure 19.



Fig. 18. Left Portion of Formed Sheet

The thickness of the sheet will be measured two times. Left formed portion of the sheet will analyze first. The thickness will be measured at maximum positions of the sheet metal as shown in figure 18. The thickness will be calculated using digital micrometer. The thickness probe will be placed at top and bottom of the sheet and the reading will be noted. All the 21 points will be measured and readings will be tabulated as shown in table 3.

The thickness will be taken in three planes i.e., Y1, Y2, Y3 positions to cover the maximum area of the sheet metal. The readings from digital micrometer will be noted accordingly which is shown in table 3. The graph will be plotted based on the values obtained. The graph will be plotted between position of sheet and thickness distribution as shown in fig 20. Based on the graph, the thickness distribution at different points can be analyzed and compared with right side part of the sheet.

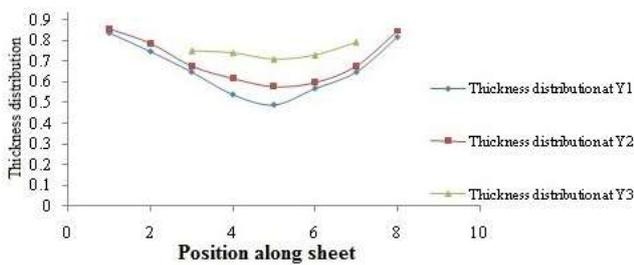


Fig. 19. Thickness Distribution of Left Portion of the Formed Sheet

The above graph shows that the thickness distribution of sheet varying at different positions. The minimum thickness achieved on right side plate is 0.49mm at Y1 position. The figure 20 shows that the thickness distribution was more in Y1 position and minimum in Y3 position. The right side formed sheet was marked with 25 points. All the points will be measured for thickness as shown in figure. The half portion of the formed sheet metal is cut with hexa blade.

3.4. Right Side Thickness Distribution of the Sheet

The right side thickness distribution of the sheet was measured with Thickness micrometer. Points were marked on the sheet at different positions to measure the thickness. This allows finding the thickness distribution on maximum portion of the sheet as shown in figure 20.

The thickness will be measured with both thickness micro meter and digital micrometer in order to get the accurate thickness values. The thickness distribution of both the left and right side portions are compared based on the graphs obtained. The cracked portion thickness also measured in the same way. The graph was plotted for the thickness distribution on the surface of the super plastically formed sheet metal.



Fig. 20. Right Portion of Super plastically Formed Sheet Metal

The right side formed sheet metal is having 25 positions marked on it for measuring the thickness and tabulated as shown in table 4.

The thickness distribution was finally plotted based on measured positions. The right side formed sheet was marked with 25 points. All the points will be measured for thickness as shown in figure. The half portion of the formed sheet metal is cut with hexa blade. The thickness will be measured with both thickness micro meter and digital micrometer in order to get the accurate thickness values.

Table 4. Right side thickness distribution of the sheet after forming

Position	at Y ₄	at Y ₅	at Y ₆	at Y ₇
1	0.84	0.84	0.84	-
2	0.76	0.77	0.79	-
3	0.69	0.71	0.72	0.79
4	0.65	0.67	0.68	0.76
5	0.53	0.60	0.65	0.71
6	0.64	0.76	0.79	-
7	0.77	0.84	0.84	-
8	0.86	0.86	0.87	-

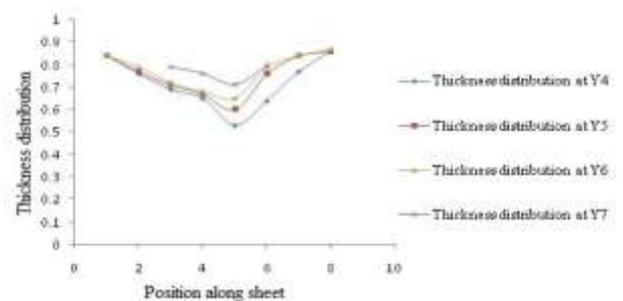


Fig. 21. Graph Showing the Thickness Distribution of Right Portion of the Formed Sheet

The above figure 22 graph shows that the thickness distribution of sheet varying at different positions. The minimum thickness achieved on right side plate is 0.53mm at Y₄ position. The figure 21 shows that the thickness distribution was more in Y₄ position and minimum in Y₇ position.

3.5. Thickness Distribution around Cracked Portion

The thickness distribution around the cracked portion is tabulated in the table 5. The crack was formed at 348°C where the sheet was formed up to 14.1mm.

Table 5. Cracked portion thickness distribution

Position at cracked portion	Thickness distribution (mm)
1	0.54
2	0.49
3	0.60

The sheet was cracked at 380°C and it has expanded up to 14.1mm. The thickness distribution of sheet metal at different positions is tabulated in table 5. The minimum thickness was achieved at position 2 as shown in the table 5. The maximum thickness was achieved at position 3 which is 0.60mm.

The figure 22 shows the thickness distribution of the sheet metal around the cracked portion after forming. The thickness around the cracked portion was minimum which is equal to 0.49mm. There after the sheet failed to expand as the sheet got crack. The graph shows that the thickness distribution at the beginning is high and low at the middle. The thickness distribution was not uniform in all the positions especially at the cracked portion.

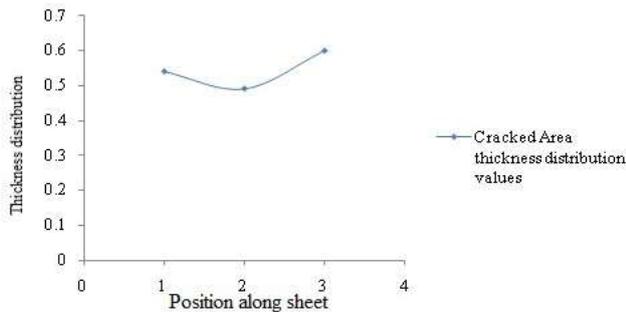


Fig. 22. Graph Showing Thickness Distribution around the Cracked Portion of the Sheet

3.6. Dynamic Modelling

The dynamic modeling of superplastic forming was done in ABAQUS 6.12 version. The material considered for the analysis was Elastic type material. The input parameters considered for the analysis are listed as follows:

1. Material type: Elastic;
2. Young's Modulus: 73000MPa;
3. Poisson's Ratio: 0.33;
4. Density: 2.78 g/cm²;
5. Applied pressure on the sheet metal: 7000 g/cm² (constant);
6. Temperature: 320°C (constant);
7. Time duration: 85 minutes.

The above parameters are considered for the analysis of sheet metal formation. The total time given as input for conducting the experiment was 85min, where the sheet was formed up to 13.09mm.

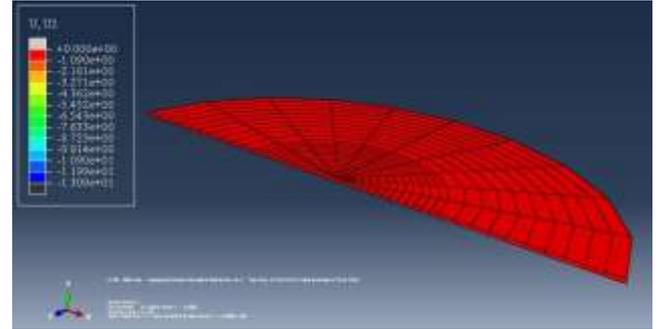


Fig. 23. Initial Formation of Sheet Metal

The formations of sheet metal for various time intervals are shown in figures 23 to 29.

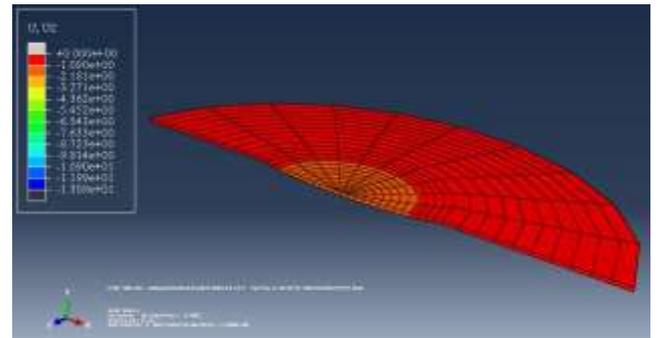


Fig. 24. Formation of Sheet Metal after 3 minutes

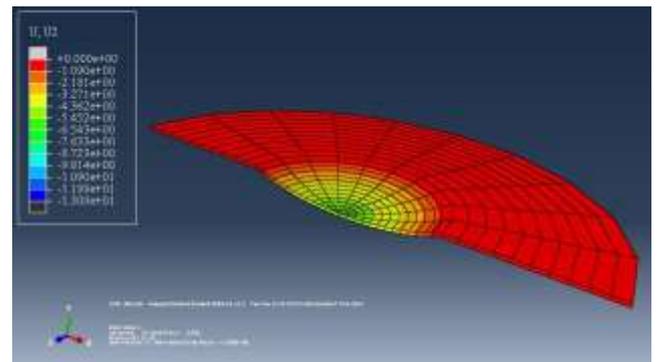


Fig. 25. Formation of Sheet Metal after 5 minutes

The initial stage before forming of the sheet metal was shown in figure 25. The formation of sheet metal after 3 minutes was shown in figure 26. The formation of sheet metal after 28 minutes was 8.03mm which is shown in figure 27. The formation of sheet metal after 42 minutes was 9.1mm which is shown in figure 29. The formation was increasing with respect to increase in time. The sheet metal was formed according to pressure and temperature given.

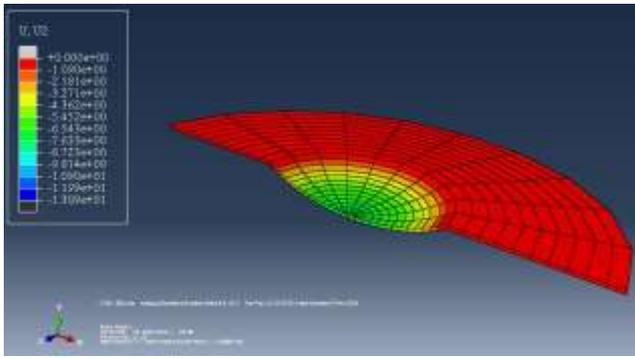


Fig. 26. Formation of Sheet Metal after 19 minutes

The formation of sheet metal after 5 minutes was 5mm which is shown in figure 25. The formation of sheet metal after 19 minutes was 6.5mm which is shown in figure 26. The formation was increasing with respect to increase in time. The sheet metal was formed according to pressure and temperature given. The time taken to complete the total analysis is 85 minutes which was divided to smaller sections based on the formation of sheet metal at different time intervals. The sheet metal was formed till 13.09mm, which will come at the final stage of the analysis. The formation for remaining times will be continued.

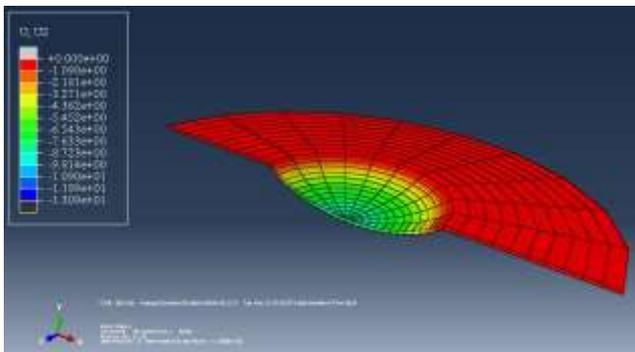


Fig. 27. Formation of Sheet Metal after 28 minutes

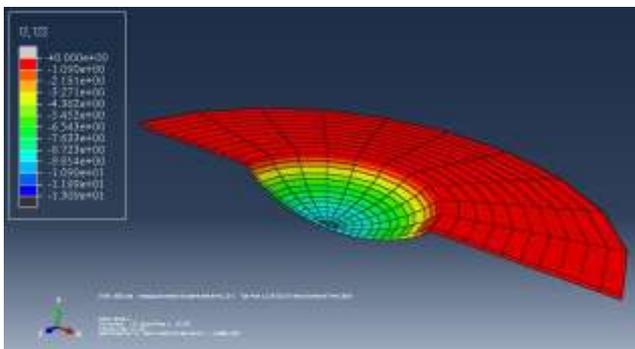


Fig. 28. Formation of Sheet Metal after 42 minutes

The time taken to complete the total analysis is 85 minutes which was divided to smaller sections based on the formation of sheet metal at different time intervals. The sheet metal was formed till 13.09mm, which will come at the final stage of the analysis. The formation for remaining times will be continued.

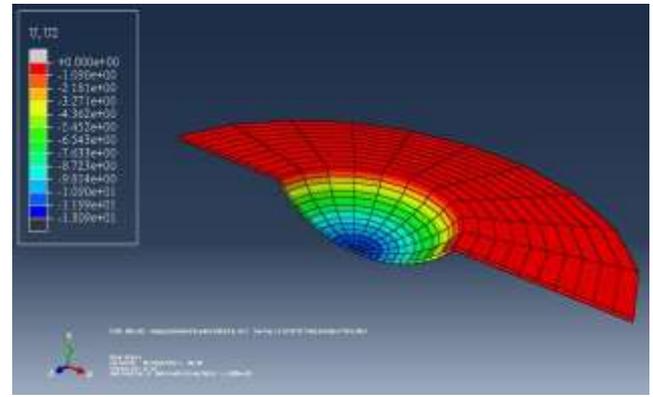


Fig. 29. Formation of Sheet Metal after 64 minutes

The formation of sheet metal after 64 minutes was 11.2mm which is shown in figure 29. The formation of sheet metal after 85 minutes was 13.09mm which is shown in figure 30. The formation was increasing with respect to increase in time.

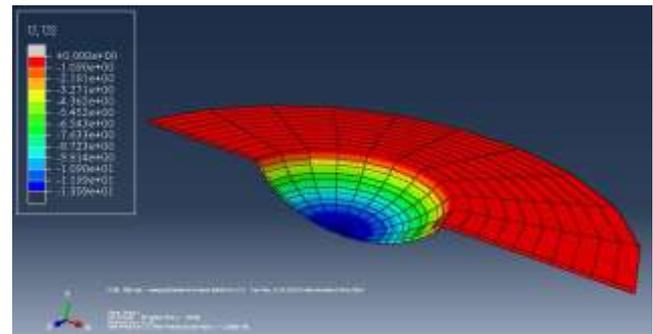


Fig. 30. Formation of Sheet Metal after 85 minutes

The sheet metal was formed according to pressure and temperature given. The time taken to complete the total formation is 85 minutes which was divided to smaller sections based on the formation of sheet metal at different time intervals. The sheet metal was formed till 13.09mm

4. CONCLUSIONS

In the present study an attempt has been made to determine the formed AA2024 sheet metal will be analyzed for thickness distribution throughout the formed surface the following conclusions are made from the study.

The experiment was conducted at variable temperature and constant pressure of 8kg/cm². The maximum temperature reaches is 348°C. The constant pressure was applied throughout the experiment.

When the temperature is at 348°C the sheet got cracked and air was leaked from the female die. The minimum thickness of the sheet after forming is 0.49mm, where crack has taken place.

The sheet was formed till 14.1mm and then failed to form further as the sheet was cracked. Forming of sheet was maximum at 320°C. After 65 minutes of

burning i.e., when the temperature is at 3200c the superplastic state has been achieved for AA2024. The sheet was cracked because of the thickness issue. The sheet thickness is 1 mm, so it formed superplastically up to 14.1mm. After that the sheet failed to withstand 8 kg/cm² pressure. It is better to use 2mm or more thickness sheet to form sheet completely to the desired shape.

The thickness distribution around the cracked portion is high as compared to thickness distribution at the remaining formed portion of the sheet.

AA2024 is also suitable for superplastic forming operations. The thickness of the sheet is 1mm which tends to form till 14.1mm. So AA2024 is suitable for superplastic forming.

The analysis work was carried out in ABAQUS 6.12 and it is found that the sheet metal was formed till 13.09mm. There after the sheet failed to form. Hence the analysis result was nearly equal to the experimental result which is 14.1mm.

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