Numerical analysis of wrinkling phenomenon in hydroforming deep drawing with hemispherical punch

H. Ziaeipoor , S. Jamshidifard , H. Moosavi , H.Khademizadeh
Department of mechanical engineering, Room:55
Isfahan university of technology
P.O. Box: 8415683111, Emam avenue, Esfahan , Fax: +98-0311-3912628
Iran
h.ziaeipoor@me.iut.ac.ir

Abstract: In this paper, effect of hydrostatic pressure on wrinkling phenomenon in hydroforming deep drawing (HDD) process of hemispherical cups with material AL6111-T4 was investigated numerically. Finite element analysis (FEA) codes could be used to understand the deformation behavior of a material during the forming process therefore ABAQUS/Explicit was used for simulations of processes and Failure criteria used in the analysis were based on the forming limit diagrams (FLDs). In addition Hill's anisotropic material model implemented in ABAQUS/Explicit was used. The simulation results of HDD and CDD processes were compared and results showed that using of hydrostatic pressure causes the sheet to stretch in the flange area and therefore push strains above the wrinkling limit curve in the forming limit diagram (FLD). As well as this external support provides a through-thickness compressive stress that delays the onset of tensile instabilities, also reduces the formation of wrinkles due to tensile frictional forces.

Key-Words: Hydroforming deep drawing – Hemispherical punch – Wrinkling – Finite element analysis

1 Introduction

Wrinkling is one of the major defects that occurs in sheet metals formed by conventional deep drawing process. Wrinkling may be a serious obstacle to a successful forming process and to the assembly of parts, and may also play a significant role in the wear of the tool. In order to improve productivity and the quality of products, wrinkling must be suppressed. Wrinkling is a kind of buckling phenomenon that prevents from forming of the sheet. If the buckling take place in the flange area it is well known wrinkling as well as it is called puckering if take place on wall of the cup. In addition circumferential compressive stress in flange area is the major reason initiation and growth of wrinkles in this region. The schematic diagram in Fig.1 shows The mechanism of wrinkling initiation and growth in the cylindrical cup deep drawing process.

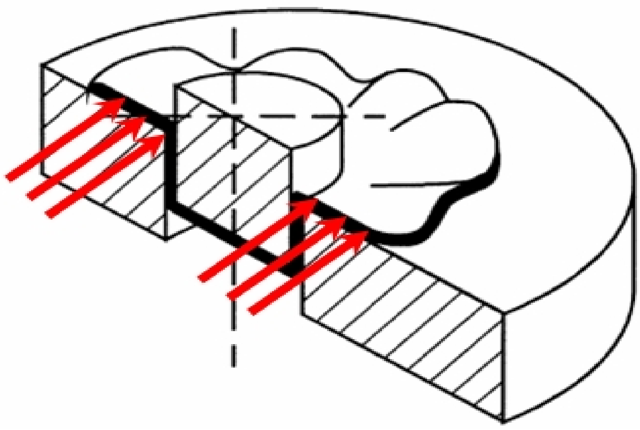

Fig.1 The mechanism of wrinkling initiation in the flange area of the cup[1]

The process of sheet hydroforming deep drawing, unlike conventional deep drawing, involves supporting the bottom of the sheet with a bed of pressurized viscous fluid during the forming process, therefore thickness distribution and quality is better with hydroforming deep drawing. HDD process are widely used in various industries such as the automobile industry, electric home appliance industry, and aircraft industry [2,3]. Numerous researchers have attempted to explain theoretically the critical condition of rapture in hydroforming process. Yossifon and Tirosh (1985,1991) predicted rapture by using the criterion of plane strain failure and wrinkling instability by energy method, they also obtained tearing and wrinkling diagrams for a process with radial pressure [4,5]. Sy-wei et al.(1993) extended the results of Yossifon and Tirosh (1991) for hemispherical cups [6]. Wu et al.(2004) and Khandeparkar and Liewald (2008) obtained rapture and wrinkling diagram for stepped punches by finite element simulation and experiments [7,8]. Thiruvarudchelvan and Tan (2006) performed theoretical analysis and experimental approach from hydraulic pressure-assisted deep drawing process [9]. Abedrabboet al.(2004) was investigated the wrinkling behavior of 6111-T4 aluminum alloys during sheet hydroforming deep drawing process numerically and experimentally and they implemented Barlat's anisotropic material in LS-Dyna code [10]. In this work how initiation and growth of wrinkles in the flange area was discussed and hill's yield function for simulation of HDD process was used. Also material behavior has followed from Hollomon's hardening equation.

In addition Forming Limit Diagram (FLD) damage criterion has been used for determining rupture instability. The results of conventional deep drawing (CDD) and hydroforming deep drawing was compared then height of wrinkling and Major and Minor strain distribution for HDD and CDD processes were obtained.

2 Conditions

The material properties of AL6111-T4 was used from experimental work that performed by Abedrabbo et al.[10]. Table 1 is shown the material properties and process parameters that used in this peper.

Table 1. Mechanical material properties and process parameters for the simulation [10]

Material	AL6111-T4
Blank Diameter , (mm)	177.8
Thickness, (mm)	1
Poisson ratio	0.33
Young's modulus ,E (Mpa)	71000
Density (gr/cm^2)	2.7
Yield stress (Mpa)	180
Ultimate tensile strength , (Mpa)	370
Strain hardening exponent, n	0.202
Strength coefficient , K	400.5
Punch Diameter,(mm)	101.6
Inner Diameter Of Blank Holder,(mm)	103.6
Outer Diameter Of Blank Holder,(mm)	200
Inner Diameter Of Draw binder,(mm)	103.6
Outer Diameter Of Die,(mm)	210
Gap Between Die and Blank holder,(mm)	4
R_0	0.832
R_{45}	0.861
R_{90}	1.422

For simulation of hydroforming deep drawing process optimum fluid pressure-punch that prevent from tearing or wrinkling has been used. Fig.2 depict optimum fluid pressure profile that obtained from Experimental work [10].

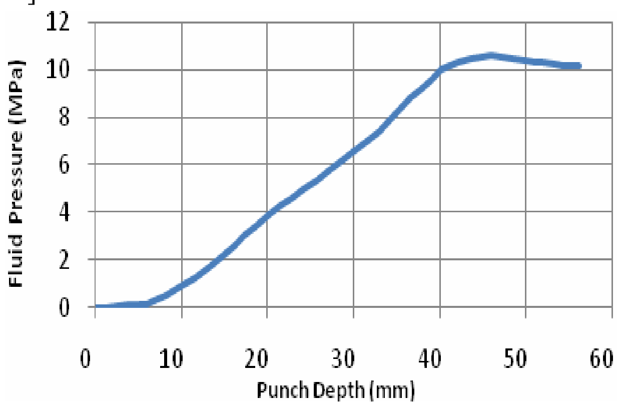

Fig.2 optimum fluid pressure profile used for FE Simulation of HDD process

3 Finite element simulation

Modeling of hydroforming deep drawing process was developed using Abaqus/CAE and commercial explicit software of Abaqus was used in the 3D simulation. All tools (i.e punch, die and blank holder) were modeled using a discrete rigid type R3D4 and the material were modeled using S4R (a 4-node quadrilateral in-plane general purpose shell, reduced integration).

Also in order to obtain desired mesh size and element geometry, the blank was partitioned to three region and 3456 elements on the blank was established by using structured mesh strategy. Fig.3 shows simulated model by Abaqus/Explicit

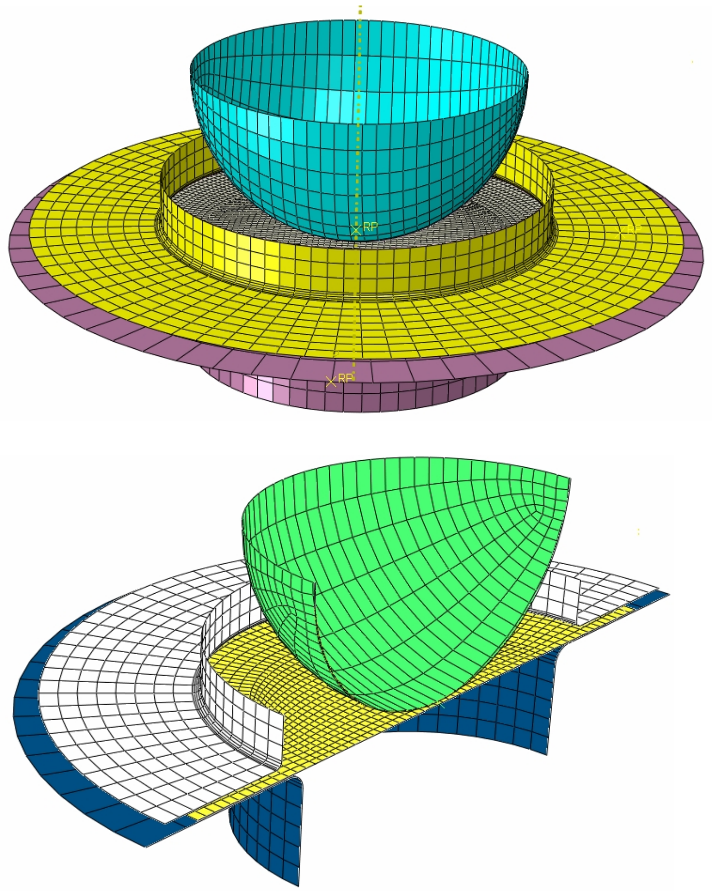

Fig.3 Simulated model by Abaqus/Explicit

Generally the kinetic energy should be a small fraction of the internal energy (less than 5 to 10%) until the dynamic effect become least and the analysis procedure has been Quasi-static [11].

Fig.4 shows the internal energy and kinetic energy during process analysis and it is obviously observed that the kinetic energy is very less than five percent of internal energy therefore the problem was solved with quasi-static procedure and simulation results are accurate and valid.

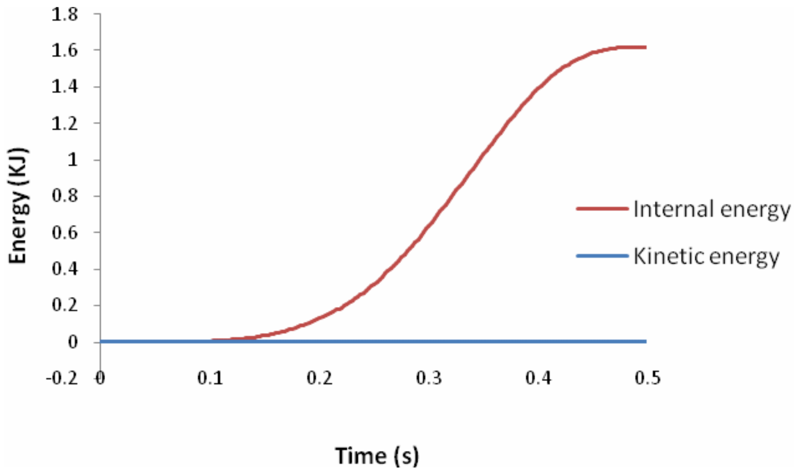

Fig.4 Comparison between total kinetic energy and internal energy during FEM analysis

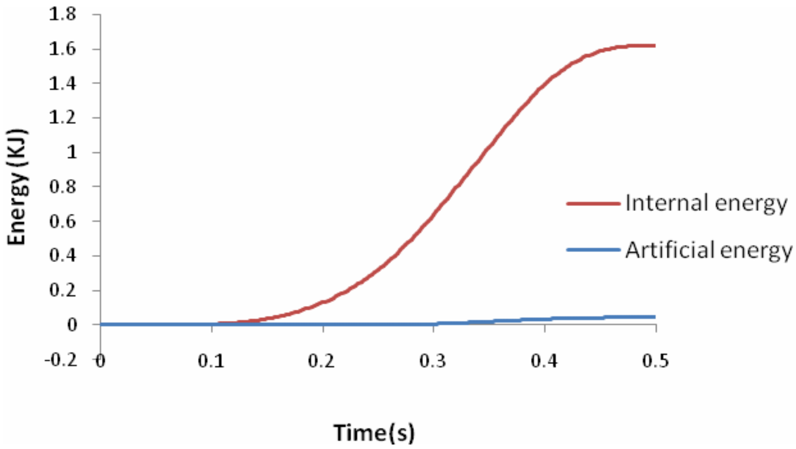

Fig.5 Comparison between artificial energy and internal energy during FEM analysis

Another important energy output variable in finite element simulation is the artificial energy which is substantial fraction (approximately 3%) of the internal energy in this analysis (see Fig.5).

Usually the artificial energy should be a small fraction of the internal energy (about 5%) until hourglass phenomenon did not occur during the analysis [11].

4 Results

Several finite element simulations were performed and for each finite element simulation run, the forming depth at which the sheet would start to wrinkle in the flange area was recorded.

Contours of visualization in Fig.6 show the cup formed by conventional deep drawing process in draw depth 51.17 millimeters. The height of wrinkle that developed in the flange area was reached to 3mm. The initial wrinkles are happen in the flange area, with develop in punch stork the height of wrinkles are increased up to gap distance between die and blank holder. The wrinkles are intended in the cup wall by more punch displacement .

Fig.9 shows the cup formed by hydroforming deep drawing process in draw depth 56.56 millimeters.
The height of wrinkle that developed in the flange area was reached to 1.64 mm. The initial wrinkles are happen in the Die corner, with develop in punch stork the height of wrinkles are increased up to gap distance between die and blank holder and while the hydrostatic pressure lost, the number of wrinkles increased. The result, as shown in Fig.8, shows that the sheet ruptures at a punch depth of 52.39mm.

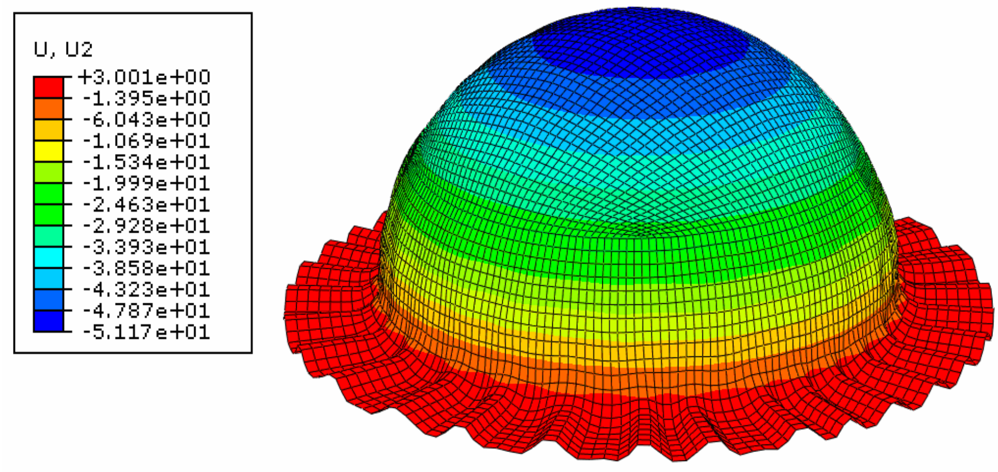

Fig.6 Simulation results of conventional deep drawing process (Draw depth 51.17mm)

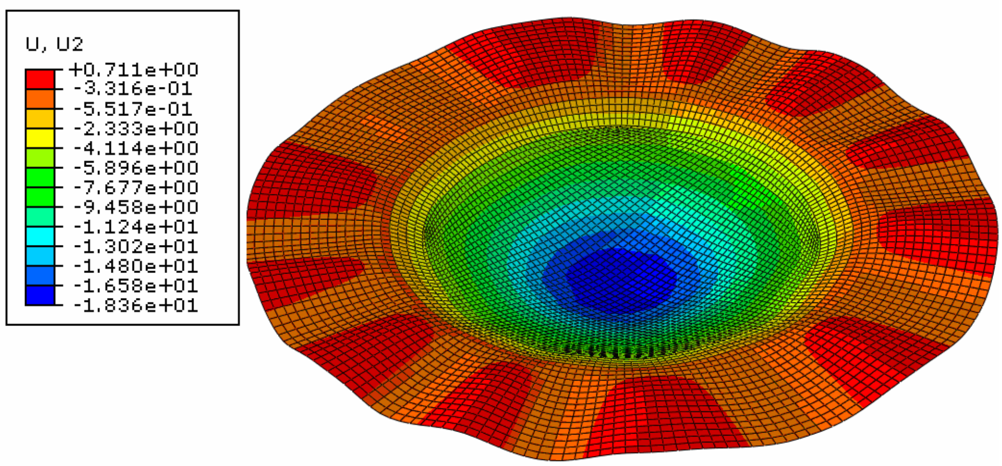

Fig.7 Initiation and growth of wrinkles in CDD process (Draw depth = 18.36 mm)

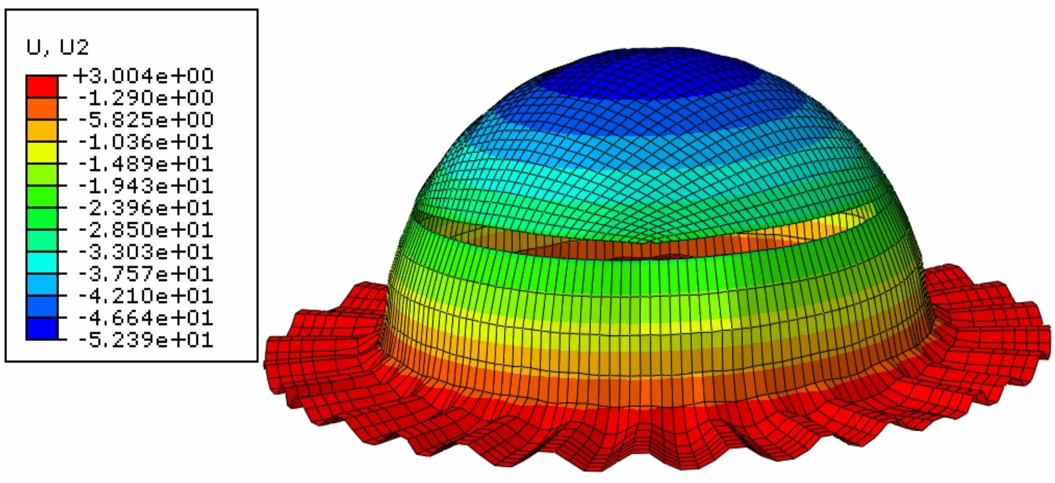

Fig.8 A cup failed by rupture (Conventional Deep Drawing)

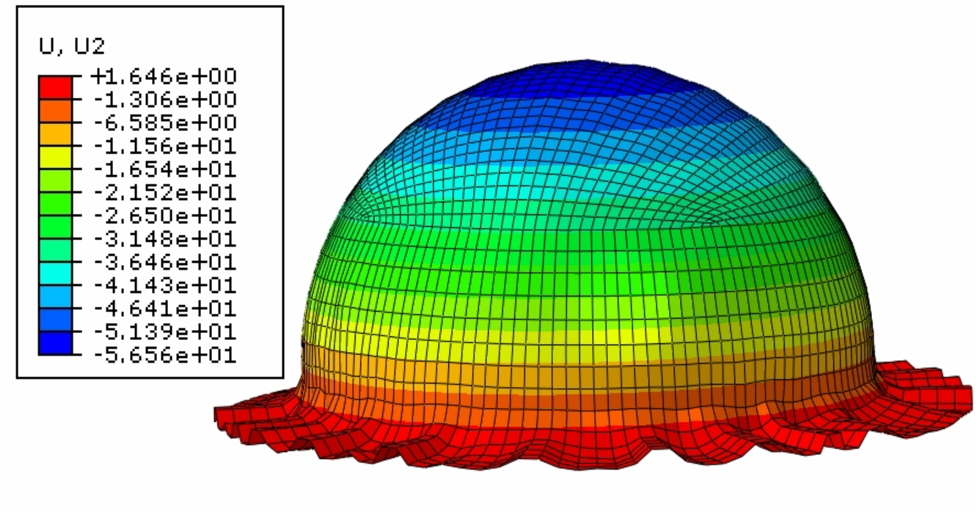

Fig.9 Simulation results of Hydroforming deep drawing process (Draw depth = 56.56mm)

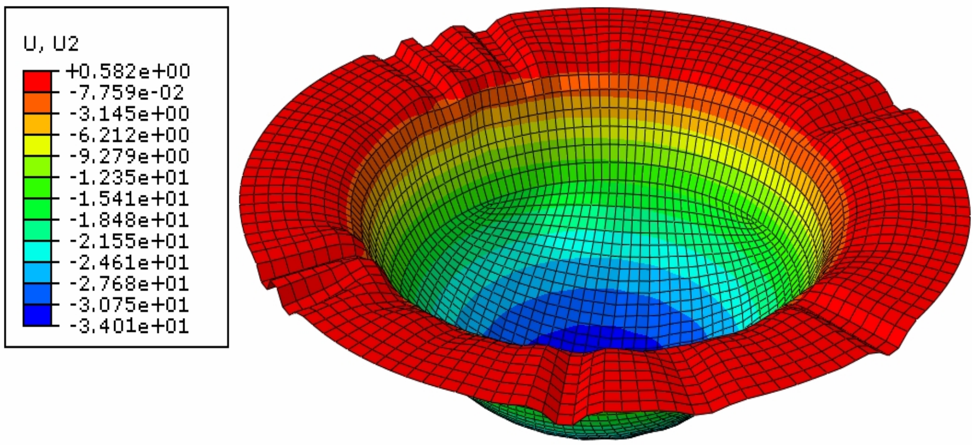

Fig.10 Initiation and growth of wrinkles in HDD process (Draw depth = 34.01 mm)

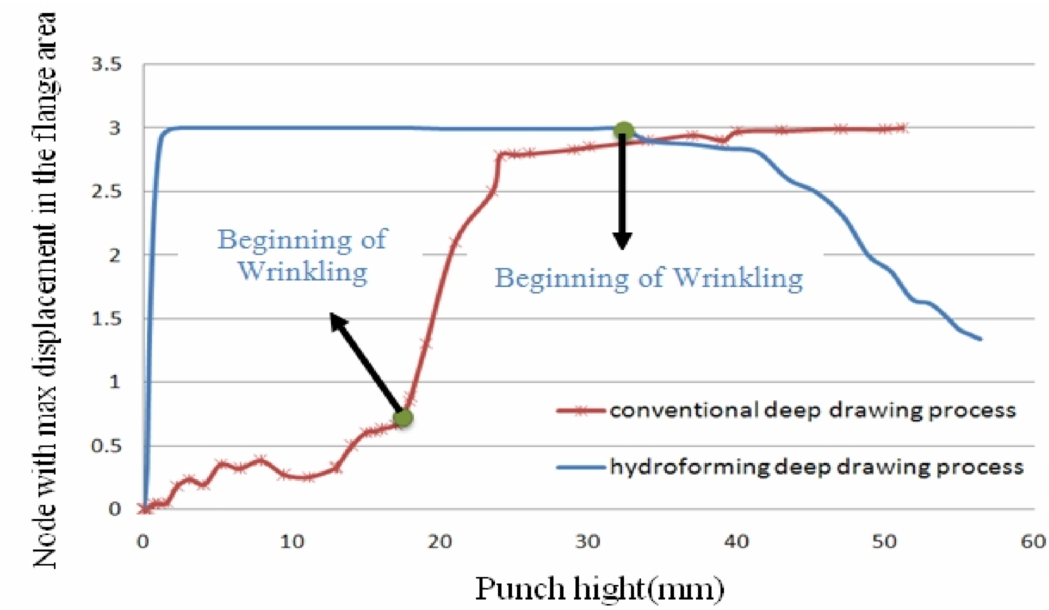

Fig.11 Punch height at beginning of wrinkling (mm) in CDD and HDD processes

Fig.11 shows the results of finite element analysis are compared and history of node with max displacement in the flange area displayed.

Figs.12–14 show the FLDs displaying plots of the minor and major strains in the flange area.

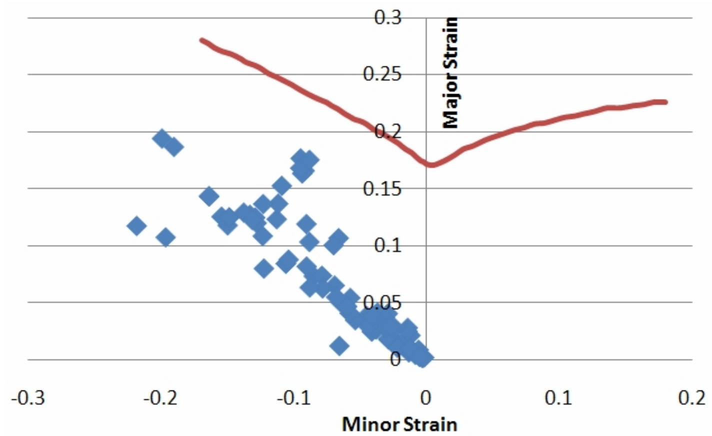

Fig.12 Major and Minor strain distribution in CDD process. (Draw depth 34 mm)

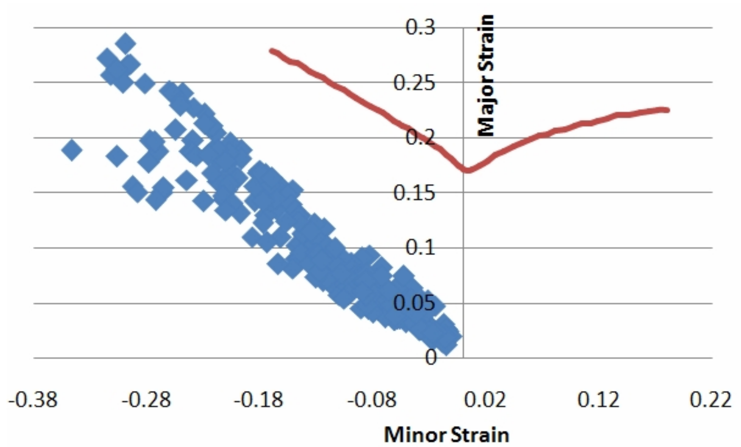

Fig.13 Major and Minor strain distribution in CDD process. (Draw depth 51.17 mm)

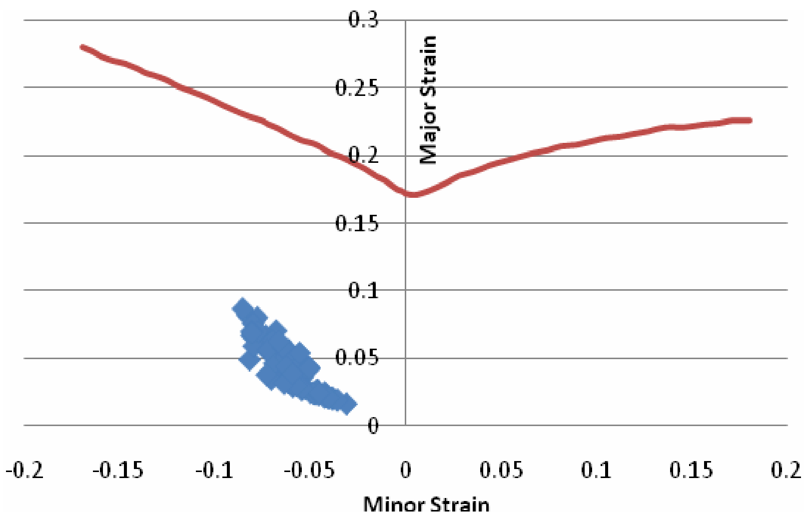

Fig.14 Major and Minor strain distribution in HDD process. (Draw depth 34 mm)

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4 Conclusion

Draw-in with conventional deep drawing, Fig.7, caused the material to wrinkle in the flange area at a punch depth of 18.36 mm . Draw-in with hydroforming deep drawing, Fig.10, allowed the material to be drawn to a depth of 34.01 mm without wrinkles or rupture. This represents a 85% improvement in forming depth without wrinkling. In hydroforming deep drawing Due to the loss of pressure on the sheet in draw depth 50.8mm (see Fig 2), compressive stresses developed in the flange area and the die corner causing the material to wrinkle.

Also with used hydrostatic pressure in deep drawing process a 11% improvement in forming depth was obtained.

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