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Finite Element Analysis of Wrinkling and Shearing of Sheet Metal Forming

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Abstract

Objectives: The objective of this work is to perform the sheet metal forming punch and die clearance for the forming of automatic ticket vending machine kiosk. **Methods/Analysis:** Modeling of sheet metal, punch and die is done. Sheet metal forming simulation is performed using ANSYS LS-DYNA and energy graph were obtained to validate the theoretically obtained clearance values. **Findings:** Different punch and die clearance values are simulated to show the wrinkling and shearing of sheet metal during the forming process. The theoretically obtained clearance value is verified with Finite Element Analysis (FEA) simulation. **Applications/Improvements:** This work shows the sheet metal forming and the effect of various punch and die clearance values at the time of forming operation.

Keywords: Clearance, Die Design, Finite Element Analysis, Sheet Metal Forming

1. Introduction

Sheet metal is simply metal formed into thin and flat pieces. It is one of the fundamental forms used in metalworking, and can be cut and bent into the variety of different shapes. Countless everyday objects are made using sheet metal forming. There are various parameters involved in obtaining quality sheet metal forming. Author in[1] studied the variable friction model in sheet metal forming with advanced high strength steel and reported that decrease in coefficient of friction with the increase in normal contact pressure. Author in[2] performed sheet metal forming and spring back simulation and reported that solid-shell element has demonstrated best performance. Author in[3] have done the analytical, and numerical investigation of wrinkling for deep-drawn anisotropic metal sheets reported about critical stress states on the orientation of principal stress axes. Author in[4] studied the simulation of wrinkling in sheet metal forming in conical cups reported that initial shape of the finite element mesh is important for accurate results. Author in[5] have published a technical note on computer-aided analysis and design of sheet metal forming processes and quantitative assessment of rigid die. Author in[6] reported about plastic anisotropy and cross hardening of sheet metal. Author in[7] studied blanking clearance and grain size effects on micro-deformation and fracture and concluded that the ultimate shearing strength increases with the decrease of foil thickness. Author in[8] investigated sheet metal forming by numerical simulation and experiment and compared the variation in numerical and experiment methods regarding die structure and overlap surfaces. Author in[9] performed the FEA and experimental comparison of Stainless Steel (SS) sheet forming with spring back effects. Author in[10] did the finite element simulation of clearance of the forming quality reported that the clearance between the punch and die will affect the precision of the shape and dimensions dramatically. Author in[11] performed finite element simulation of the shearing mechanism in the blanking of sheet metal and reported that the roll-over depth increases with increasing punch penetration and clearance and penetration depth at crack initiation depends on the clearance between the punch and die. Author in[12] studied the wrinkling behavior of laminated steel sheets concluded that it is invalid to model the laminated sheet as a solid panel. Author in[13] studied formability of epoxy based fiber

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metal laminates and reported about the ductile fracture. From the previous studies, it is observed that the FEA is a most important tool to simulate the behavior of sheet metal forming. The clearance in sheet metal forming is an important factor to be addressed for the better quality of sheet metal forming. Thus, the aim of this study is to show the effect of clearance in sheet metal forming as shown in Figure 1.

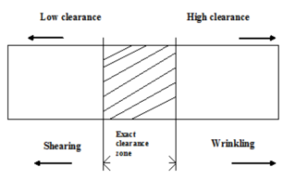

Figure 1. Effect of clearance in sheet metal forming.

2. Materials and Methods

2.1 Modeling of Components

The kiosk model of ticket vending machine is considered as punch and similar shape of a die is modeled in ANSYS. A sheet metal of 0.455 mm thickness is modeled. The modeled components are shown in Figure 2. The modeled components of punch and die are shown in Figure 3. The assembled model of components is shown in Figure 4. The material taken as sheet metal is AISI 316 Stainless Steel (SS). A bilinear isotropic material model is taken for this simulation. Classical bilinear isotropic hardening model uses two slopes (elastic and plastic) to represent the stress-strain behavior of the material. The stress-strain behavior can be specified at only one temperature. The input material properties of AISI 316 SS are presented in Table 1.

Table 1. Properties of AISI 316 SS

Sheet metal Properties	Values
Young's modulus (Mpa)	$2.1x10^5$
Poisson's ratio	0.29
Yield stress (Mpa)	170
Density (Kg/mm^3)	$8x10^{-6}$
Tangent modulus (Mpa)	850

Mpa, Mega pascal

The punch will be a rigid material with all degrees of freedom constrained except the Z-direction. The punch must have a vertical direction of movement. Even though this material model is rigid contact surface, it is necessary to give elastic material properties which are used to define the contact stiffness between mating as presented in Table 2. The die material considered for this analysis is metal ceramic.

Table 2. Material properties of punch

Properties	Values
Density (Kg/mm^3)	$8x10^{-6}$
Young's modulus (Mpa)	$2.1x10^5$
Poisson's ratio	0.29

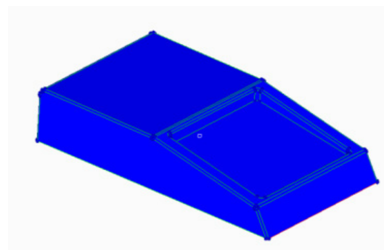

Figure 2. Kiosk model.

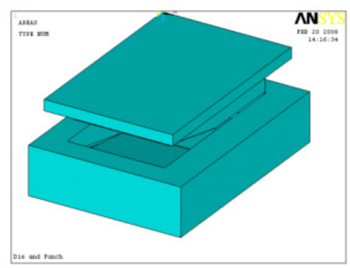

Figure 3. Assembly of punch and die.

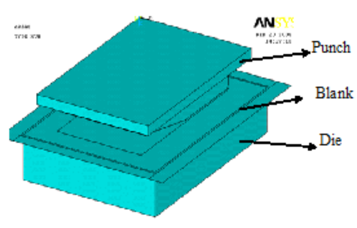

Figure 4. Assembly of punch , blank and die.

2.2 Formula for Clearance

The theoretical formula of clearance is the function of thickness (t) of the sheet metal and allowance (a). The formula for clearance is c = a.t. Here the sheet metal considered as soft Stainless steel, so the allowance value is taken as 0.060 and thickness of sheet metal is 0.455 mm.

Based on the calculation the obtained clearance is 0.028 mm.

3. Finite Element Analysis

The ANSYS LS-DYNA is a general purpose finite element code for analyzing the large deformation dynamic response of structures. This also has explicit time integration ability. The element type used for sheet metal is Shell 163. The high surface to volume ratio of the work piece in sheet metal forming gives the opportunity of using structural elements which make use of the plane shape of the sheet. The most common element used for sheet metal forming is the shell element. The number of integration points through the thickness is taken as 5. This will allow more accurate prediction of the plasticity due to bending. Shear factor of 5/6 is suggested value for this element and the thickness at the node 1 is 0.455 mm. The other thicknesses will default to this value.

The assembled model meshes in ANSYS. Blank and punch are meshed with different mesh size. The blank which is of primary importance to be analyzed for its simulated results is given relatively fine meshing. The punch is given a relatively coarse meshing. The meshed model is shown in Figure 5. Due to complicated large deformation dynamics which typically occur during an explicit dynamic analysis, determining contact between components in a model can be extremely difficult. The surface-to-surface contact is established between the punch, die and sheet metal. The frictional coefficient provided between contacts as 0.29. For each contact definition, birth time and death time are specified. These allow activating contact at required time during the transient analysis and then deactivating it at later time. The punch has only vertical movement, and the portion of the blank which is to be tightly held by the blank holder is restricted from all displacements and rotations and assuming no slip within the blank-blank holder interface.

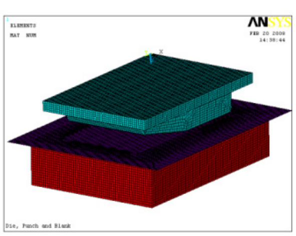

Figure 5. Meshed model.

3.1 Applying the Load

The displacement load is being applied on the punch. This moves the punch downward direction with uniform velocity. Figure 6 shows the linear relationship of the punch displacement with time. The experiment time of 0.015 seconds is specified so that simulation gets stopped once it reaches the end point of the specified period. Output file frequency, the number of steps for the simulation is also being specified. This will ensure that the simulation process will be automatically stopped after simulating for the 0.015 seconds of the experiment. The iteration details for 0.455 mm thickness sheet metal are presented in Table 3.

Table 3. Iteration details

Trail No	Clearance (mm)
1	0.008
2	0.013
3	0.018
4	0.023
5	**0.028**
6	0.033
7	0.038
8	0.043
9	0.048

mm: millimeter

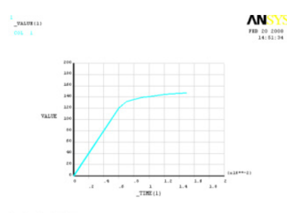

Figure 6. Load curve.

4. Results and Discussions

4.1 Simulation for Lower Clearance Values

In the first simulation purposely the clearance value of 0.02 mm is subtracted from the theoretically obtained clearance value of 0.028 mm. i.e., the clearance value is reduced to see the effects on a blank. Then the simulations two to four are performed by adding 0.005 mm clearance with the previous simulation. The formed model shows the shearing of the blank during forming. Figure 7 shows the formed sheet metal model for the simulation of 0.018 mm clearance. The kinetic energy in the energy graph will be in the upward direction during forming of sheet metal and after the completion of forming the kinetic energy curve moves towards the downward direction. It is observed that in the energy diagram the kinetic energy curve was stopped during the forming as shown in Figure 8. The reason is that the shearing or rupture takes place in the model for this clearance value. In the first to fourth simulations the formed model and its energy plot clearly shows the formation of shearing in blank because of this simulations are done for smaller clearance values than the theoretically obtained clearance values. The formability of the sheared part can be influenced by the quality of its sheared edges. The appropriate clearance is a function of the type of material, its temper, and its thickness and the size of the blank and its proximity to the edges of the original sheet. Clearances range between 2% and 8% of the sheet thickness, but they may be small as 1% or as large as 30%. In study[14] theoretically obtained clearance value is almost 5% of the sheet thickness. Shearing usually starts with the formation of cracks on both the top and bottom edges of the work piece, and these cracks eventually meet each other and separation occurs.

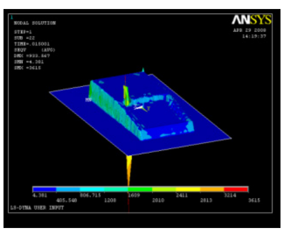

Figure 7. Simulated model for 0.018 mm clearance.

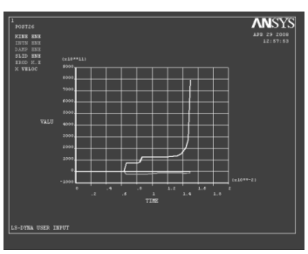

Figure 8. Energy graph for 0.018 mm clearance.

4.2 Simulation for Theoretical and Higher Clearance Values

Further, the fifth to ninth simulations are performed. Figure 9 shows the simulated model of sheet metal for the fifth simulation. In the fifth simulation, the clearance of 0.028 mm is used which is calculated theoretically. The formed sheet metal is relatively good when compared with all the simualtions. The fifth iteration energy plot shows the kinetic energy is moving upward during forming, and after forming it moves downward direction gradually as shown in Figure 10. Hence, from the formed model and the energy graph, it is revealed that the 0.028 mm clearance gives the exact forming with free of defects such as shearing and wrinkling. In the sixth to ninth simulations, the clearance values are increased. The energy plot shows the kinetic energy is increased to the certain extent and then decreases and again increasing as shown in Figure 11. This indicates that the higher the clearance value produces wrinkling in the sheet metal. Figure 12 shows the ninth simulation for higher clearance values with more wrinkling formation. Wrinkling may occur when the minor stress in the sheet is compressive.

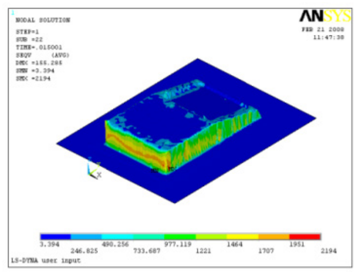

Figure 9. Simulated model for 0.028 mm clearance.

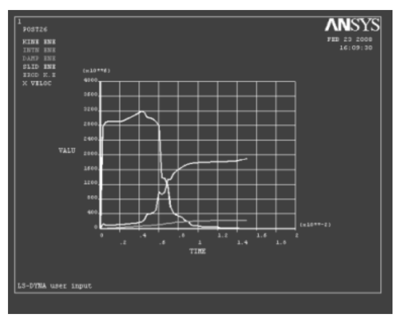

Figure 10. Energy graph for 0.028 mm clearance.

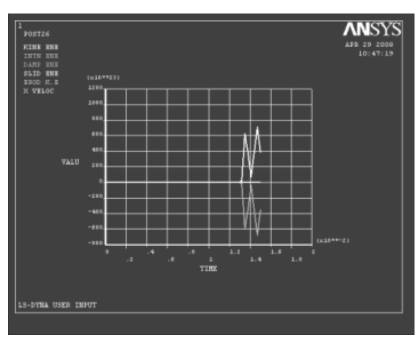

Figure 11. Energy graph for higher clearance.

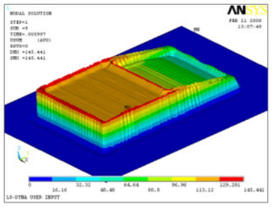

Figure 12. Simulated model for 0.028 mm clearance.

5. Conclusion

An explicit dynamic finite element model of the kiosk of automatic ticket vending machine has been done using ANSYS LS-DYNA solver. The simulation of sheet metal forming is successfully developed to obtain the exact clearance value. Energy graphs were plotted to observe the shearing and wrinkling defects during forming. In this forming process theoretically obtained clearance value of 0.028 mm shows the good forming with free of defects such as shearing and wrinkling. When higher the clearance values (From iterations sixth to ninth) wrinkling are formed in the model. For lower clearance value (From iterations one to four) shearing is placed in the model. During the fifth simulation, the forming is relatively good when compared with other simulations. When the clearance value is too low, there is more shearing, similarly when the clearance value is too large leading to more wrinkling. The theoretical clearance value is verified with FEA. Thus, it is proved that the effects of clearance in sheet metal forming.

6. References

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