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COMPARATIVE NUMERICAL AND EXPERIMENTAL INVESTIGATION OF CONVENTIONAL DEEP DRAWING AND RUBBER ASSISTED FORMING CUP MADE UP OF STAINLESS STEEL304

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ABSTRACT

Conventional deep drawing processes are being replaced by better forming processes such as hydro farming and rubber assisted forming. The main objective of introducing these new processes is to improve the permeability of the process and to produce parts with very complex features. In the present work, a sample part made out of Stainless Steel 304 is formed using both conventional process and rubber assisted process. Natural rubber is used as a rubber diaphragm to assist during forming. The formability of the processes is verified by measuring thickness of the part at various sections and studying the post forming microstructure. The paper gives in detail about the experimental set up, rubber properties, FEM simulation and micro structural analysis.

KEYWORDS: Stainless Steel, Natural Rubber & Forming

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Original Article

INTRODUCTION

The Deep drawing process is a sheet metal forming process where a punch is utilized to force a flat sheet metal to flow into the gap between the punch and dies surfaces. As a result, the sheet metal will deform into desired shapes like ,cylindrical, cone, or boxed shaped part along with complex parts [1]. In this process number of defects can occur in the final product. Some of those defects are wrinkling in the flange, wall, tearing, earing, surface scratches and non- uniform stresses and strains [2]To overcome those problems in conventional deep drawing, many innovative deep drawing techniques have been proposed in the last few decades [3]. A new method in a deep drawing called rubber assisted forming is introduced by Guerin in 1940 [4]. Rubber assisted forming adopts a rubber pad contained in a rigid box acting as a die which uses a single metall punch. The incompressible elastomer exerts a hydrostatic pressure on the sheet metal by deforming at constant volume [5]. As the punch advances, and the rubber behaves like a hydraulic fluid exerts equal pressure throughout the surface of the work piece when it is pressed by block or punch [6]. The main purposes of these processes are to enhance the limiting drawing ratio, releases the component from the fracture to minimize the variation of the thickness of drawing cups and to reduce the cost of tooling especially for irregular geometry. The Guerin process was modified and improved to develop the deep drawing process such as Version-Hydroform process [7]. The rubber assisted deep drawing is equivalent to the version-hydroform process. The hydroform process includes die cavity partially filled with hydraulic fluid, and rubber membrane is placed to cover the blank. The forming pressure is balanced by fluid pressure [7]. In this work, rubber assisted farming has been designed without any hydraulic pressure. The compressive pressure can be generated by placing a thin rubber sheet between the die and sheet metal. Literature survey [7] suggests that polyurethane has been used generally as rubber diaphragm. The polyurethane rubber is a hyperelastic material, and generally, it is assumed as nearly incompressible during deformation [8] However, in the present work, natural rubber is used as it exhibits high tensile strength and elastic property at room temperature.

The components in conventional and rubber assisted deep drawing are listed in **Error! Reference source not found.**.

Table 1: The Components in Conventional and Rubber Assisted

Conventional	Rubber Assisted Forming
Die	Die, Die block
Blank holder	Blank holder
Punch	Punch
Sheet	Sheet, rubber

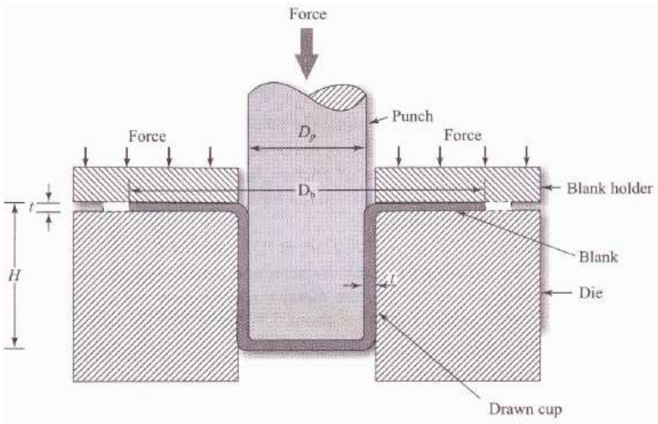

Figure 1: Conventional Deep Drawing

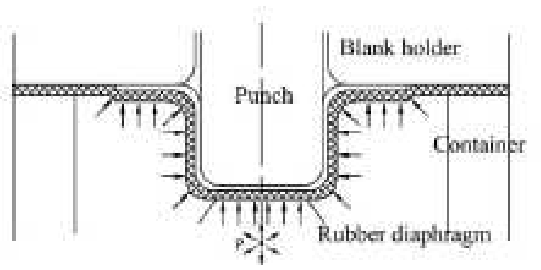

Figure 2: Sheet Hydroforming with a Rubber Membrane [22]

EXPERIMENTAL SETUP AND TOOLING

The sheet metal forming experiment has been carried out on a hydraulic press machine for both the cases, i.e. conventional, and rubber assisted deep drawing. In the hydraulic press machine, die is clamped to the base and punch is placed at the top of the press machine, the stainless steel 304 is placed on the upper surface of the die. The sheet metal is flat and is formed in the conical part similar to the shape of the punch. The blank holder is held tightly by C-clamps so that it can hold the sheet firmly. A blank holder is used in a draw due to prevent the formation of wrinkles as compressive action rearranges the metal from flange to sidewall[9]. Velocity is provided to the punch during the process so that the punch presses the sheet results in sheet deformation, which help to conform the final shape of the die cavity. The clearance between sheet, die and the blank holder is controlled closely to minimize the movement of the party and to avoid wrinkles. The punch and the die radii are sufficient so that it does not tear the steel sheet. In rubber assisted deep drawing, the counter pressure is applied by adding thin rubber sheet between the die and stainless steel 304 sheets.

The experimental setup is fabricated for drawing the stainless steel 304 sheets to form a cup in a conical shape. For the experiment, the punch, die, die block and holder are made of mild steel material. In one case, drawing has been carried out with the conventional punch and die and in another case, rubber sheet was used between the die and sheet so that the part will form more uniformly.

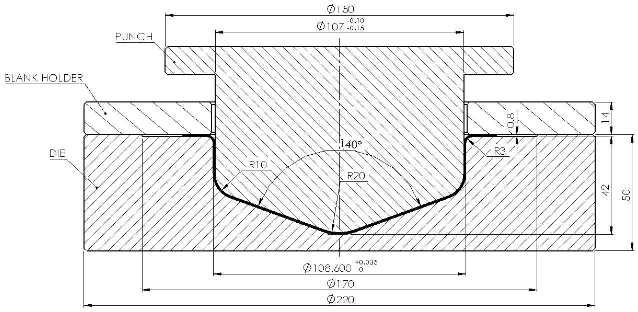

Figure 3: Tool Assembly for Conventional Deep Drawing

In the conventional deep drawing, there is a Solid Die and Solid Punch. During a deep drawing operation, the work piece is subjected to the various types of stresses.

There is a radial stress on flange zone due to the blank being pulled into the die cavity and there is also a compressive stress along the circumference which is due to the blank-holder pressure. The radial tensile stresses lead to compressive hoop stresses because of the reduction in the circumferential direction. The flange of the blank attempts to wrinkle because of this hoop stress; however, the blank-holder should prevent this from happening [10]. The clearance between the die and punch is kept approximately equal to the thickness of the component. Here the component thickness is 0.85mm.

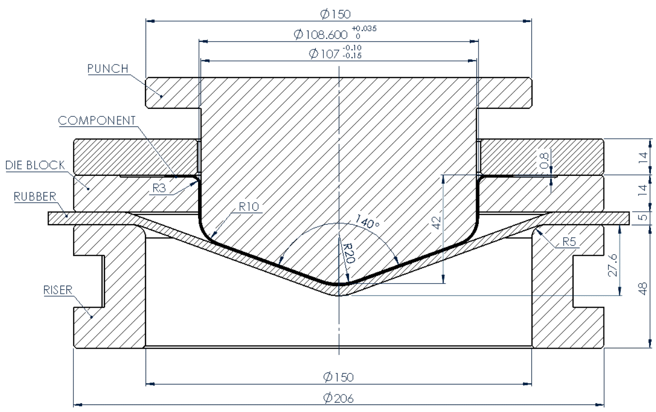

Figure 4: Tool Assembly for Rubber Assisted Deep Drawing

The assembly of rubber assisted forming is similar to the Version-Hydro form setup and presently without any Hydraulic pressure. In Rubber assisted deep drawing there is die block instead of Solid Die. Below the die block, Rubber sheet was used. The hydraulic pressure is also used to generate required compressive stress and to improve the permeability of the process. In the present case, natural rubber sheet thickness 4mm is used.

MATERIAL CHARACTERIZATION

For Finite Element Analysis of Deep Drawing, the characterization of material is very important. In the present study, the blank is made of stainless steel 304 and natural rubber sheet is used in rubber assisting forming. Tensile testing of the stainless steel 304 is carried out as per [11] standard and the testing of natural rubber has been carried as per ASTM D 412. [12]

Table 1: Properties of Stainless Steel 304

Property	Value
Yield stress(Y)	297.54 MPa
Ultimate Tensile strength(UTS)	715.69 MPa
Strain Hardening index(n)	0.4
Strength Coefficient(K)	1540.348
Density	7.8 E-009 kg/mm^3
Young's Modulus(E)	210 GPa
Poisson's Ratio	0.3

Table 2: Properties of Natural Rubber

Properties	Value
Thickness (mm)	3.3
Hardness(Shore A)	34~38
UTS (MPa)	17
Elongation at break(%)	645

Figure 5: Stress-Strain Plot of Natural Rubber

ANALYSIS IN ABAQUS

To avoid a trial and error tryout procedures, the sheet metal forming simulation is increasingly being used in academics and industry [13]. Finite element simulation for stainless steel 304 cup is carried out in finite element code ABAQUS-explicit. The simulation is carried out for both conventional, and rubber assisted deep drawing. The Detailed description of the code and its application are explained in ABAQUS manual [14]. The component design in ABAQUS/CAE is treated as the shell. The punch, die & blank holder is assumed to be rigid while rubber and sheet are reformable. Both elastic and plastic material properties are given in the definition of Material Model. The Actual stress-strain curve is used for modeling of rubber material during the rubber assisted deep drawing process which is best suitable for 'Marlow Material Model' [15] of rubber. The section thickness 0.8mm for stainless steel and 4mm for rubber is used. Here the dynamic explicit analysis is carried out to get accurate results in minimum simulation time [16].

The blank has meshed with conventional shell element 'S4R'. The element S4R is a 4-node, quadrilateral stress/displacement shell element with reduced integration and a large strain formulation. This element allows transverse shear deformations. It uses reduced integration to avoid shear and membrane locking. As tool components are assumed to be rigid therefore rigid element 'R3D4' has been used for their discretization. Element R3D4 uses a 3-d, 4-node bilinear quadrilateral rigid element. The dimensions of the blank elements should be uniform since the minimum size of the elements has determined the step size of the calculation. Contact is modeled between the components in both conventional, and rubber assisted deep drawing. The friction coefficient between the blank and blank holder (using coulomb assumption) is tangential behavior and have the value of 0.15 for steel blanks.

Penalty based approach of contact, where the friction effects are described via the Coulomb law [17] [18] [19]is used for both conventional, and rubber assisted deep drawing, Symmetric boundary conditions are applied on the nodes lying at the symmetry planes. The die and holder are completely constrained in both conventional, and rubber assisted deep drawing process. The die block also constrained in cases of rubber assisted deep drawing. Symmetrical boundary conditions are specified on the appropriate edges of the blank and rubber. Punch is constrained in other directions except for axial direction. The velocity of 1000 mm/min is provided to punch in the axial direction for both conventional, and rubber assisted deep drawing.

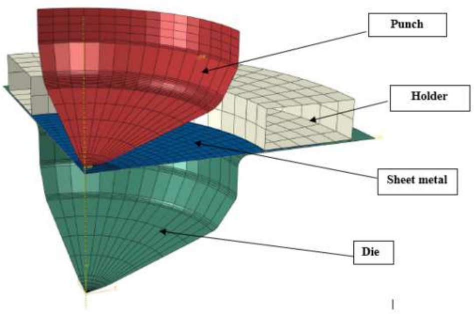

Figure 6: Finite Element Model of Conventional Deep Drawing

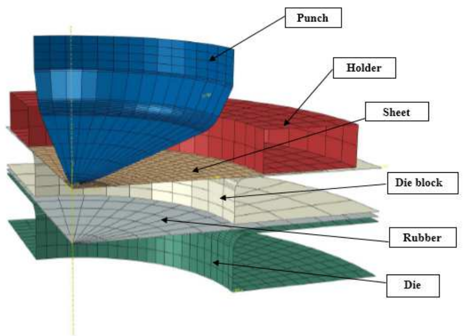

Figure 7: Finite Element Model of Rubber Assisted Deep Drawing

RESULTS AND DISCUSSIONS

The numerical results are evaluated for conventional and rubber assisted, deep drawing process using the finite element technique. The blank material used for the numerical simulation is stainless steel 304 of 0.8mm thickness. For rubber assisted deep drawing process thin natural rubber 4mm thickness is used. The experimental results, the variation in thickness along the cup wall, variation of Von-Mises and maximum principal stress is studied and compared to both conventional and rubber assisted deep drawing process. Finally, microstructure is compared.

Experiment Results

The stainless steel 304 with thickness 0.8mm formed by conventional deep drawing and rubber assisted deep drawing as shown in figure 8 and figure 9

Figure 8: Component Formed by Conventional Deep Drawing

Figure 9: Component Formed by Rubber Assisted Deep Drawing

Thickness Analysis

The numerical simulation is carried out and compared to conventional and rubber assisted forming process (Figure 10 and 11). The thickness variation along the cup wall is observed for the same punch velocity, and higher thickness reduction is achieved for rubber assisted forming process (Figure 12). The thickness build-up near holder region is reduced in rubber assisted forming process.

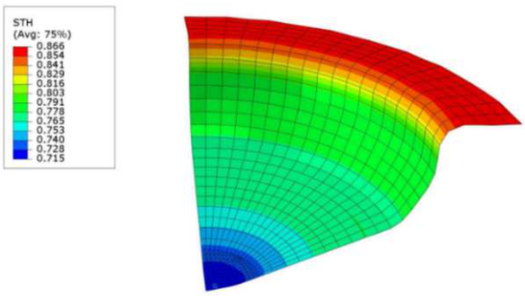

Figure 10: Thickness Distribution in Conventional Deep Drawing

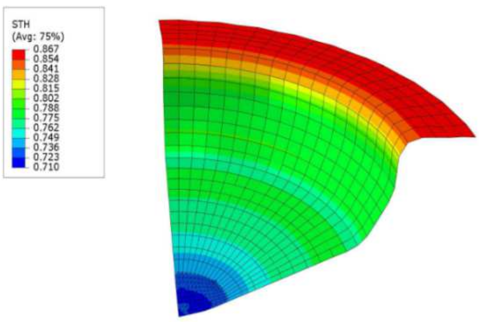

Figure 11: Thickness Distribution in Rubber Assisted Deep Drawing

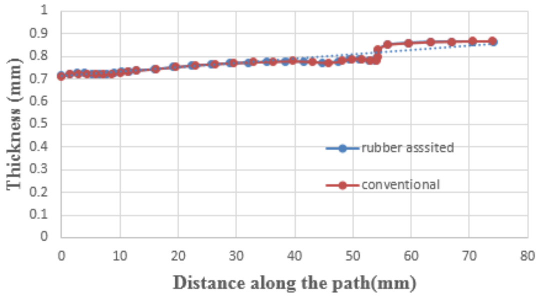

Figure 12: Thickness Distribution along the Distance from Cup Centre with Rubber Assisted Deep Drawing

Stress Analysis

In the numerical simulation of conventional and rubber assisted forming, the Von-Mises stress distribution and Plastic strain are studied.

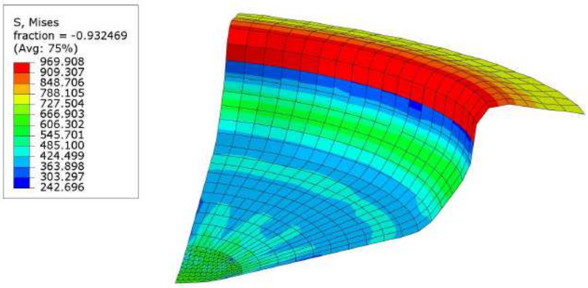

Figure 13: Von-Mises Stress in Conventional Deep Drawing

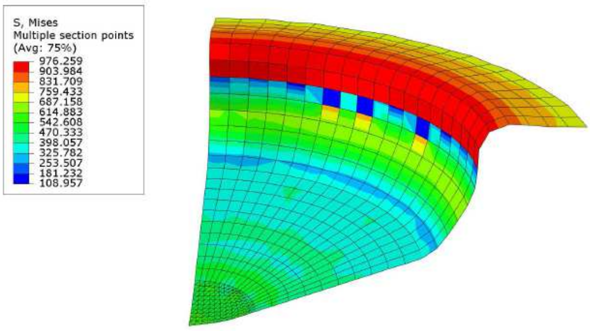

Figure 14: Von-Mises stress in Rubber assisted deep drawing

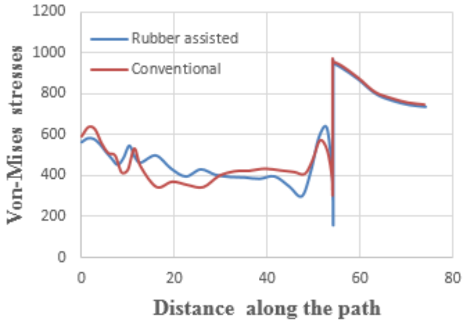

Figure 15: Von-Mises Stress Comparison

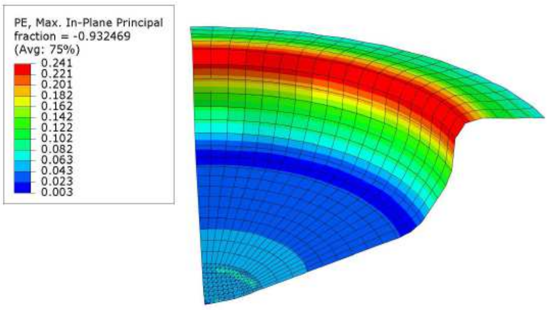

Figure 16: Plastic Strain in Conventional Deep Drawing

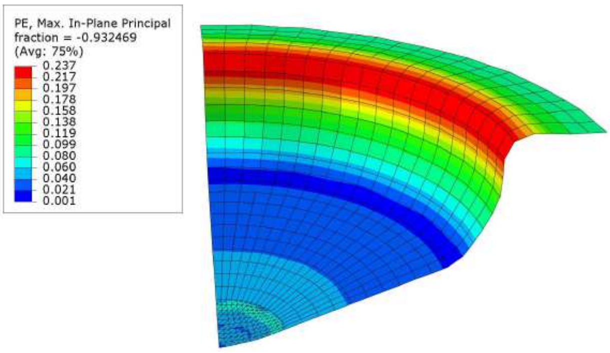

Figure 17: Plastic Strain in Rubber Assisted Deep Drawing

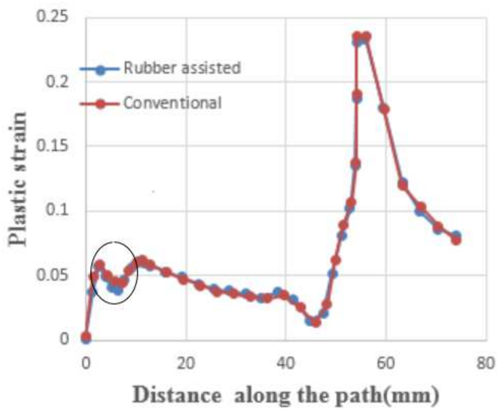

Figure 18: Plastic Strain Comparison

From the Figure 15 it is observed that, in comparison to conventional forming process, the Von-Mises stress distribution in rubber assisted forming is more at some points and Plastic strain distribution is almost same, a marked region some difference is observed, i.e. near the cup region, and it is more conventional farming. This is due to high thickness reduction near the cup region.

Less difference is observed in numerical simulation of thickness, Von-Mises stress and plastic strain for the rubber assisted & conventional process. That is the reason another way of comparative study is extended with micro-structure analysis.

Micro Structure Analysis and Comparison

Samples are prepared using a 10mm width of the component along the profile. The samples are prepared as per

ASTM E3-11 [20] standard. The analysis is carried out to study the variation in micro structure, size, a zone of twinning and micro-hardness variation. The micro-structure grain analysis is carried out as per ASTM E112 [21]. The micro-structure is captured at four locations in both the components.

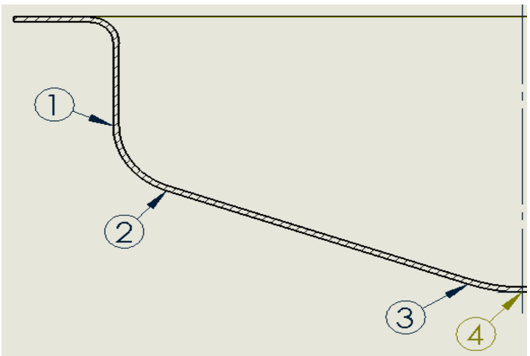

Figure 19: Locations for Micro Structure Analysis

The micro-structures at four locations for conventional and rubber assisted deep drawing as shown in figure

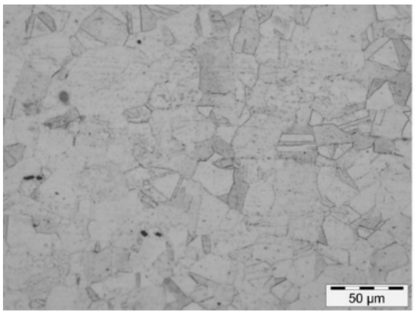

Figure 20: Rubber Assisted at Location-1

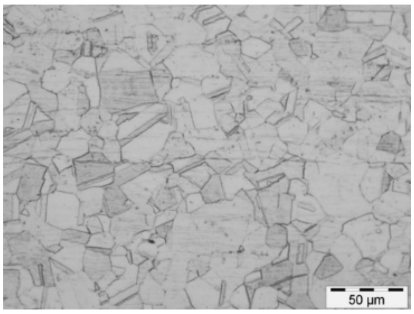

Figure 21: Conventional at Location-1

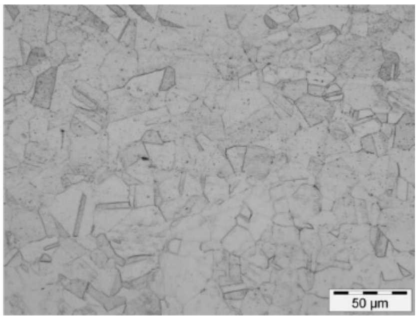

Figure 22: Rubber Assisted at Location -2

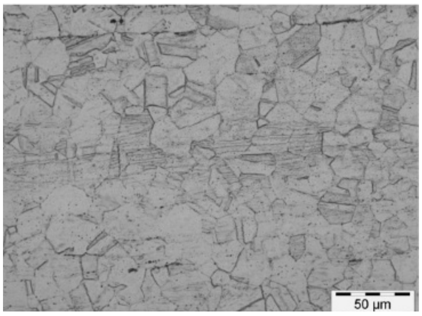

Figure 23: Conventional at Location-2

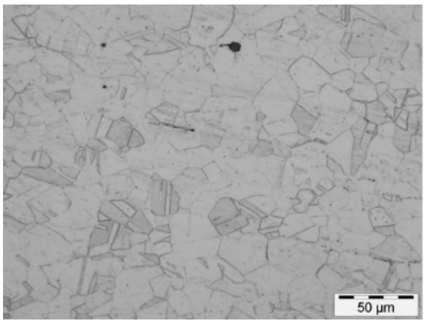

Figure 24: Rubber Assisted at Location-3

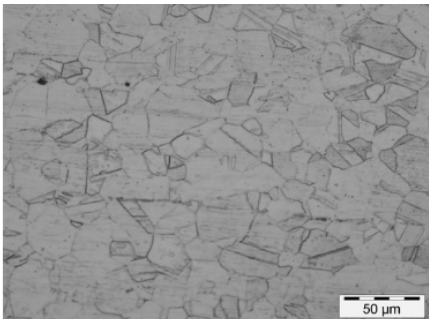

Figure 25: Conventional at Location-3

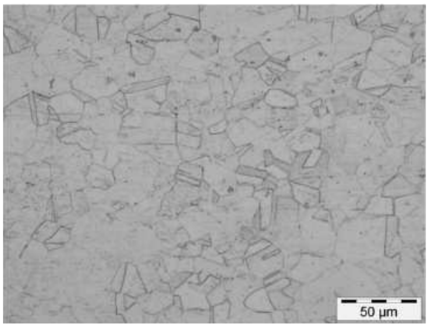

Figure 26: Rubber Assisted at Location-4

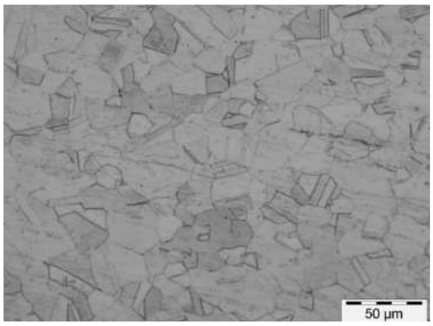

Figure 27: Conventional at Location-4

Figure 20 to Figure 27 Micro-structures at location 1, 2, 3 & 4 respectively, for conventional and rubber assisted deep drawing.

Comparison of micro-structures of conventional and rubber assisted deep drawing process deformation is considered at the outer surface, and flow lines are clearly visible at the micro- structures for the conventional deep drawing process even grain patterns are not uniform. Hence it can be inferred that the deformation in this case, is not uniform. The comparison of micro-structures at location 2 is presented in figure 19 (b) the flow lines are very dense and clearly visible in 'conventional process,' and also the grains are more distorted. Whereas 'Rubber assisted' has very fine flow lines which indicate that deformation is significantly less.

CONCLUSIONS

In this paper, experimental and numerical investigation of conventional and rubber assisted forming cup made up of stainless steel 304 is carried out and compare at micro- structure level. The finite element model is evaluated using an experiment. Good correlations between two analysis is observed. The micro-structures observed is same, and there is no significant pattern of grain distortion. From the numerical and experimental comparison, it was proved that the defects and non-uniform stresses occurring in the conventional deep drawing could be overcome by rubber assisted deep drawing. Finally, it is observed that introduction of rubber assisted deep drawing improves the drawing operation.

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