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Process Parameters on the Mean Residual Stress of Aluminum Alloy 3004-H19 Cups in the Deep Drawing Process

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Abstract: ***Residual stress causes visible distortion and reduces corrosion resistance of desired cups. It is the aim of every manufacturing industry to attain quality and maximize profit, thus the cost associated with heat treatment and other residual stress relieving processes should be minimized. The 3004 aluminum alloy is widely used in the container, packaging and automobile industry. This paper presents a 3D explicit deep drawing finite element analysis (FEA) executed with explicit dynamics module in ANSYSR15 workbench. The effect of die-shoulder radius, punch-nose radius, radial clearance, lubrication and punch velocity on the mean residual stress was investigated. A blank of 100mm diameter and 3mm thickness was used in the model. The mean residual stress was determined from the geometric mean of the maximum von-mises and maximum principal stress results for better accuracy. The results showed increasing the die-shoulder radius up to five-time sheet thickness, increasing the punch-nose radius up to four times sheet thickness, setting the punch velocity to 1mm/s, additional radial clearance/sheet thickness between 15-20% and effective lubrication between the tools and blank helps minimize residual stresses.***

Keywords: Ansys, Deep-Drawing, mean residual stress, Finite element, effective lubrication

1. Introduction

Deep drawing is one of the most relevant metalwork processes used in producing sheet metal parts, it was first developed in 1700s [1]and has consequently been studied extensively until it became an important working process. The residual stresses left in the cup wall after deep drawing can be very large. For a material prone to stress corrosion, premature failure can in many cases be attributed to the residual stresses. In austenitic stainless steel the residual stresses can lead to splitting of the cup wall after the deep drawing due to stress corrosion cracking. This phenomenon is called delayed cracking or stress cracking or stress corrosion [2].

The 3004 aluminium alloy is widely used in the container, packaging, and automobile industry in manufacturing a large number of parts. Currently, the demand for metal containers in the world is in the order of 410 billion units per annum. Out of this, drink cans account for 320 billion and processed food cans account for 75 billion. It is also known, that for the majority of food and drink containers, the cost of the processed metal accounts for 50-70% of the total cost [3]. It is the aim of every manufacturing industry to minimize production cost thus the cost associated with heat treatment and other cups residual stress relieving processes should be minimized. Residual stresses have a strong influence that are rarely taken into account in the specifications of the cups because it requires a lot of experiments to work out specifications taking the residual stresses into account [4]. Experimental techniques play the main role in residual stress determination. Several destructive or nondestructive experimental methods based on different physical principles are developed [5]. Frequently used ones include diffraction (xray, neutron) techniques, ultrasonic techniques, bending methods or destructive techniques based on residual stress relieving measurement. The hole-drilling residual stress measurement method [6,7] is a destructive technique based on the original residual stress relieving by drilling a small hole into the material surface. The method is labeled as semi destructive, as the material damage is very small and often removable. Traditionally, the method has been used for measuring uniform residual stresses, that is, stresses that do not vary significantly with depth from the specimen surface. Strain gauge or optical [8] methods are most often used for strain measurement. The standard ASTM E837 [9] has been adopted as the basic concept of the method, however, many modifications and improvements have been developed. Much attention has also been given to the use of the hole drilling method to measure residual stresses that vary with depth from the surface [10,11]. Despite its evident simplicity deep drawing of a cylindrical cup is a very complicated process as it involves many process parameters that determines the nature of the products. The process parameters need optimization to produce the desired products. Analytical and experimental methods can be used to study deep drawing process. The finite element method has been sufficiently developed for the analysis of metal forming process. Despite the large number of publications on different parameters involved in the process they are still far from being optimized and work is still required to render the deep drawing process efficient and cost effective [12,13]. The cup is formed by the plastic deformation of the sheets through the movement of the punch along the die cavity under the influence of the punch force and it is accompanied by several stresses. Such conversions can be obtained in a single step or multiple steps. The major deep drawing the parameters influencing the mean residual stresses include the blank holding force, punch-die radial clearance, punch-nose radius, die-shoulder radius, friction conditions between the punch and blank, mechanical properties of blank, friction conditions between the blank and die, friction conditions between the blank and blank holder and punch speed. The radial clearance, punch-nose radius, die-shoulder radius is a major the tool design parameters while lubrication, blank holding force and punch velocity are operating parameters.

The main aim of this paper is to investigate the effect of five major parameters. The effect of die-shoulder radius, punch-nose radius, radial clearance, lubrication and punch velocity on the mean residual stress. Lubrication conditions includes the co-efficient of friction between punch/blank, co-efficient of friction between blank/die and the co-efficient of friction between blank/blankholder. The optimum parameter which will minimize these residual stresses was determine for profit maximization in the industrial deep drawing of Aluminium alloy 3004-H19.

Masoud Kardan et al., used ANOVA and Taguchi design of experiments to determine the percentage contribution of the deep drawing parameters on residual stress of AISI 1006 carbon steel cups, results of the L27 orthogonal array showed the sheet thickness had the major influence (56.616%),the die-shoulder radius had an influence of 17.604% , the punch-nose radius 2.574%, the blank holder had 3.757%,co-efficient of friction between punch/blank had 0.086%, co-efficient of friction between blank/die had 1.696% and the co-efficient of friction between blank/blankholder 5.892%.The maximum error was 11.776%[14]. Parameters like the friction coefficient between the punch and blank, blank and blank holder, blank and die are essential to be determined for an excellent simulation results which will give optimum products in the real deep drawing process. M. El sherbiny et al., reported the fluid lubricant with (μ= 0–0.3), is more suitable for friction between punch and blank, to reduce the thinning of the cup. But the solid lubricant with (μ = 0.3–0.7), is more suitable for friction between punch and blank. So, the value of μ is recommended to be about (0.3). The fluid lubricant with (μ = 0.125-0.2), is more suitable for friction between holder and blank. (μ) should be about 0.14. The fluid lubricant with (μ = 0.125–0.2), is more suitable for friction between die and blank. (μ) is recommended to be about 0.125 to reduce the thinning and the maximum residual stresses of the cup [15].

The knowledge of theories of elastic failure makes it evident that studying the effect of the varying process parameters on the equivalent stresses of cups enables a more accurate analysis. The distortion energy theory model is one of the simplest models to predict cup failure and applicable for a ductile material such as the 3004 Aluminium alloy. Von-mises or maximum distortion energy criterion states that a material will fail when the shear energy per unit volume stored in the material reaches the yield shear energy per unit volume in simple tension. This can be expressed in terms of the three-dimensional principal stress as

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = \sigma_y^2 \qquad (1)\ [16]$$

Generally, lubricants are classified into fluid($0 \le \boldsymbol{\mu} \le 0.3$), solid($0.3 \le \boldsymbol{\mu} \le 0.7$) and dry($0.7 \le \boldsymbol{\mu} \le 1.0$) lubricants. Different types of drawing lubricants are used, depending on the depth of a particular draw. Generally, the effectiveness of a deep drawing lubricant depends on its ability to form an adsorbed film of sufficient strength and oiliness on the metal surface being drawn. The three types of drawing lubricants are drawing oils, emulsions and lubricants containing both oils with solids. Drawing oils form an adsorbed film, and they take the form of light or soluble oils such as straight mineral oil or emulsions of soluble oil and soap, or of heavy oils, fats, and greases such as tallow or lard oil. Aqueous solutions of non-oily lubricants containing some suspended solids are called emulsions. These lubricants are not widely used in deep drawing because they contain little or no oil. Lubricants containing both oil and solid substances are used in applications involving severe drawing, these lubricants contain oily components that reduce friction and heat. The combination of the oil and the solids together produces enough lubrication for severe drawing applications such as deep drawing. [17]..

2. Material Properties

The blank is made of aluminium alloy 3004-H19. The material is modelled as an elastic–plastic material with isotropic elasticity. It is known for its excellent specific strength, corrosion resistance and formability. Table 1 gives the mechanical properties and Table 2 gives the chemical composition of the blank material.

Table 1: Mechanical properties of aluminium alloy 3004-H19[18]

Property	Value
Density(**ρ**)	2720 Kg/m^3
Modulus of Elasticity	6.9E10 Pa
Poisson's ratio	0.33
Ultimate Tensile Stress	295N/mm^2
Yield stress	285N/mm^2
Maximum Allowable stress	280N/mm^2

Table 2: Chemical Composition of Aluminium Alloy 3004-H19[18]

Element	Al	Fe	Cu	Mg	Mn	Si	Zn
Amount (wt%)	98.2	<=0.7	<=0.25	0.7-1.3	1-1.5	<=0.3	< =0.25

3. Modelling and simulation

3.1 Methodology

Explicit Dynamics was used to carry out this analysis in ANSYS workbench R15 as deep drawing is a non-linear problem which involves the inelastic collision of the punch and the blank, the punch moves down with a certain velocity and exerts force on blank. The travel of the punch through the die is analysed using a time integration method starting from the beginning of the punch contact with the blank till the cup is formed in the die. The mean residual stress is taken to be geometric mean of the von-mises/maximum principal stress.

The effect of five parameters on the mean residual stress will be discussed.

This includes;
- Effect of Punch-nose radius
- Effect of Die-shoulder radius
- Effect of Punch-Die Clearance
- Effect of lubrication conditions
- Effect of draw speed (Punch Velocity)

A cup with inside diameter of 55mm, thickness of 3mm and minimum height of 35mm is to be drawn from a blank of 100mm diameter.

- The Punch-nose was modelled in five (5) grades 6mm, 8mm,10mm,12mm and 15mm.
- The Die-shoulder radius was modelled in six (6) grades 6mm, 8mm,10mm,12mm 15mm and 18mm
- The Punch-Die Clearance was modelled in five (5) grades(3mm,3.15mm,3.3mm,3.45mm,3.6mm) which corresponds to 0%,5%,10%,15%,20% additional clearance /sheet thickness respectively.
- The coefficient of friction (lubrication conditions) between the blank/punch (μ_p) blank/die (μ_d), blank/blankholder (μ_h) were modelled in 5grades (0.10,0.15,0.2,0.25,0.3)
- The punch velocity was modelled in five grades (1,1.5,2,2.5,3) mm/s

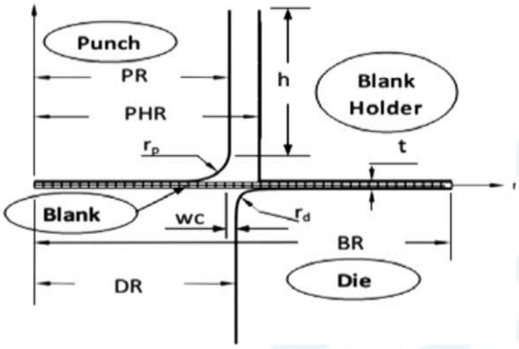

Figure 1: Geometry of deep drawing assembly [15].

3.2 Geometry and Mechanical Modelling:

The Geometry modelling is done with the design modeller while mechanical modelling is done with the mechanical modeller; it imports the geometry from the design modeller for further analysis. A blank holding force of 15KN is assigned to the blank holder which is sufficient to prevent wrinkling or tearing of the drawn cups. Fig 2 shows the meshed model of the tool assembly.

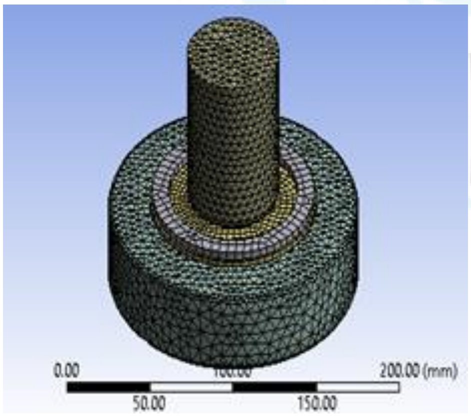

Figure 2: Meshed Model

4. Results and Discussion

4.1 The Die-shoulder radius

Fig. 3 illustrates the effect of die-shoulder radius on the mean residual stress. The stress value is maximum for 6mm die-shoulder radius(213MPa). The mean residual stresses of the aluminum alloy 3004-H19 cups decreases as the die-shoulder radius is increased up to 15mm. This is about five times the sheet thickness. At this minimum point the mean residual stress value of 148MPa is observed. Beyond this point the residual stress increases up to 168MPa for 18mm die-shoulder radius. The reduction is a result of better material flow due to the increase in die-shoulder radius.

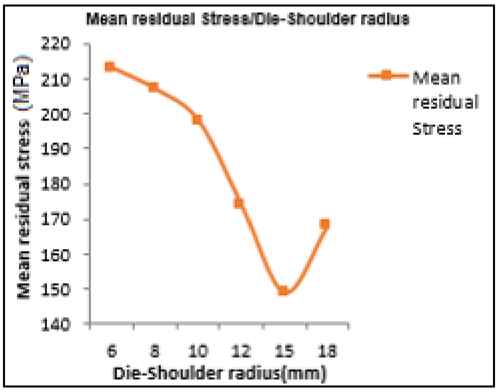

Figure 3: Variation of mean residual stress with “different die-shoulder radius”.

4.2 The Punch-nose radius.

Fig. 4 shows the effect of punch-nose radius on the mean residual stress of cups. The mean residual stresses are maximum for 8mm punch nose radius(198MPa). The mean residual stresses decrease and the punch nose radius is increased up to 12mm.At 12mm punch-nose radius which is about 4times sheet thickness the minimum stress value of (149) Mpa is observed. As the punch-nose radius is increased further to 15mm the mean residual stress increases to 172(MPa).

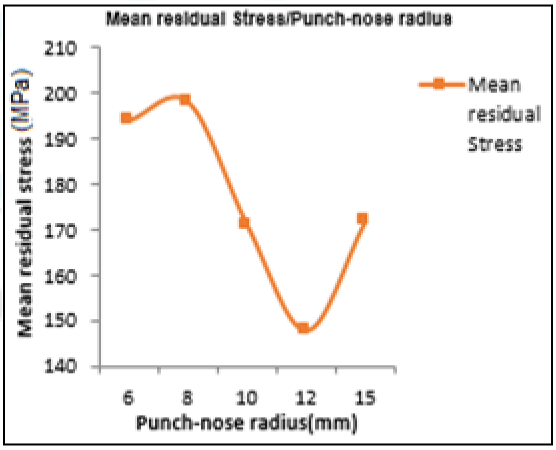

Figure 4: Variation of mean residual stress with “different punch-nose radius”.

4.3 The radial clearance

Fig.5 shows the effect of radial clearance between the punch and die on the mean residual stress. The additional clearance per sheet thickness is the percentage of sheet thickness added to the sheet thickness which forms the gap between the punch and die (radial clearance). There exist and inverse relation between the mean residual stress and the gap between the punch and die. The residual stress decreases as the additional clearance/sheet thickness increases from 0 to 20% additional clearance/sheet thickness. The values are maximum at zero additional clearance per sheet thickness(227MPa) and minimum at 20% additional clearance per sheet thickness. Beyond this point (20%) While increasing the additional clearance per sheet thickness might considerably yield further reduction in residual stress, there might be a non-uniform thickness distribution of the blank known as thinning.

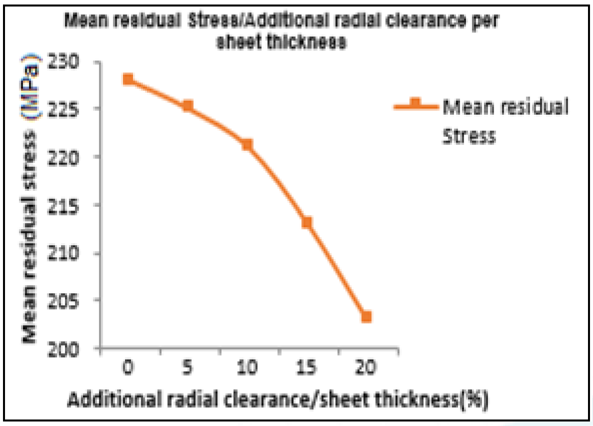

Figure 5: Variation of mean residual stress with "different radial clearance".

5. Lubrication

Lubrication plays an important role in tool wear reduction and residual stress minimization of tools and products. Lubrication conditions can be attributed to the co-efficient of friction between contact regions of the punch, blank, die and blank holder.

5.1 The coefficient of friction between punch and blank

The friction between the punch and blank is bonded through the flow of the metal in the die cavity, the relative motion of the punch with respect to the blank is minimum thus at the point of contact the co-efficient of friction is best defined as static which was used in the analysis. Fig. 6 shows the effect of co-efficient of friction between punch/blank on the mean residual stress. The stress values decrease as the co-efficient of friction increases up to 0.25. This because at the punch nose higher co-efficient of friction is required for sufficient contact and effective pulling of the material across the die cavity. As the co-efficient of friction is increased beyond 0.25 the residual stress begins to rise.

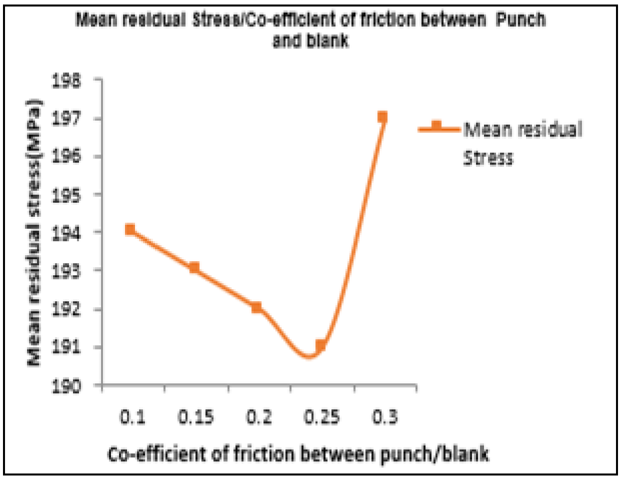

Figure 6: Variation of mean residual stress with coefficient of friction between punch and blank.

5.2 The co-efficient of friction between blank and die

Fig. 7 shows the effect of co-efficient of friction between blank/die on the mean residual stress. The mean residual stress decreases as the co-efficient of friction between the blank and die decreases up to 0.1. The stress values are maximum for the higher friction co-efficient. Although In deep drawing zero friction is practically impossible in contact regions between tool and blank, nevertheless sufficient friction (say 0.12) is required to keep the blank in contact with the die as it moves across the die to avoid wrinkling and minimize residual stresses.

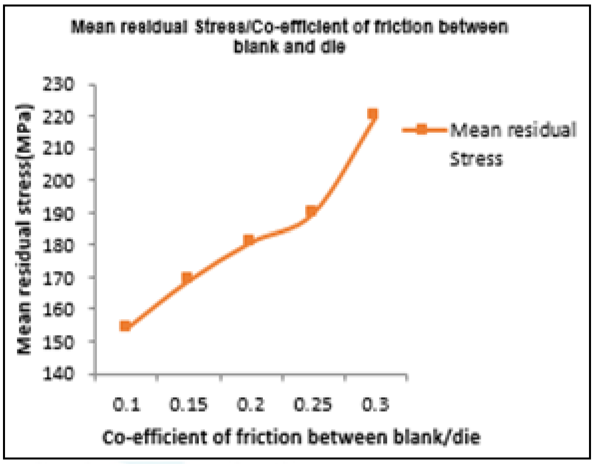

Figure 7: Variation of mean residual stress with friction conditions between blank and die.

5.3 The coefficient of friction between blank and blank holder

The blank holder controls the metal flow through the die with the aid of the blank holding force and the friction between the tool and the blank. The friction conditions between the blank and blank holder is also important as the blank holding force. From the stress contour band fig. 8, it can be seen that the flange held by the blank holder experiences minimum residual stresses but notwithstanding, the friction between the blank and holder affects the residual stresses at the cup walls and corners as the punch forces the sheet through the die. Fig. 9 illustrates the effect of co-efficient of friction between blank/holder on the mean residual stresses. The mean residual stress decreases as the co-efficient of friction between the blank and holder increases up to 0.17 and this is because lower co-efficient of friction tend causes excessive flow of the material at the die-shoulder which tends to increase the strain rate mean residual stress. As it increased further beyond 0.17 the mean residual stresses increase and this is because for the set punch velocity, very high co-efficient of friction (say 0.55) tends to restrict the movement of the sheet through the die and thus favour fracture while setting up excessive residual stresses.

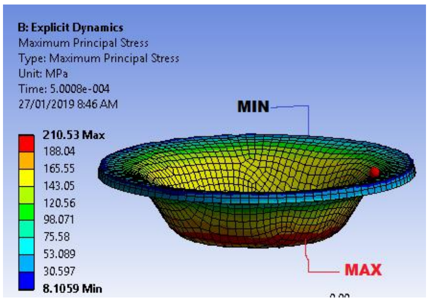

Figure 8: Results Contour bands showing location of maximum and minimum stresses

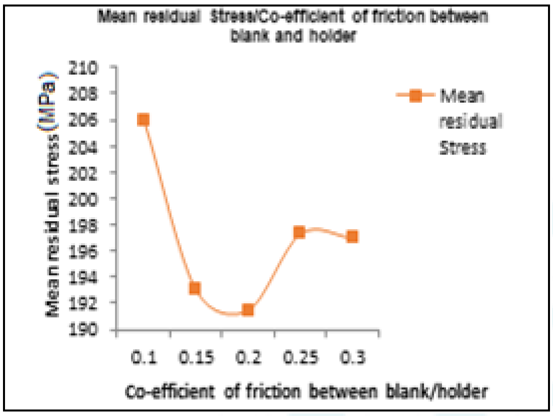

Figure 9: Variation of mean residual stress with friction conditions between blank and holder.

4.5 The punch velocity (Draw speed)

Fig. 10 shows the effects of punch velocity on the mean residual stress. There exist and inverse relationship between the mean residual stresses and draw speed between 1mm/s to 3mm/s It is observed the minimum stress value is at 1mm/s(60mm/min) draw speed.

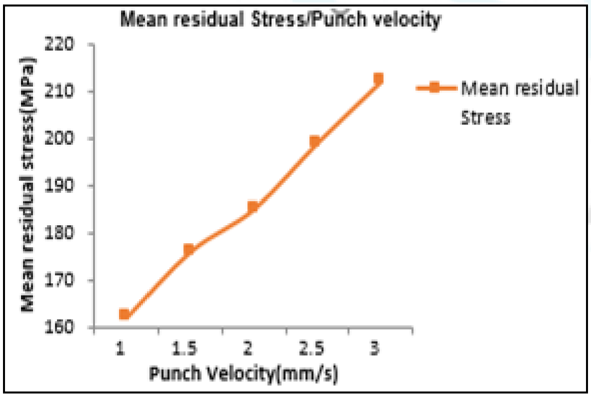

Figure 10: Variation of mean residual stress with punch velocity.

6. Conclusion

It is an explicit finite element analysis carried out on ANSYS explicit dynamics workbench using 100mm diameter,3mm thick Aluminium Alloy 3004-H19 blank and 15KN blank holder. The effects of die-shoulder radius, punch-nose radius, radial clearance, types of drawing lubricants, lubrication conditions between material/tools and punch velocity on the mean residual stresses of cups has been studied. Residual stresses can be minimized by

- Increasing the die-shoulder radius up to five-time sheet thickness,
- Increasing the punch-nose radius up to four times sheet thickness
- Setting the punch velocity to 1mm/s
- Ensuring additional radial clearance/sheet thickness between 15-20%
- Utilizing a fluid lubricant with μ_p =0.25 for friction between the punch and blank
- Utilizing a fluid lubricant with μ_h=017 for friction between blank holder and blank
- Utilizing a fluid lubricant with μ_d=0.12 for friction between blank and die.

Further work: In this present paper the effect of each parameter has been studied keeping most other parameters level constant because of the large number of parameters and levels. Intermediate simulations show there may exist slight variations if the other parameters kept constant varied simultaneously with the studied parameter. This will require Ideally 16807(7^5) simulations to cater for the 7 parameters in five levels. Taguchi design of experiment can be used to determine the percentage contributions of the various parameters. The simulations can be executed based on the Taguchi orthogonal arrays to reduce analysis and computation time while still giving priority to accuracy. Combined with ANSYS optimization module the best combination of process parameters (Blank holding force, die-shoulder radius, punch-nose radius, radial clearance, punch velocity, lubrication between material and tool) to minimize thinning and residual stresses can be determined.

References

[1] Bushan Sanjay, Paysheti,Shekari Yadgiri Gajjal (2012), Design Of Draw Die For Cylindrical Cup Formation, *International Engineering Research Journal* PP.453-458.

[2] B.Linga Reddy, P.V.R.Ravindra Reddy, B.Chenna Kesava Rao(2013),"A review on residual stresses in deep drawing" *International Journal of Innovative Research in Science, Engineering and Technology*. Vol. 2, Issue 3

[3] Coles R, Kirwan MJ. (2011) Food and beverage packaging technology. London:Blackwell Publishing;pp.344.

[4] Maeder G, Renault S.A, Malmaison R, (1992*)* "How to Account for Residual Stresses: Examples in the Automotive Industry, Residual stresses*",Ed Hauk, V., Hougardy, H.P., Macherauch, E., Tietz, H.D, DGM Informationsgesellschaft mbH*

[5] Lu, J. (1996), "Handbook of Measurement of Residual Stress", (ed) The Fairmont Press, Inc., Lilburn.

[6] Niku-Lari A, Lu J and Flavenot J. F, (1985), "Measurement of residual-stress distribution by the incremental hole-drilling method", *Journal of Mechanical Working Technology*, Vol.11, pp.67-188

[7] Anon, (1993), "Measurement of Residual Stress by the Hole Drilling Strain Gauge Method", Vishay-Measurements Group, Inc. Raleigh.

[8] Zhu Wu, Jian Lu and Bongtae Han, (1998), "Study of Residual Stress Distribution by a Combined Method of

Moire Interferometry and Incremental Hole Drilling" *Journal of Applied Mechanics*, Vol.65, pp. 837-850

[9] ASTM E 837, (1985), "Determining Residual Stresses by the Hole-Drilling Strain-gage Method", *American Society for Testing and Materials*,Philadelphia.

[10] Kelsey R.A, (1956), "Measuring Non-Uniform Residual Stresses by the Hole- Drilling Method," Proc. Soc. Exp. Stress Anal., Vol.14(1), pp. 181–194.

[11] Bijak-Zochowski M, (1978), "A Semi-destructive Method of Measuring Residual Stresses," VDI-Ber., Vol.312, pp. 469–476.

[12] Kondapalli Siva Prasad and Chalamalasetti Srinivasa Rao (2014) "Study on Effect of Die Corner Radius in Deep Drawing Process*" Pyrex Journal of Engineering and Manufacturing Technology*. Vol 1(1) pp 011-016 November, 2014. Pyrex Journal of Engineering and Manufacturing Technology. Vol 1(1) pp 011-016.

[13] Adnan I. O. Zaid, Fadhil A. Hashim (2017) "Effect of Punch and Die Profile Radii on Deep Drawing of Galvanized Steel*" International Journal of Scientific & Engineering Research, Volume 8, Issue 1*.

[14] Masoud Kardan,Ali Parvizi,Ali Askari(2018)" Influence of process parameters on residual stresses in deep-drawing process with FEM and experimental evaluations" *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, Vol 40:157.

[15] M. El Sherbiny , H. Zein, M. Abd-Rabou, M. El shazly"(2014) Thinning and residual stresses of sheet metal in the deep drawing process", Materials and Design 55 pp 869–879.

[16] R. S Khurmi "Strength of material", S.Chand publications New Delhi.

[17] www.thefabricator.com "choosing a lubricant for deepdrawing"

[18] www.matweb.com "Mechanical properties of aluminium alloys",Aluminium association inc.

[19] Suchy Ivana, (2006) "Handbook of die design". 2nd ed. McGraw-Hill Publishing; pp. 385–457 Pocket Telephone, Inc.