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FEM ANALYSIS OF SINGLE POINT INCREMENTAL FORMING PROCESS AND VALIDATION WITH GRID-BASED EXPERIMENTAL DEFORMATION ANALYSIS

CHENNAKESAVA R ALAVALA

Professor, Department of Mechanical Engineering, JNTUH College of Engineering, Hyderabad, India

ABSTRACT

In single point incremental forming (SPIF) process, the blank is formed in a stepwise approach by a displacement-controlled round nose tool. Due to specific strain paths induced by the process and limited plastic zones in the contact region between the tool and the workpiece, the formability limit diagrams are different from the traditional deep drawing process. In this paper, the SPIF process is numerically exercised and experimentally validated with grid-based deformation process. Development of strain fields encountered in incremental forming is reported and material formability of AA2024-O is evaluated on conical formed shapes.

KEYWORDS: Single Point Incremental Forming, AA2024-O, Finite Element Analysis, Grid-Based Deformation Process

INTRODUCTION

In conventional deep drawing of metal sheet is used to form a cup by forcing a punch against the center portion of a blank that rests on the die ring. A number of materials such as AA1050 alloy [1], AA1070 alloy [2], AA1080 alloy [3], AA1100 alloy [4], AA2014 alloy [5], AA2017 alloy [6], AA2024 alloy [7], AA2219 alloy [8], AA2618 alloy [9], AA3003 alloy [10], AA5052 alloy [11], AA5039 alloy [12], Ti-Al-4V alloy [13], EDD steel [14], gas cylinder steel [15] were also tested for superplasticity for deep drawing of cups. In recent years, the cup drawing process is also extended to single-point incremental forming (SPIF) process. This process enables the manufacturing of a desired shape by an incremental deformation in a small contacted region. Because of this slicing technique, complicated products can be fabricated by using a simple shaped punch driven by a numerically controlled milling machine without die. It is presented that accuracy of the obtained shape due to springback effect [16], heterogeneous thickness strain distribution [17] and fabrication time are limitations of the process. Previous work in this field has been studied to predict the influence of the wall angle, tool diameter, step down, and the sheet thickness for AA3003-O material [18]. In the literature, the finite element simulations have been performed using explicit finite element code LS-DYNA to investigate the thickness distribution of the formed parts [19].

In this paper, the superplastic deformation of SPIF forces is presented, based on experimental results as well as analytical relations derived from finite element analysis results.

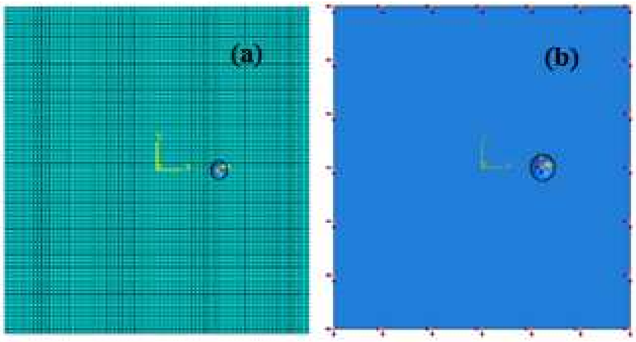

Figure 1: Finite Element Modeling: (a) Mesh Generation and (b) Boundary Conditions

FINITE ELEMENT MODELING

In the present work, ABAQUS software code was used for the numerical simulation of SPIF process to fabricate conical cups. The material was AA2024 alloy. The sheet and tool geometry were modeled as deformable and analytical rigid bodies, respectively, using ABAQUS. They were assembled as frictional contact bodies. The sheet material was meshed with S4R shell elements (figure 1a). The fixed boundary conditions were given to all four edges of the sheet as shown in figure 2b. The boundary conditions for tool were x, y, z linear movements and rotation about the axis of tool. True stress-true strain experimental data were loaded in the tabular form as material properties. The tool path geometry was generated using CAM software was imported to the ABAQUS as shown in figure 2. The superplastic deformation analysis was carried out for the equivalent stress, strain and thickness variation.

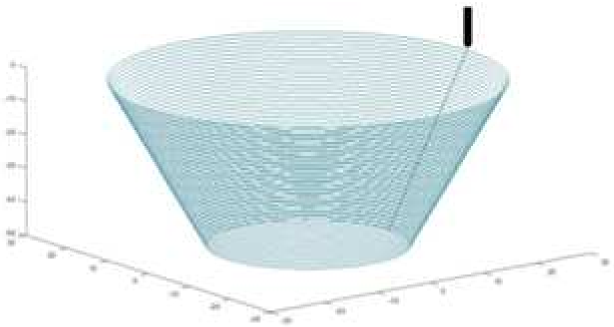

Figure 2: Tool Path Generation

RESULTS AND DISCUSSION

The standard values are: tool diameter of 6 mm, sheet thickness of 1.0 mm, wall angle of 45° and depth increment (Δz) of 0.5 mm. The feed rate and rotational speed were, respectively, 300 mm/min and 3000 rpm. Metal Drawing Oil 15 was used as lubricant.

Maximum Equivalent Stress and Strain

For the conical cup, the maximum equivalent stress induced was 276.0 MPa (figure 3). The maximum equivalent stress was found in the side walls of cups. To validate the simulation results obtained by the ABAQUS finite element method software, the finite element grid of 5.0 mm size was created on the backside of the cup material. The stress and strain obtained by the finite element method coincides with the pattern on the cups (figure 5). From the experiments conducted on CNC machine to draw conical and pyramidal cups, the maximum strains were found to be 2.10 for the conical cups without any rupture. The error in the results was 2% with element size of 2mm. These are nearly equal to the simulation results. Hence, the finite element procedure was validated.

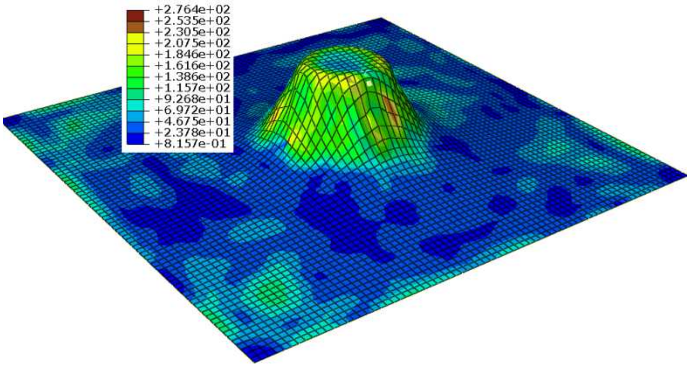

Figure 3: Equivalent Stress Induced in Conical Cup

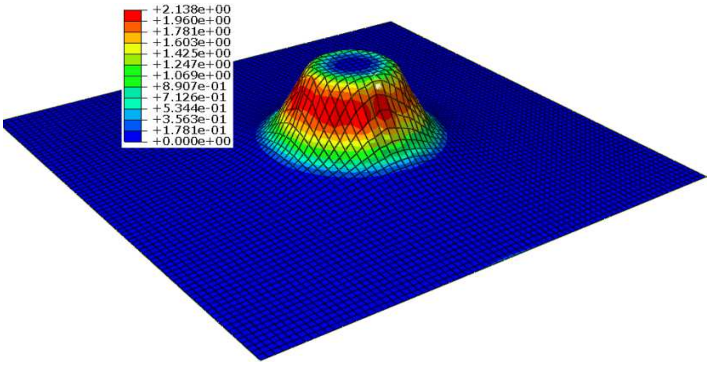

Figure 4: Major Strain Induced in Conical Cup

It is possible to analyze the evolution of the strain amplitude during the incremental forming of the conical cup. Figure 6 presents the major strain along the radial direction for all the 30 incremental forming loops of the conical cup. The first ten loops, the strain increment amplitude was less than 0.8. The variation between the increment step size and the strain increment was linear, probably due to elastic deformation. After the tenth loop, the major strain increment amplitude highly increases with a constant depth increment step size of 1 mm (figure 6). As a consequence, the major strain increases rapidly along radial path, leading to plastic deformation.

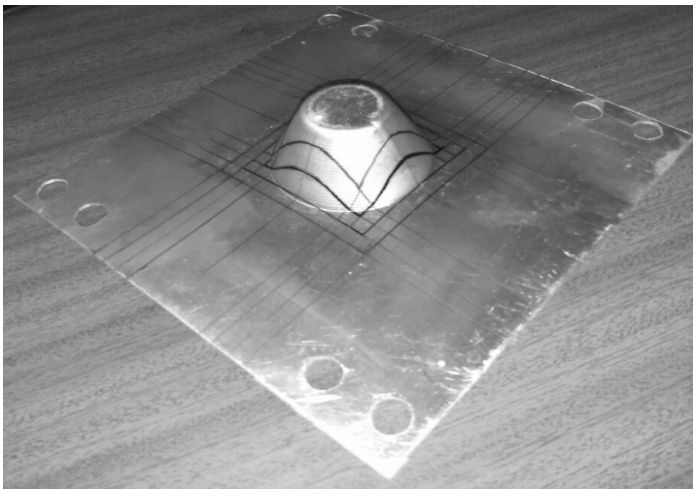

Figure 5: Conical Cup drawn on CNC Machine

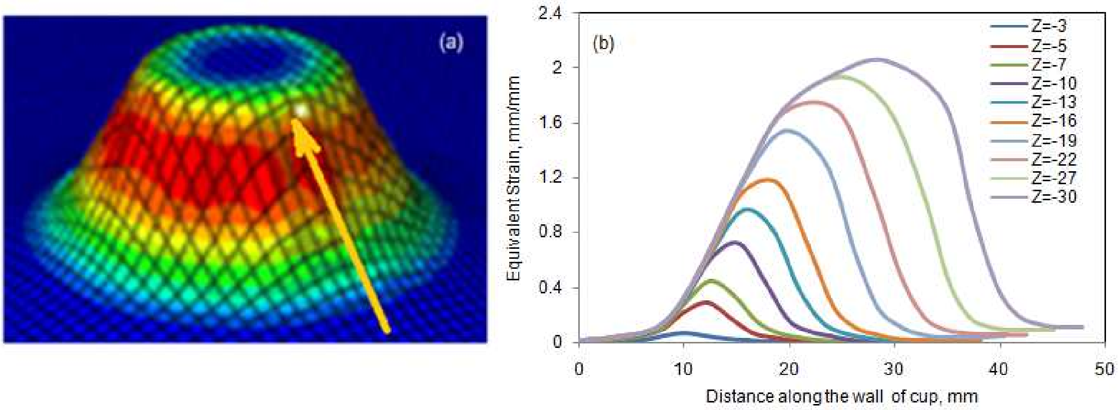

Figure 6: Major Strain Induced during SPIF Process: (a) FEM Result and (b) Experimental Result

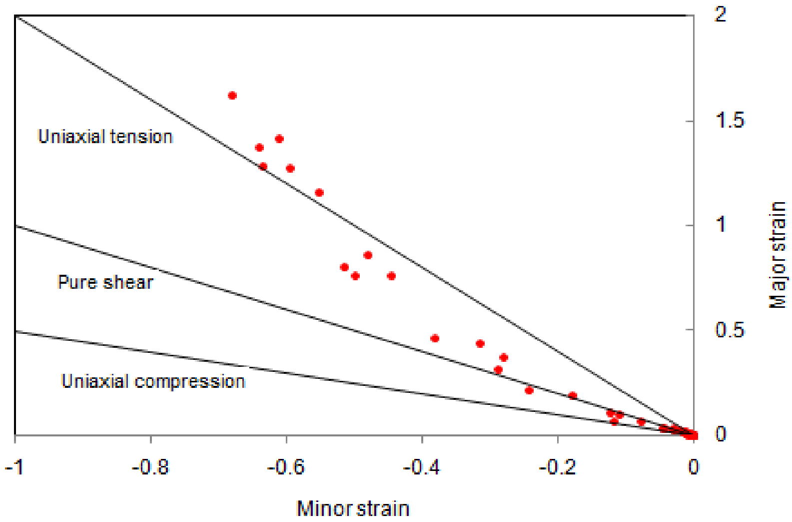

Figure 7: Formability Limit Diagrams of Conical and Pyramidal Cups

Formability Limit Diagram

Figure 7 represents the formability diagrams for the conical cups. The formability limit diagram is dominated by the uni-axial tensile stress [20-22]. The thickness variation along the walls of conical and pyramidal cups is shown in figure 8. The thickness reduction was found to be maximum along the side walls of the cup. The thickness reductions in the flange and the bottom of the cups were negligible.

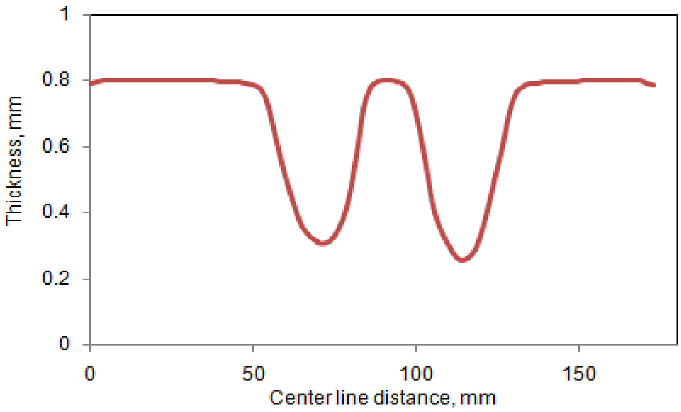

Figure 8: Thickness Variation along the Walls of Conical and Pyramidal Cups

CONCLUSIONS

The AA2024 formability of conical cups in single point incremental forming has been evaluated with finite element method. The results obtained by the FEM simulation software has been validated with grid-base deformation analysis experimentally. The analysis of the formed cups has shown that the fracture occurs in the uniaxial stretching domain. It is also experimentally reported that the reduction of sheet thickness is highly predominant in the side walls of the cups.

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