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Optimizing Sheet Metal Formation through Advanced Hydroforming Simulation Technique

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Abstract

In this study, we investigate into the simulation of sheet metal hydroforming for crafting the cap of the axle-hub of a tip trailer within our manufacturing facility. This cap serves a crucial role in safeguarding wheel bearings from the detrimental effects of dust, sand, and dirt. The motivation for this work arises from the challenges encountered during the fixation of a conventional dust cap, which often falls off when subjected to pressure or threading, particularly when the tractor is in motion. The innovative approach pursued in this research involves the utilization of lightweight aluminum sheet metal for cap production, owing to its facile formability. The cap design incorporates four evenly distributed holes around its circumference and secures to the flange using screws. Prior to the manufacturing phase, a simulation of the cap-forming process was conducted using ANSYS Model 15, a computer-aided engineering program. The necessary models were crafted in CATIA, a computer-aided design program, streamlining the entire process to enhance efficiency, reduce costs, and minimize manpower requirements. The simulation encompassed three different thicknesses (1 mm, 2 mm, and 3 mm) for two distinct aluminum alloys, namely 1100 and 5652. The objective was to discern the optimal alloy for the forming process. Essential mechanical properties, including ultimate tensile strength, modulus of elasticity, and yield stress, were input into the ANSYS program to accurately reflect the materials' behavior during forming. The outcomes of our investigation revealed that aluminum alloy 5652 outperformed 1100 in terms of formability. The former exhibited a forming pressure of 300.2 MPa, while the latter required 298.3 MPa for the same forming depth (40 mm) across all three thickness variations. Additionally, the study demonstrated that 5652 is not only more efficient but also safer and more resilient than 1100.

1. Introduction

Hydroforming is a forming technology for tube and sheet material aiming at high part strength for the manufacturing of simple and complex geometries [1]. Hydroforming is a manufacturing process that uses the pressure exerted by a hydraulic medium to produce deformations of a sheet or tubular blank [2]. One of the most important objectives of hydroforming process is the production of the parts with a minimization of thickness, weight reduction and to obtain a uniform thickness [3,4]. Additionally, hydroforming improves formability, reduced need for secondary operations, and lower tooling costs [5]. The sheet hydroforming process, uses high pressure fluid for deformation of a blank (sheet) into a desired shape with die [6]. A large number of studies have been carried out to optimize design and process parameters in conventional sheet metal forming processes to enhance formability and to develop new materials and processes with improved formability [7]. 5XXX alloys, in particular, have a good formability, and are used in automotive inner panels [8]. Ayan Roy Naskar and et al. [9] used explicit Finite Element Analysis program in ANSYS and ABAQUS software programs, to predict optimized forming parameters, include the punch force, blank holding force, forming factor, and hydrostatic pressure will contribute to cost reduction of the processed metal through curtailment in material usage and manufacturing time. The present results are validated with previous experimental readings to check the feasibility of simulated analysis. The comparison reveals that both the readings show a good agreement in thickness distribution and load-displacement relationship. Vahid Modanloo and et al. [10] enhanced sheet metal formability by employing a mineral grease pressure medium in the hydrodynamic deep drawing process on the flat bottom of pure copper and DIN 1.0338 steel cups. Experiments and finite-element method (FEM) simulations were investigated. After that, two pressure media—grease and water—with varying viscosities are used in the experiments. When grease has a higher viscosity than a water pressure medium, the forming force increases by an average of 16%. Bharatkumar Modi [11] carried out Finite element (FE) simulations to predict formability with Square cups that drawn using constant and variable blank holding force techniques. The results of FE analysis have been found to be in good agreement with experimental data. This paper is used the ANSYS program to simulate the sheet cap to know the optimum pressure required to form it before the manufacturing process occurs.

2. Finite Element Method

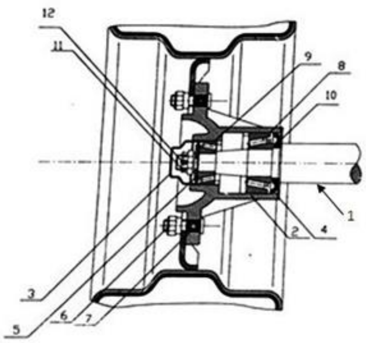
The finite element method (FEM) is a numerical technique for solving problems to find out approximate solution of a problem [12], which are described by the partial differential equations or can also be formulated as functional minimization. Approximating functions in the finite elements are determined in the terms of the nodal values of a physical field, which are sought. FEM subdivides a whole problem or entity into numbers of smaller simpler parts, called finite elements, and solve these parts for the problems. The main advantage of FEM is that it can handle complicated boundary conditions and geometries with very ease technique [13].

2.1. Advantages and Disadvantage of FEM

1. Implementation of any type of boundary conditions is very easy.
2. Automatic mesh or grid generation techniques to assist in model building.
3. Any type of loading can be handled.
4. The element sizes can be varied throughout the model. Wherever it is necessary, we can use fine meshes.
5. Altering the element model with different loads, boundary condition and other changes on the model can be done easily [3].
6. Need for computer programs and facilities.
7. Gives so global competition.
8. FEA software's are costlier.
9. Even though FEA software's are user friendly but they are not relatively easier for use [14].

2.2. Dust Cap of Axle- Hub Assembly

Figure (1) below shows the axle and hub assembled of the tip trailer produced in our company with 4-ton capacity which is fastened with agriculture tractor. The dust cap is used to shield bearings, grease, and other inner hub components from dust and contaminants.



No.	Part No.	Name	Quantity
1	52-03-100DV	axle	1
2	521-03-304DV	hub	2
3	52-03-201DV	Cap	2
4	521-03-401DV	Washer	2
5	521-03-402DV	Washer	2
6	52-03-637A	Nut	12
7	DD127/3DV	Stud bolt	12
8	SKF 32309	Bearing	2
9	SKF 32306	Bearing	2
10	100x50x12	Seal	2
11	DIN 937	M24nut	2
12	DIN 94	Ø5x45 pin	2

Figure (1): The axle-hub assembly.

3. The Experimental Work

There was a problem in assembly of manufactured dust cap with the manufactured hub of tip trailer. A dust cup falls on the land when the tractor is moved as shown in Figure (2).

Figure (2): Fall of the dust cup**.**

Therefore, two types were used to solve that problem, one of them was fixing the cap by threading with the hub as shown in Figure (3), and the other one was by pressing the cap with the hub as in Figure (4). The two treatment solutions were not successful. The aim of this research is to design a cap that holds by using bolts fixed on the hub surface as in Figure (5) below.

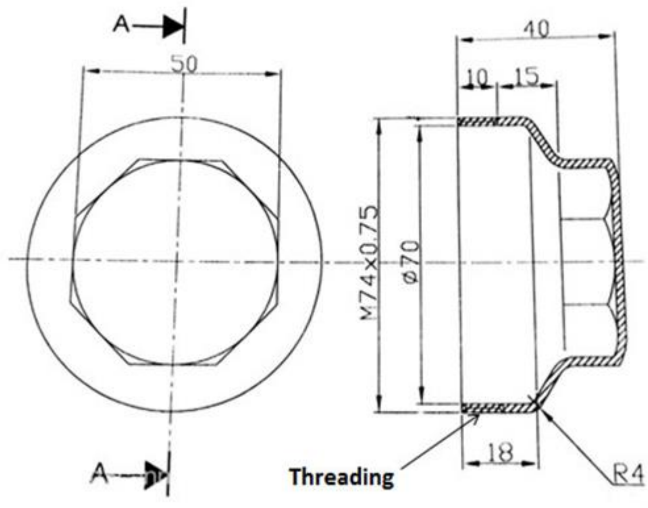


Figure (3): Threading cap.

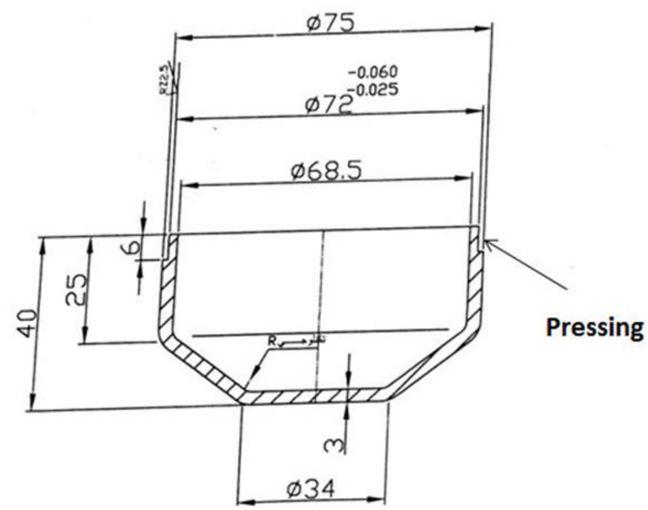


Figure (4): Pressing cap.

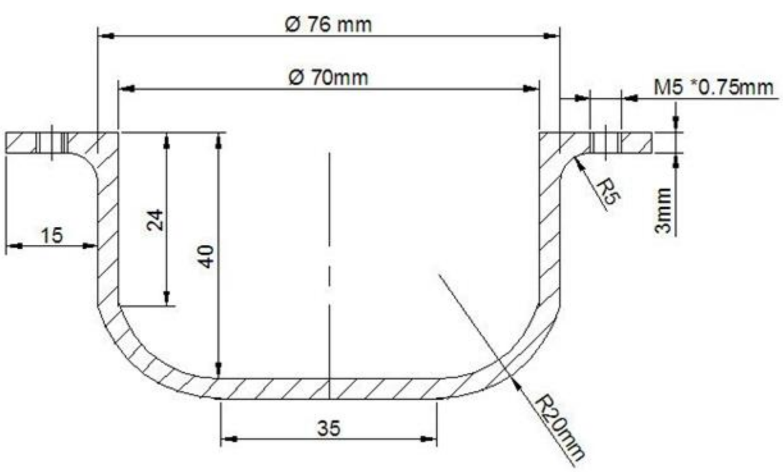


Figure (5): The bolting cap.

This project is mainly carried out with the aim of selecting the suitable thickness of aluminum alloy sheet material for the cap. The cap is modeled in ANSYS workbench software packages v15. Static structural analysis is carried out in ANSYS software to determine the equivalent stress, and deformation (depth of forming).

Because of the complex nature of the hydroforming process, the behavior of the process was done in the simulation study, using the following steps:

1. From the engineering data cell put the new material properties of aluminum cap material. Table (1) below shows the mechanical properties of two used aluminum alloy [15].

Table (1): Mechanical properties of aluminum alloys.

Material	Modulus of Elasticity (MPa)	Tensile Strength (MPa)	Tensile Yield (MPa)	Poisson's Ratio
Aluminum 1100	69.000	90	34	0.33
Aluminum 5652	70.000	195	90	0.3

2. Draw model of cap by using geometry cell in analysis system.
3. Making the area of the cap with a diameter of 70 mm to be formed at different thicknesses (1, 2 and 3mm).
4. Applying boundary conditions to the geometry: edge fixed support and pressure that applied gradually till to reach 40 mm depth.
5. The problem is solved using SOLVE command.

4. Results and Discussion

Aluminum and its alloys have been widely applied in the automotive, aircraft and telecommunication industries for their excellent characteristics, such as light weight and high strength [16]. Table (2) shows the applied of pressure required to form sheet cap and corresponding deformation (depth), using the Von Mises equivalent stresses for three thicknesses.

Table (2): The applied pressure and the resulted equivalent stress.

Material	Thickness (mm)	1	2	3
Al-1100	Pressure (MPa)	11.252	90.34	300.2
	Deformation (mm)	40.004	40.008	40
	Von Mises stress (MPa)	8.705	15.591	23.230
Al-5652	Pressure (MPa)	11.13	89.7	298.3
	Deformation (mm)	40.032	40.006	40.007
	Von Mises stress (MPa)	8.528	14.859	22.186

Figure (5a, b, & c) shows the depths obtained to formed a cap using 1100 aluminum material with corresponding pressure required 11.252, 90.34 and 300.2 MPa for 1,2 and 3mm thickness respectively.

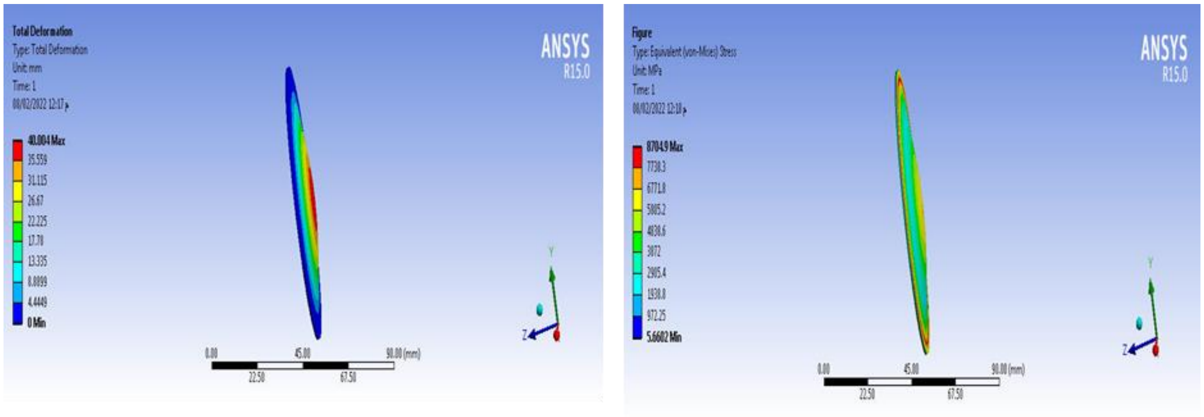


Figure (5-a): The total deformation and equivalent stress for 1100 with the applied pressure 11.252MPa.

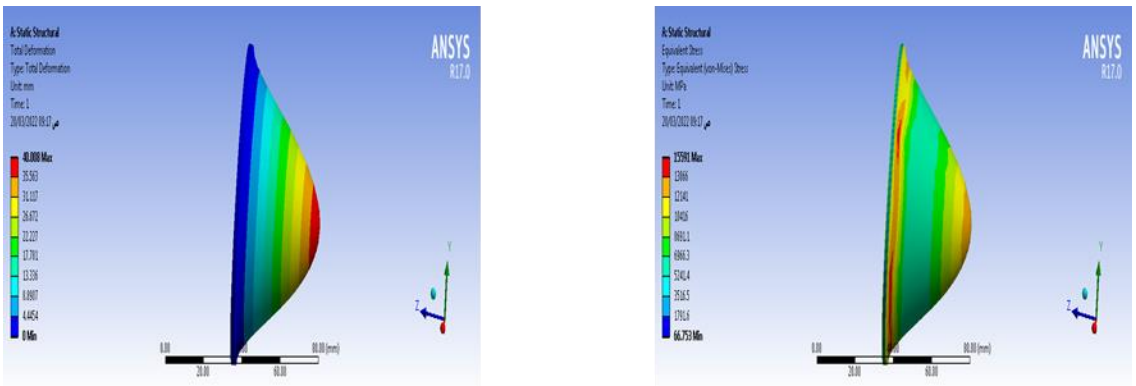


Figure (5-b): The total deformation and equivalent stress for 1100 with the applied pressure 90.34 MPa.

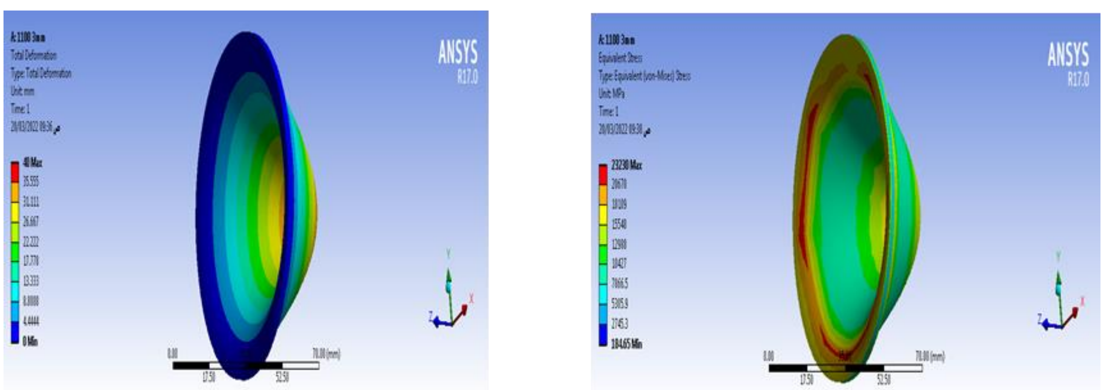


Figure (5-c): The total deformation and equivalent stress for 1100 with the applied pressure 300.2 MPa.

Figure (6a, b & c) shows the depth required to form a cap using 5652 aluminum material with corresponding pressure required 11.13, 89.7, and 298.3 MPa for 1,2 and 3mm plate thickness, respectively.

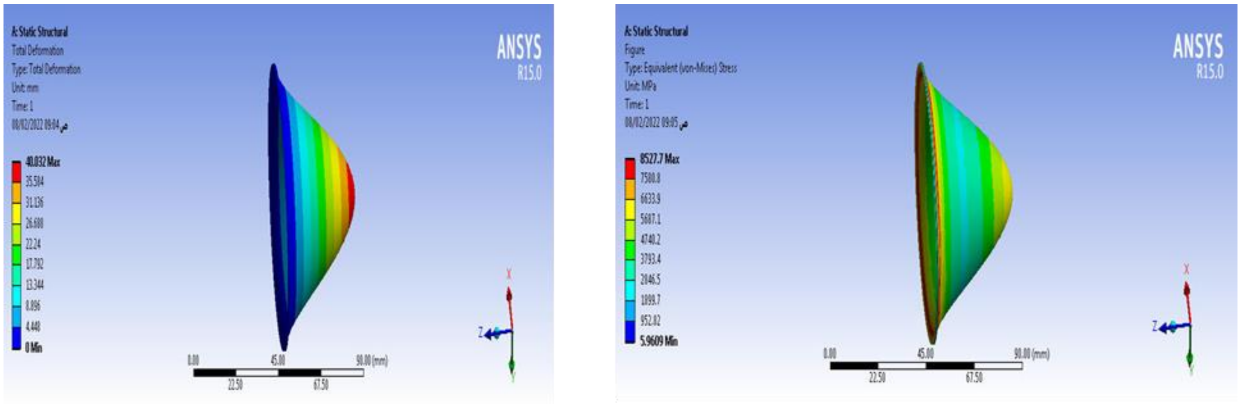


Figure (6-a): The total deformation and equivalent stress for 5652 with the applied pressure 11.13MPa.

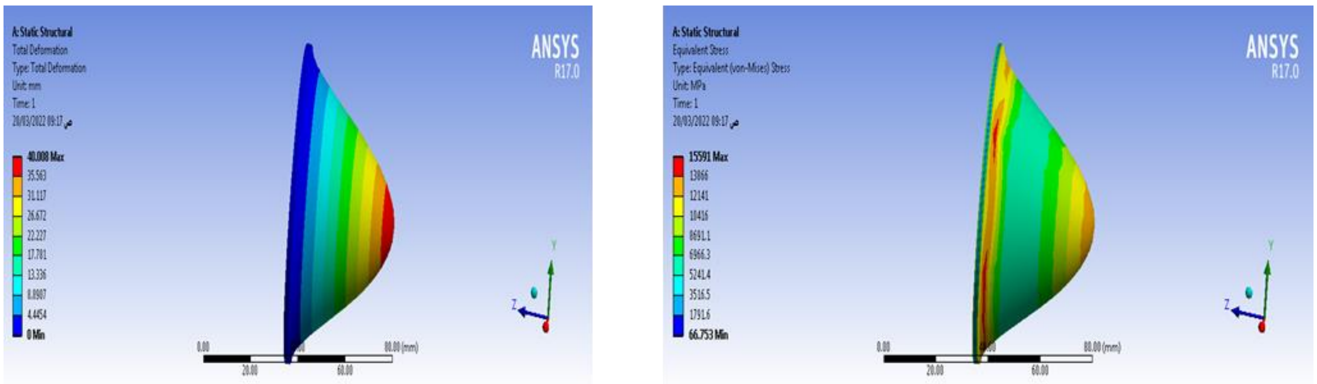


Figure (6-b): The total deformation and equivalent stress for 5652 with the applied pressure 89.7 MPa.

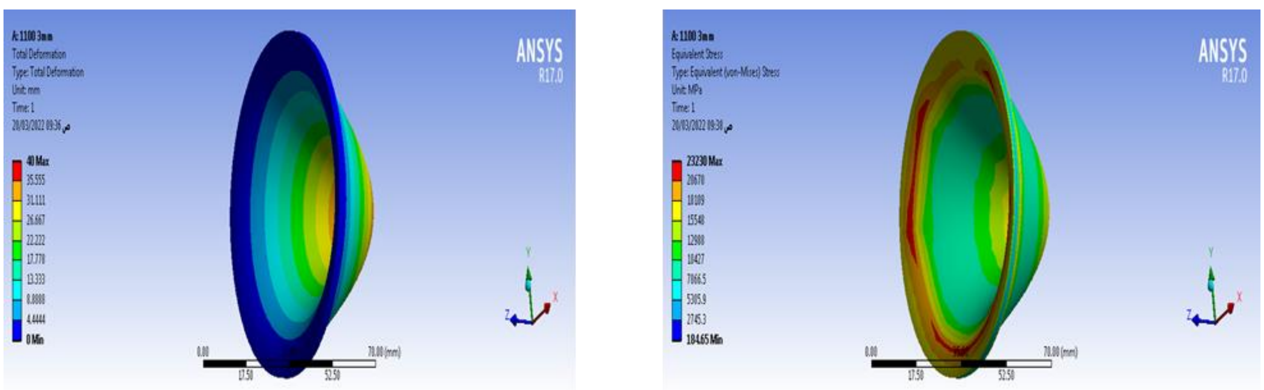


Figure (6-c): The total deformation and equivalent stress for 5652 with the applied pressure 298.3 MPa.

The factor of safety equation is used to predict the preference for using two metals in the cap forming process.

$$\textbf{factor of safety } (\boldsymbol{\partial}) = \frac{\textbf{Tensile Yield}}{\textbf{Actual strength}} \quad \textbf{(1)}$$

$$(\boldsymbol{\partial})\textbf{case 1100 a} = \frac{\mathbf{34}}{\mathbf{8.705}} = \mathbf{3.9} \quad \textbf{(2)}$$

$$(\boldsymbol{\partial})\textbf{case 5652 a} = \frac{\mathbf{90}}{\mathbf{8.528}} = \mathbf{10.5} \quad \textbf{(3)}$$

$$(\partial)\text{case 1100 b}=\frac{34}{15.591}=2.1 \quad (4)$$

$$(\partial)\text{case 5652 b}=\frac{90}{14.859}=6 \quad (5)$$

$$(\partial)\text{case 1100 c}=\frac{34}{23.230}=1.4 \quad (6)$$

$$(\partial)\text{case 5652 a}=\frac{90}{22.186}=4 \quad (7)$$

The above resultant values of cap forming simulation analysis were carried out for two different materials. The results were indicated little difference in the amount of pressure required to obtain the depth of forming, therefore equivalent stress also has a bit little difference. Equations of a factor of safety above showed that the 5652 aluminum is better and safer than 1100 aluminum.

5. Conclusions

A dust cap is used in the tip trailer wheel to prevent dust or other small particles from entering and damaging components. The analysis and design optimization of the cap were carried out to make it easy to holds on the hub surface. Analysis has been achieved by comparing simulation of strength with two different aluminum materials 1100 and 5652, with different thicknesses. Aluminum 5652 shows higher strength, and low pressure required to form the cap than 1100.

Conflict of Interest: The authors declare that there are no conflicts of interest associated with this research project. We have no financial or personal relationships that could potentially bias our work or influence the interpretation of the results.

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