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COMPARISON BETWEEN LOW-CARBON STEEL AND GALVANIZED STEEL BY DEEP DRAWING UNDER THE INFLUENCE OF DIFFERENT PARAMETERS

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Abstract:
Deep drawing is used to make a lot of different shapes. The purpose of this paper is to evaluate the thickness alteration behavior of deep-drawn cylindrical cups with dimensions (41.5 mm) and high (30 mm) under the influence of diverse factors such as the radius of the die's (R_d = 9, 6.3 mm), velocity (v = 100, 300, 500 mm/min), thickness (t_o = 0.7, 0.5 mm), and the kind of metals used (L.c. steel and G. steel). ANSYS Workbench 21.0 software was used to implement the numerical simulation process, followed by constructing a cylindrical cup. The results reveal the highest thinning thickness (10.062% FEA, 15.626% EXP) in the curve area of the cup with low-carbon steel (t_o = 0.7 mm), while growth in punch speed and a decrease in the radius of the die results in higher thinning. The findings revealed a good agreement between experimental and numerical work, with the highest discrepancy being 5%. The galvanized steel metal demonstrated superiority in the cup's curve region, where the thinning rate was less than 2.35% compared to the low-carbon steel. Working with smaller radii makes the cup break while working with larger radii makes it wrinkle more. So, intermediate radii, which are four to ten times the width of the piece, need to be worked.

Key words: thickness distribution, the radius of the die, velocity, the thickness of the sheet, low-carbon steel, and galvanized steel

INTRODUCTION

Deep drawing is a sheet metal shaping method frequently used to manufacture products quickly. Deep drawing converts the workpiece configured by pressing the metal into a die bore with a punch. Sheet metal forming is among the most diffuse production techniques used to plastically deform a material into the required shape [1]. Deep drawing output in newfangled manufacturing often has complicated shapes. So, these have to go through a series of steps to get the final shape free of flaws. It's important to evaluate the thickness distribution to determine how good a product is [2]. The way the thickness spreads is one of the most critical quality requirements for sheet-formed items. Deep-drawn parts don't have a uniform thickness; typically, they are thinner than the thickness of the workpiece at the punch radius and more extensive than the thickness at the flange region. Thickness distribution following deep drawing can concentrate stresses, expediting part deterioration [3]. Wrinkling, thinning, and fracturing are typical faults in deep drawings. These flaws concern the product's safety and performance [4]. The selection of parameters for the draw process is crucial as it directly affects the result's quality and determines the procedure's success. The formability of sheet metal in the deep drawing process is influenced by two main categories of parameters: geometrical parameters and physical characteristics. It is crucial to acknowledge that they are all interconnected; at times, a modification in one suggests a modification in the others. Carefully selecting these factors may optimize the material's formability, reducing flaws like ripping, wrinkling, and earing in the deep drawing process. Using numerical calculations and simulation tools has significantly reduced expenses for designing and testing stamping operations. These systems assist in design and production. Simulation software mostly estimates metal flow, identifies potential flaws, and selects the appropriate parameter [5].

The project aims to evaluate thickness distribution across a cylindrical cup's wall. The study assessed the behavior of thickness modification in deep drawing. The shape of the object is cylindrical and is determined by several criteria like the radius of the die (R_d = 9, 6, 3 mm), velocity (v = 100, 300, 500 mm/min), thickness (t_o = 0.7, 0.5 mm), and the kind of metals used (L.c. steel and G. steel). The research attempts to assess the thickness distribution throughout the cup's wall. The numerical study was performed using ANSYS Workbench 21.0 software to compare the cup created by deep drawing with the cup made using two metals. Figure 1 shows the steps to produce.

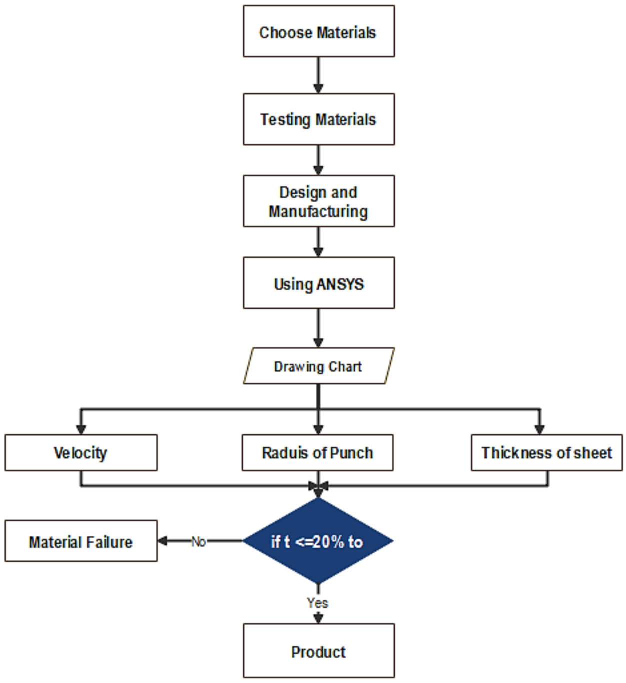

Fig. 1 Flow chart showing the steps of the research

BACKGROUND TO THE ANALYSIS

Studies of the deep drawing process of cylinders (Fig. 2) have been carried out over several years to offer data on the most efficient operation.

Fig. 2 Manufacturing of a cylindrical cup

A productive study by Waleed Jawad [6], the present study examined the impact of punch profile radius on the deep drawing process of a cylindrical cup regarding the load, the distribution of thicknesses, and strain distribution. The radius of the punch profile does not impact the drawing load. When the radius of the punch profile is at its maximum, the thinning of the material's thickness and higher values of effective strain are increased. Kardan et al. [7] studied punch force and thickness distribution optimization in the deep drawing process. The parameters most significantly impacting thickness distribution are blank thickness, die radius, and lubrication condition at the holder-blank interface. Consequently, it is imperative to consider the starting blank thickness and die shoulder radius as crucial criteria in the deep drawing process. These parameters must be carefully established to achieve the least punch force and uniform thickness distribution. Kumaravel & Venkatesh [8] generated a cylindrical cup with no defects. This will be accomplished by examining several process factors, with particular emphasis on the geometric shape of the die, which is considered the most crucial parameter.

Mohammed [9] conducted an analytical study on the deep drawing operation of complex cups. The results of a study into the influence of load on strain and thickness across the wall of the cup were analyzed. According to the findings, the drawing technique has a higher maximum punch load than the redrawing technique. The complex cup that results from the drawing technique thins significantly more near the cup's curve. Muhsin J. Jweeg, & et al. [10] looked at the impact of the factoring process, such as velocity, the thickness of blank, angle die, and species metal, on the fluctuation of thickness when manufacturing a conical cup by deep drawing. Thinness increased with increasing values of Lankford coefficients, angle die, blank thicknesses, and R-values. Speed had little influence on the fluctuation of the thickness. Ken-ichi Manabe et al. [11] examined the influence of velocity and force of blank holding on the behavior of flange deformation and the distribution of wall thickness. According to the findings, the use of a changing BHF method significantly impacts maintaining a uniform wall thickness distribution. In contrast, the use of a changing velocity has a significant impact on shortening the amount of time required to process superplastic materials. Hashemi & Roohi [12] reduced the amount of spring-back and thinning that occurs during the deep drawing process of steel sheets. A numerical simulation was used to analyze the relationship between the die and punch radii and the force the blank holder applied. The outcomes were visible. Thinness percentage was most affected by the radius of the die profile. The study primarily focused on the forces exerted during punches by Brathikan et al. [13]. This refers to the exertion of force applied to pull the thing. The findings indicated that some forms of failure, such as fracture thinning and cracks, appeared when excessive force was applied. The investigation was to establish the correlation between different factors and their impact on the formation load and reductions in thickness Anand et al. [14]. The study's findings indicate that it is possible to meet the necessary forming load and provide a uniform thickness distribution by reducing the parameters of the blank radius and punch nose radius while increasing the die nose radius. Mankayarkarasi, et al. [15] augmentation of blank thickness resulted in an amplified load effect during the deep drawing process, leading to an elevated occurrence of fractures in the wall of the resultant cup [16]. The material characterization of the thermoplastic response of EK4 deep drawing steel is the topic of this article. It goes overusing the Hill-48 phenomenological model to simulate material plastic anisotropy. The article also covers the yield criterion and offers relevant formulae. Experimental and theoretical on the deep drawing operation of octagonal cups was carried out by Mohammed & Jawad [17]. An analysis was done on the findings of a study that looked at how speed and sheet thickness affected strain and wall thickness throughout the cup. The results show that the drawing method's greatest speed results in greater thinning. The drawing method produces an octagonal cup that thins much more along the cup's curvature [18]. The formability of TWB was studied, allowing the values and application points of the blankholder forces to be determined. The experimental blank holder system with elastic blank holder and adjustable blank holder forces distribution was applied. This article presents the results of the FEM simulations performed using the simulation LS-Dyna program [19] using the finite element modeling of cold draw forming. The friction coefficient was calculated by comparing the force and load recorded curves [20]. The deep drawing process and the EFG method are provided in the paper. Both the modeling and the outcomes are shown about the application of the Finite Element Method (FEM). The EFG approach is implemented in the Ansys/Ls-Dyna program, which is the foundation for the numerical analysis.

METHODOLOGY

A wide range of metals may be used to conduct deep drawing procedures. Several are frequently used. The choice of metal for deep drawing is contingent upon the specific demands of the given application, including several criteria such as the desired shape, strength, form ability, resistance to corrosion, and cost-related concerns. Therefore, the use of metal is considered an important criterion in the deep drawing process. This study addressed the influence of diverse factors such as the radius of the dies, velocity, the thickness of the sheet, and changing metals on thickness distribution across the wall of a cylindrical cup [21, 22]. The ANSYS program was employed to run simulations and analyze the deep drawing transactions. And then manufacturing dies and punches. The work methodology has been divided into four major sections, described below.

Material Specifications and Test Properties

The workpiece material's yield strength, ductility, and strain-hardening behavior affect formability and forgeability. High-ductility materials are simpler to shape, while low-ductility materials may fracture or rip during deep drawing. The mechanical properties of the unformed blank and cylindrical cup metals significantly influence the operational performance. This study employed low-carbon steel galvanized steel sheets with specified thicknesses of the metal blank sheets (t_o = 0.7, 0.5 mm) and a specified diameter of the metal blank sheets (80 mm). These materials were selected based on their ease of shaping and extensive use in several industrial sectors, such as stamping operations, fuel and water tank production, and numerous other applications [23]. Furthermore, it is readily accessible at the nearby marketplace. Table 1 lists the chemical constituents of metals used in the drawing procedures. Samples of the unformed blank were cut using a wire cut machine with the specification numeral E8M of the ASTM standard to achieve more precise findings from the FEA Analysis.

Table 1
The chemical structure in weight percentages of two metals

Low-carbon steel (1008-AISI)											
Test 1008-AISI	C %	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %	Mo %	V %	Al %
	0.06	0.02	0.32	0.015	0.021	0.03	0.03	0.09	0.002	0.001	0.05
	<= 0.1	<= 0.3	0.3-0.6	< 0.03	< 0.03	< 0.2	< 0.25	< 0.25			
Galvanized steel sheets (ASTM A653)											
Test ASTM A653	C %	Mn %	P %	S %	Cr %	Ni %	Cu %	Al %			
	0.0687	0.434	0.0168	0.0113	0.0242	0.0158	0.0207	0.0260			
	<= 0.1	<= 0.6	<= 0.03	< 0.035	< 0.15	< 0.2	< 0.25				

Standard samples are tensile tested to ASTM E8M standards to ensure metal mechanical properties. All results are used by (FEA) to ensure accurate analysis results. A wire cut EDM machine cut tensile samples from workpieces in three rolling directions (0°, 45°, and 90°). We took three samples per direction. as shown in Figures 3A and B show the direction and dimension of the tension sample in (mm),

Fig. 3 (A) Specimens angle after cutting, (B) Desing of Sheet Metal

Table 2 presents the outcomes of the tensile test conducted on the specimens, using data inputted using the numerical analytical software ANSYS Workbench [24].

Table 2
Mechanical Characteristics of the cup a cylindrical and an unformed blank

Properties	Low-Carbon Steel	Galvanized Steel
Stress yield (MPa)	228	243
Stress yield of cup cylindrical (MPa)	291	311
Modulus of elastic (GPa)	200	210
Density	7.8	7.85
Poison's ratio	0.3	0.28

MODEL WITH FINITE ELEMENTS

Several commercial software packages now feature finite element analysis (FEA). While many engineering businesses provide numerical simulation solutions, ANSYS Workbench stands out for its user-friendly interface that simplifies sophisticated numerical simulation methods. FEA is now essential for developing forming processes. The proper selection of the model's material properties is the stage of the simulation process that requires the utmost attention to detail to provide accurate results. Utilizing Von Mises's yield criterion is how the phrase "yielding stress" is defined. Table 2 contains low-carbon steel (AISI 1008) and galvanized steel (ASTM A653) as materials since they are used in this finite element simulation.

The proceeding FEA Analysis was used to schema and prototype a cylindrical cup for the operation and analyze the impact radius of the die, speed of punch, and sheet thickness on the thickness distribution across the wall of the cylindrical cup. The cylindrical cup with inner measures (41.5 mm) and a height (30 mm) is created using the three pictorial techniques shown in Figure 4.

Fig. 4 Cylindrical cup dimension

The system's steady structural analysis is used to do geometry and make a paradigm for deep drawing. The stiffness behavior of the tools (die, blank holder, and punch) is rigid, and the task is structural steel. The PLANE185 element can accurately model plasticity and significant deformation, making it a suitable choice for inclusion in the mesh. The tetrahedral meshing and body sizing refers to the determination of the element size (2.5 mm) specifically designed for the material of the blank. Sweep meshing, with an element size of 3.5 mm, serves as the tool for punching and dieing. There are four main steps to the work. The methodical processes required to create a model, especially for deep sketching, are known as model creation. Explain the ideas and foundations of geometry: Establish the component's necessary dimensions, including its height, diameter, and thickness. Because extremely thin meshes need a lot of time and memory, creating a sufficient mesh is an important stage in the simulation process. However, creating a suitable mesh might significantly decrease this. The PLANE185 element in the mesh can replicate the plasticity and significant deformation that led to its selection. Get in touch: Make sure the simulation starts with the contact conditions properly initialized. This could involve making the punch's initial contact with the sheet metal. The meshing process is illustrated in Figure 5. The firm surface is provided by the TARGE170, which was made for the tool (punch, die). Manufactured CONTA174 is used for the blank's substance. Three contact pairings are used to construct the analysis of the deep drawing operation: the punch and the top blank, the top blank holder and the bottom blank, and the die and the bottom blank for the stage.

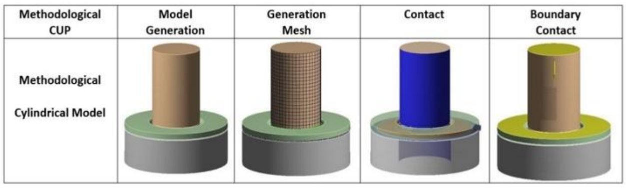

Fig. 5 The steps for the FEA Analysis model

Figure 6 shows the steps to make the circular metal cup in the ANSYS program.

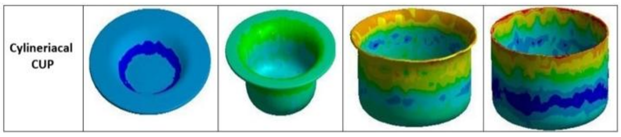

Fig. 6 Cylindrical cup analysis

The coefficient of friction is contingent upon both the material composition of the contacting bodies and the degree of surface roughness. The coefficient of friction at the tools-blank interface for the first stage is assumed to be constant, with a value of μ = 0.1. The blank holding force ranges from 10 to 20 KN. Figure 5 shows how a cylindrical plank turns into a cup, whose diameter is large at the beginning and whose height is small. Then, the diameter gradually decreases, and the height increases.

EXPERIMENTAL METHODOLOGY

Each of these cups is made using a cylindrical die during fabrication. The dies were made of tool steel using a CNC turning machine. It shows the cylindrical punch and die used in the work test study A cup with dimensions of (41.5 mm) and height (30 mm) in Figure 7.

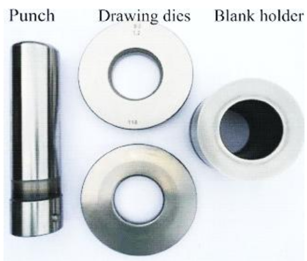

Fig. 7 Cylindrical rollers, punches, and dies are used for production

A tool for deep drawing and testing equipment that may be used for producing and in Figure 8.

Fig 8 Shows The Deep Drawing die Utilized

Distribution of thickness

The purpose is to appreciate the thickness of the wall cup. A grid pattern was printed using 5 mm radius circles, as illustrated in Figure 9.

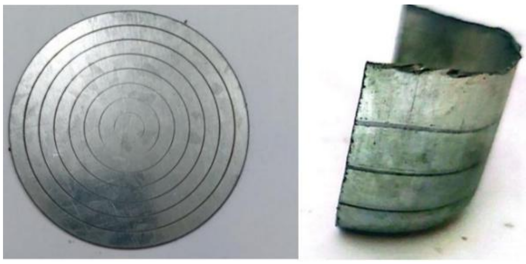

Fig. 9 shows deformation in the product cup

Half the cups were cut using a wire cut machine at the points where concentric circles and straight lines meet in the grid; the thickness was measured with a digital micrometer. In this section, utilize percent thinning to expound the thickness decrease and various forming parameters since thinning is a main fault, and the cup fails if it reaches 20% of the thickness. The thinning % may be calculated using the calculation below [25]. This paper describes a viable methodology for evaluating stamping lubricants under near-production settings using the deep drawing test and finite element (FE) analysis. Good lubrication in stamping processes helps to prevent wrinkling, early fracture, and localized thinning. Lubrication also lowers tool wear in high-volume production. Determining trustworthy friction data for a specific lubrication system is critical for successful process design and simulation using FE analysis. This investigation used The deep drawing test to evaluate five stamping lubricants (four dry film lubes and one wet lube) [26].

$$\%\ \text{thinning} = \frac{thickness\ original - thickness\ after\ deformation}{thickness\ original} \times 100\% \quad (1)$$

THE RESULTS AND DISCUSSION

The production of a cup free from defects is of utmost importance. Two significant drawbacks of the deep drawing procedure include thinning and wrinkling problems. To achieve a cup that is free from defects in practical and analytical possesses and a uniform distribution wall cup, it was essential to possess knowledge of the regulated parameters for this purpose and impact the overall quality of the product cup. Using ANSYS and a work test, the study found that the thickness distribution in the corner radius region of a completely drawn cup is greater than in the side wall region. The thickness was measured from the flat cup's center to its highest point. These numbers indicate that the thickness of the metal beneath the cup's bottom remains constant. In the case of the other cup areas, the thickness will vary depending on the following parameters.

Effect velocity

The thickness distribution and operation condition were velocity (v = 100, 300, 500 mm/min) and (R_d = 6 mm). With a rising velocity, it gets thinner in thickness and amounts to the highest thickness thinning (7.057% FEA, 8.793% EXP) at the corner radius area of (L.c.steel) with (t = 0.7 mm) and maximal velocity. A layer of paint protected the galvanized steel with a thickness (t = 0.7 mm) and the least thinning (4.013% FEA, 4.698% EXP), as illustrated in Figure 8. After that, the intensity of the stress varies from area to region, which results in an alteration in the thickness of the material in each location.

More thickening happens at the end of the cup due to compressive hoop stress at the end cup, as shown in Figure 10.

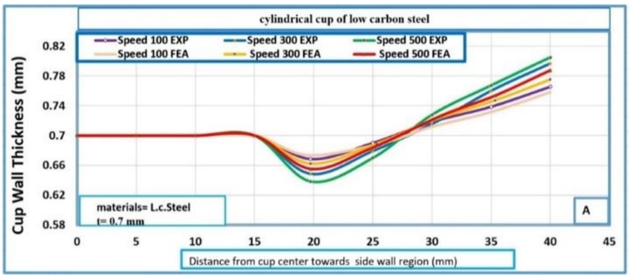

Fig. 10 Thickness distribution at varied punching speeds of low-carbon steel

Figure 10 shows the details of the difference between thickness and distance from the center. The radial distance from the cup's apex to its center sets the thickness distribution. The grid spacing must be uniformly distributed to obtain desirable results in the thickness distribution accuracy. The metal's thickness is maintained from R0 to R15 (at the bottom of the cup); however, it decreases to R20 (in the cup's curve region). After that, it gets thicker until it reaches R40 from R20 at a constant drawing speed of (v = 500 mm/min). The observed phenomenon in this area can be attributed to compressive stress and its correlation with increased thickness, especially when the drawing speed reaches 500 mm/min.

Figure 11 reveals that the thickness distribution of the Galvanized steel cup is irregular. Comparing the two metals, the galvanized steel metal demonstrated superiority in the cup's curve region, where the thinning rate was less than 1.35 percent compared to the low-carbon steel.

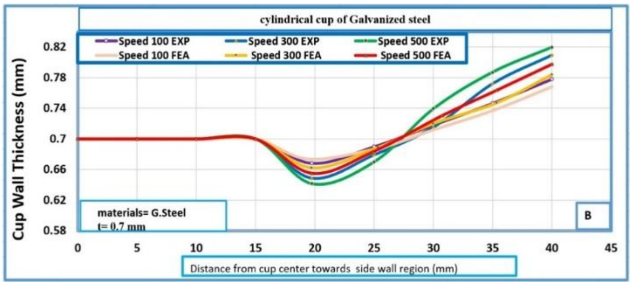

Fig. 11 Thickness distribution at varied punching speeds of Galvanized steel

More thickening (0.817 mm) happens at the end of the cup compared to the low-carbon steel at (v = 500 mm/min). An increase in velocity leads to a higher thinning percentage. However, it is important to note that the thinning rate should not surpass 20%. If the 20% surpasses this threshold, the manufacturing might be considered largely unsuccessful.

Effect the radius of the die's

The distribution of thickness and the operation condition were changed by changing the radius of the curvature die (R_d = 3, 6, 9 mm) and velocity (v = 100 mm/min). With reducing the die's radius, it gets thinner in thickness and reaches the maximum thickness thinning (12.114% FES, 9.814% EXP) at the corner radius area of (L.c. steel) with the thickness (t = 0.7 mm) with the lowest (R_d = 3 mm) radius of curvature die. The greatest punch load occurs when the curve radius is sharper due to the improved forming process resulting from plastic bending under tension. The size reduction (R_d) also increased heat buildup, hence causing a weakening of the die material and more thinning. After that, the intensity of the stress varies from area to region, which results in an alteration in the thickness of the material in each location. More thickening happens at the end of the cup to compressive hoop stress at (R_d = 9 mm). A finding indicates that expanding the radius of the die beyond 6 mm enhances the draw ability of cups but with a concomitant increase in the likelihood of wrinkling during the drawing process, as clarified in Figures 12 and 13.

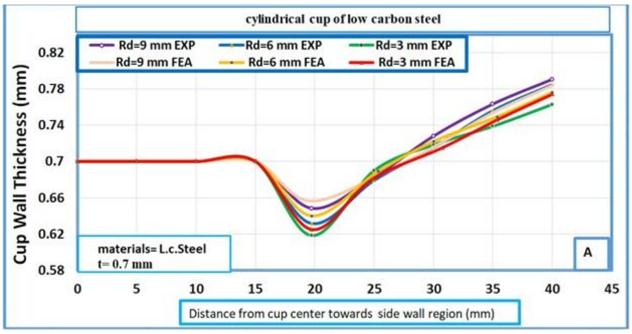

Fig. 12 Thickness Distribution At Varied Die's Curvature Radius of Low-Carbon Steel

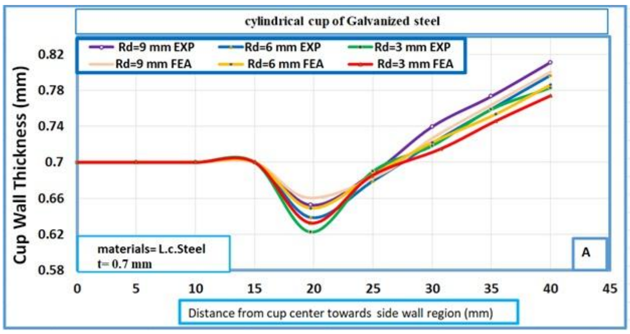

Fig. 13 Thickness Distribution At Varied Die's Curvature Radius of Galvanized Steel

A comparison of the two metals shows the galvanized steel metal demonstrated superiority in the cup's curve region, where the thinning rate was less than 3.35% compared to the low-carbon steel. More thickening (0.811 mm) happens at the end of the cup compared to the low-carbon steel at (R_d = 9 mm). Working with a die that has a radius of curvature of 6 mm is considered advantageous. Figure 14 shows the cup that became wrinkled due to increasing the speed (v = 500 mm/min) and decreasing the die radius (R_d = 3 mm). Figure 14 shows the wreckage.

Fig. 14 The rim of the cup is in a state of destruction

Effect of the Thickness of Blank

With the rising thickness of the blank, it gets thinner in thickness. It reaches the maximum thickness thinning (10.062% FEA, 15.626% EXP) at the Curved region with (t = 0.7 mm, L.c. steel) maximal velocity and lowest (R_d = 3 mm) where the thinning rate was less than 1.85 % compared to the low-carbon steel (t = 0.5). The presence of a layer of paint gave protection to the workpiece with (0.5 mm, G. seel) has the least thinning (6.938% FEA, 8.798% EXP) in the sidewall zone with the smaller speed of the punch (v = 50 mm/min) and biggest (R_d = 9 mm). After that, the intensity of the stress varies from area to region, which results in an alteration in the thickness of the material in each location. More thickening happens at the end of the cup due to compressive hoop stress. This thickening gets worse as maximal velocity and (R_d = 9 mm) with a thickness (t = 0.7 mm, G steel). The galvanized steel metal demonstrated superiority in the cup's curve region, where the thinning rate was less than 2.35% compared to the low-carbon steel. Following an extensive analysis of the drawing procedure for two metals, several factors were considered, including speed at three different levels, mound geometry at three different levels, and two thicknesses for each metal. A total of 24 laboratory samples were tested, and the outcomes were presented as the velocity rose and there was a greater amount of thinning in the cup curve area.

Additionally, the size of the mound impacts the thinning in the cup curve when it is small, as it necessitates a higher force, which in turn affects the durability of the die. Working and analyzing the results shows that working with smaller radii results in cup failure, whereas working with big radii causes greater wrinkling. Hence, moderate radii, four to ten times the thickness of the workpiece, must be worked. This article demonstrates that working on mold radii of 6 mm yields the greatest results. Operating at high speeds is essential in manufacturing processes as long as it doesn't compromise product quality. Wrinkling is more likely to occur at 500 mm/min or higher rates, requiring a reasonable pace. This study showed a speed of 100 mm/min was optimal.

CONCLUSIONS

The purpose of this project is to evaluate the distribution of thickness on the variables deep drawing that included the radius of the die's curve, velocity, the thickness of the sheet, and types of metals: Low-carbon steel (1008-AISI) and galvanized steel sheets (ASTM A653) in Both the FE analysis and the experimental work created a cylindrical cup with the dimensions of (41.6 mm) and high (30 mm). The following are the findings and inferences from this study:

- The highest punch load is at the sharper die curve radius because plastic bends more quickly when it is under stress. Increasing the die radius beyond 9 mm makes drawing easier but also makes the cup more wrinkled. For die Profile Options, 6 mm is the best depth for the die curve.
- The best speed for working with galvanized steel is 100 mm/min, which gives the most uniform thickness distribution. Conversely, low-carbon steel can be worked at a range of speeds (100-300 mm/min) because high speeds generate more wrinkling, even though high speeds are essential in manufacturing operations as long as they do not compromise product quality.
- The higher speed caused the distribution to reduce (0.642 mm). The growth rate speeds up the process of strain-hardening in metal, but the changes in thickness are not all the same in metals.
- High friction between the blank and the surface of the die leads to a reduction in the thickness of the cup's curve area due to the smaller (R_d = 3 mm) die's wall curvature radius. Due to the mold's smaller radius, more effort is needed to overcome the metal's resistance to shape the metal and create the cup.
- A comparison between the thicknesses found that t = 0.5 mm the thinning rate was less than 1.85% compared to t = 0.7 mm when work on t = 0.7 mm is best cups because the reduction rate thickness is acceptable. Because of this thickness, the thickness distribution on the cup wall was better than that of the other thicknesses.
- A comparison of the two metals showed the galvanized steel metal demonstrated superiority in the cup's curve region, where the thinning rate was less than 2.35% compared to the low-carbon steel because there is a coating of paint that protects the metal throughout the deep drawing process.
- The presence of a paint coat protects galvanized steel, resulting in less thickness thinning than low-carbon steel.
- Due to the inability of the developed and constructed molds to make cups of this thickness of 0.5 mm & 0.7 mm, they were specified for this investigation.
- Additional factors that may be explored in this study include lubrication, radial clearance between die and punch, and their effects on the deep drawing process.

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