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Calculation of Deep Drawing Force in CR4 Metal Forming

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Abstract: *Deep drawing process is sheet metal forming process. Deep drawing is a mostly use this process in the automobile industry for formation of sheet metal part. In deep drawing forming process used to manufacture 3-D parts from thin sheet metals. In deep drawing process there are some factors which affected the process that factor called as process affected parameter of deep drawing. lubrication, die corner radius, punch corner radius, punch force, material properties, thickness of material, blank size, punch and die edges, punch speed, etc. are the most important parameters. Wrinkle and thinning on the surface of the material those are most occurs defect on the part. Die edges and Punch radius has the mostly affected on the deep drawing of sheet metal. Friction between punch, die cavity and material also affected for wrinkle formation. Punch force and entry of punch causes material thinning. This paper presents on deep draw sheet metal forming analysis. Ansys simulation is used to carry out the results of behaviour of the product. Main purpose of this paper is to calculate the required force use to perform the deep drawing operation therotically. Cup shape product take trial on mechanical press. It also shows the required machine capacity to fulfil the production requirement. From taken practical dimension die and punch in company. Using these dimensions the CAD model is generated in CATIA. This model is converted into igs format and imported in Ansys. The force required to develop the part, deformation and defect like tearing, wrinkles etc. can be obtained through simulation. Using of this easy to find out the part defect, material wastage, material deformation, die life , punch and die friction.*

Keywords: Deep Drawing, Part Development, Punch velocity and Force, Ansys simulation, force on punch.

I. INTRODUCTION

Deep drawing is the sheet metal forming process in which sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. Deep drawing is a mostly use this process in the automobile industry for formation of sheet metal part. Sheet metal forming is an important manufacturing process for producing a large variety of automotive parts and aerospace parts as well as consumer products. Deep drawing is a forming process involving variety of material flow conditions. During this process if the process parameters are not selected properly the blank sheet develops some defects. Therefore, it is very important to optimize the process parameters to reduce the defects in the parts and to minimize the production cost. In the deep drawing process metal sheet place on the blanking die and stroke out then blanking punch cut the blank in die cavity. Deep drawing is the tensile-compressive forming of a sheet metal blank convert to a hollow body which is open on one side and other side is close.

Products like automotive components, aircraft parts, cans, cylinder cup, and submarine hulls are manufactured using deep drawing procedure. [3] The important variable in deep drawing is property of sheet material, surface finishing of punch and die, lubrication, BHF, clearance between punch and die, stages of drawing, coefficient of friction between blank and rigid parts etc. Punch force perform an important role to draw sheet metal blank into required shape component. It is difficult to obtain exact required force on the punch to draw metal blank into required depth. The sheet metal industry faces a number of problems during development of the Die, punch holder, punch, draw punch and other parameters of required part manufacturing. These operations are complicated and calls high competency on the part design, material selection and process factors.

During this process a blank of the sheet metal is hold between the die holder and the blank holder. When the punch force is applied on blank and blank holder hold the blank to prevent wrinkle formation and to control the material flow during the deformation. When the punch is pushed the blank in to the die the sheet deforms plastically and it takes the desired shape of the tools. Deep draw is complicated process and needs highly skilled workers to produce error free assembly. For this process consider the temperature effect on die, blank, blank holder. It stated that as temperature increases contact pressure decreases. For reducing the temperature use the proper lubrication during the draw to reduce the friction. This paper is based on the calculation of different part use in deep drawing process such as blank diameter, affected parameter, draw ratio, draw force, clearance, machine tonnage etc. In above referred papers feed the basic required data but not shows the actual procedure to find the punch force require to develop defect free component.

II. Process Description For Part Development

Practically development die is very expensive method and this required very large time and high cost so we use conventional methods. With help of Computer-aided engineering we design the actual component and find out actual area of formation. This technique saves work, time and cost. First theoretically calculate deep drawing component (Emergency dish) dimension like cup height 36mm, cup diameter 130 mm, sheet thickness 1.2 mm to get the and blank diameter, blank holing force, drawing force, clearance between die and punch, etc. From the component dimension draw the 3D part drawing in the CATIA software. From this 3D parts deep drawing process assembly generated. This assembly imported in Ansys software in igs format, by applying material property and boundary conditions values simulation is carried out. As results after simulation we get the required punch force by using force probe tool.

A. Theoretical Calculation

Main deep drawing process parameters are calculated by using standard formulas as follows

Blank Diameter $D = (d^2 + 4dh)^{0.5}$ (1)

Draw Ratio = h/dp (2)

Punch and Die Clearance C= T+ k (10 T) (3)

Drawing Force empirical relation

$p = \pi * dp*t*S*((D0/dp) – C)$ (4)

FOS taken as 1.5,

Blank Holding Force is approx. 20% to 30 % of Draw Force

(B.H.F.) = 30 % of Draw Force (5)

Press Tonnage P = p + (B.H.F.) (6)

Table I: Design calculation values

Equation No.	Parameters	Values
1	D	180 mm
2	h/dp	0.3439
3	C	2.04 mm
4	p	26 ton
5	B.H.F.	8 ton
6	P	34 on

B. CAD Model of part

The solid model of Emergency cup is modeled using 3D modeling software CATIA (generative sheet metal design workbench) based on drawing taken for analysis.

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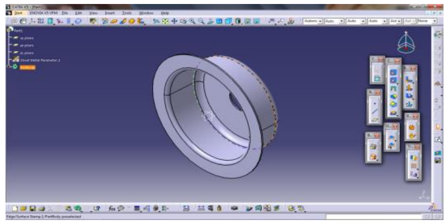
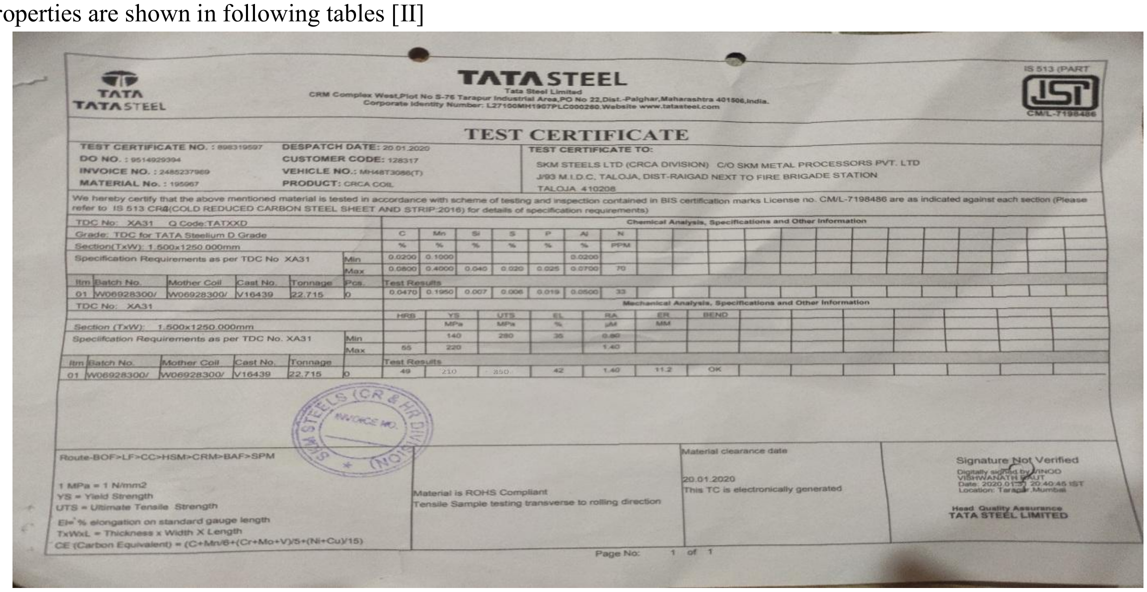


Figure 1: CAD Model in Catia

C. Material Property

For deep Drawing process low carbon steel material is used to minimize the defect generation. For deep drawing process EDD (Extra Deep Draw) material is used. There are HR (hot roll carbon steel) and CR (cold roll carbon steel) two type of material. There are some types or grade of CR materials like CR1, CR2, CR3, CR4, and CR5 requirements and suggestions CR4 EDD material is used for deep drawing process. CR4 is cold rolled steel with high elongation and lower carbon content. It is good for cold forming process. CR4 material Chemical and Mechanical properties are shown in following tables [II]



TATA STEEL

TATA STEEL
Tata Steel Limited
CRM Complex West,Plot No S-76 Tarapur Industrial Area,PO No 22,Dist.-Palghar,Maharashtra 401506,India.
Corporate Identity Number: L27100MH1907PLC000260.Website www.tatasteel.com

IS 513 (PART
ISI
CM/L-7198486

TEST CERTIFICATE

TEST CERTIFICATE NO. : 898319597
DO NO. : 9514929394
INVOICE NO. : 2485237969
MATERIAL No. : 195967

DESPATCH DATE: 20.01.2020
CUSTOMER CODE: 128317
VEHICLE NO.: MH48T3088(T)
PRODUCT: CRCA COIL

TEST CERTIFICATE TO:
SKM STEELS LTD (CRCA DIVISION) C/O SKM METAL PROCESSORS PVT. LTD
J/93 M.I.D.C. TALOJA, DIST-RAIGAD NEXT TO FIRE BRIGADE STATION
TALOJA 410208

We hereby certify that the above mentioned material is tested in accordance with scheme of testing and inspection contained in BIS certification marks License no. CM/L-7198486 are as indicated against each section (Please refer to IS 513 CR4(COLD REDUCED CARBON STEEL SHEET AND STRIP:2016) for details of specification requirements)

TDC No: XA31 Q Code:TATXXD
Grade: TDC for TATA Steelium D Grade
Section(TxW): 1.500x1250.000mm

Chemical Analysis, Specifications and Other Information

		C	Mn	Si	S	P	Al	N
		%	%	%	%	%	%	PPM
Specification Requirements as per TDC No XA31	Min	0.0200	0.1000				0.0200	
	Max	0.0800	0.4000	0.040	0.020	0.025	0.0700	70
Test Results		0.0470	0.1950	0.007	0.006	0.019	0.0500	33

Itm	Batch No.	Mother Coil	Cast No.	Tonnage	Pcs.
01	W06928300/	W06928300/	V16439	22.715	0

TDC No: XA31
Section (TxW): 1.500x1250.000mm

Mechanical Analysis, Specifications and Other Information

		HRB	YS	UTS	EL	RA	ER	BEND
			MPa	MPa	%	μM	MM	
Specification Requirements as per TDC No. XA31	Min		140	280	36	0.80		
	Max	55	220			1.40		
Test Results		49	210	350	42	1.40	11.2	OK

Itm	Batch No.	Mother Coil	Cast No.	Tonnage	
01	W06928300/	W06928300/	V16439	22.715	0

SKM STEELS (CR & HR DIVISION) INVOICE NO.

Route-BOF>LF>CC>HSM>CRM>BAF>SPM

1 MPa = 1 N/mm2
YS = Yield Strength
UTS = Ultimate Tensile Strength
El= % elongation on standard gauge length
TxWxL = Thickness x Width X Length
CE (Carbon Equivalent) = (C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15)

Material is ROHS Compliant
Tensile Sample testing transverse to rolling direction

Material clearance date
20.01.2020
This TC is electronically generated

Signature Not Verified
Digitally signed by VINOD VISHWANATH RAUT
Date: 2020.01.31 20:40:45 IST
Location: Tarapur,Mumbai

Head Quality Assurance
TATA STEEL LIMITED

Page No: 1 of 1

Figure 2: Material test report CR4

Quality		Yield Stress Mpa	Tensile Strength Mpa	Elongation Percent AMin		Hardness
Designation	Name	Max		Lo = 80 mm	Lo = 50 mm	HR (30T)
CR4	Extra Deep Drawing Aluminum Killed	210	350	36	37	50

Table II: Mechanical properties of material

For the proportional limit the tangent modulus is equivalent to young's modulus. Above the proportional limit the tangent modulus changes with strain and it is accurately calculate by using actual from test data. The Ramberg–Osgood equation state the relation between young's modulus to the tangent modulus and this is one of the methods for obtaining the tangent modulus. The tangent modulus is playing an important role in describing the behavior of materials that have been stressed beyond the elastic region. The tangent modulus determines the "softening" or "hardening" of material that generally occurs when it begins to yield. Tangent modulus is calculated by using constant n is 5, modulus of elasticity 200Gpa for Ramberg–Osgood Equation.

$$Et = \frac{E * \sigma ys}{\sigma ys + 0.002 * n * E \left(\frac{\sigma}{\sigma ys}\right)^{n-1}}$$

Tangent modulus for EDD material is computed by using above equation is 2694061000 Pa = 2.69 * 109 Mpa

D. Finite Element Analysis

Assembly in igs format, file generated from Solid Work in catia is imported in Ansys software. EDD material properties as density,bulk modulus, shear modulus, tangent modulus, yield strength, young's modulus, poisons ratio ultimate strength are missing in Ansys material library so it is necessary to create custom material properties for EDD in material library. Following table shows the material property assign to blank.

Table III: Material property of CR4 EDD

Properties of Outline Row 3: CR4

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7861.1	kg m^-3
4	Isotropic Elasticity		
5	Derive from	Young's Modulus an...	
6	Young's Modulus	2.0484E+11	Pa
7	Poisson's Ratio	0.29	
8	Bulk Modulus	1.6257E+11	Pa
9	Shear Modulus	7.9397E+10	Pa
10	Bilinear Isotropic Hardening		
11	Yield Strength	2.1E+08	Pa
12	Tangent Modulus	2.6851E+09	Pa
13	Tensile Yield Strength	2.1E+08	Pa
14	Tensile Ultimate Strength	3.5E+08	Pa

Meshing is done by using Ansys Mechanical APDL with element size for blank and other body parts are 2mm, and 3mm respectively.. Contact between the punch and blank, blank holder and blank is frictional also die is stationary and punch, blank holder are translational in motion. Punch travels to positive Y axis; displacement is set as 36mm from the contact of blank. The transient simulation is carried out for better convergence of the problem for deflection, stresses, joint probe force. The results are as follows:

1. Total Deformation is 34 mm and the thickness of bottom circle is around 10 mm. this shows the total deformation is acceptable value.

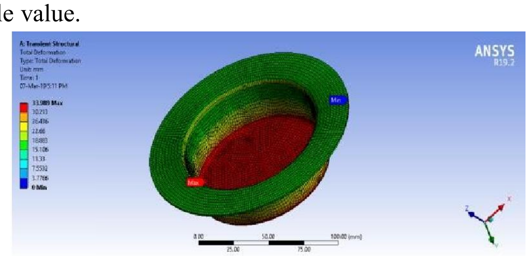


Figure 3: Total deformation of Cup

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2. Equivalent Elastic Strain is 0.0089. This value shows the ratio of change in dimension with original dimension. From the results we can say that wall thickness is not toothin.

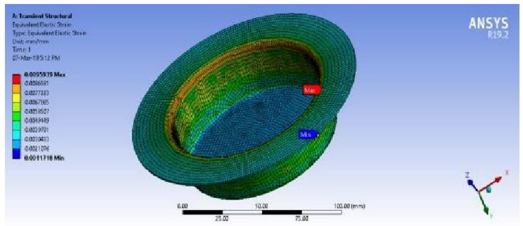

Figure 4: Equivalent Elastic Stain of Cup

3. Shear stress indicates the fracture or failure in material. If shear stress is large then wearing tearing or surface distortion defect generate in product mainly at edges. In this case shear stress is within limit, but on the edge of neck region surface shows the chances of tearing

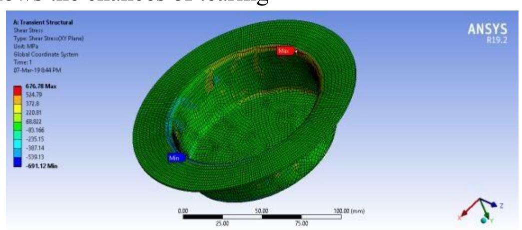

Figure 5: Shear Stress of Cup

Table IV shows the reaction force generated on X, Y, Z axis of the punch. Considering this value and mathematical formula resultant is calculated which shows the 30.37 ton force to positive yaxis

Definition	
Type	Joint Probe
Result Type	Total Force
Results	
X Axis	2.9783e+005 N
Y Axis	-48.583 N
Z Axis	766.65 N
Total	3.1783e+005 N

Table IV: Punch Joint Probe Result

4. In deep drawing process due to stretching phenomenon of sheet thickness varies from region to region. As depth of drawing increases thickness decreases i.e. wall thickness reduces. This results are calculated with the help of Altair inspire form software.

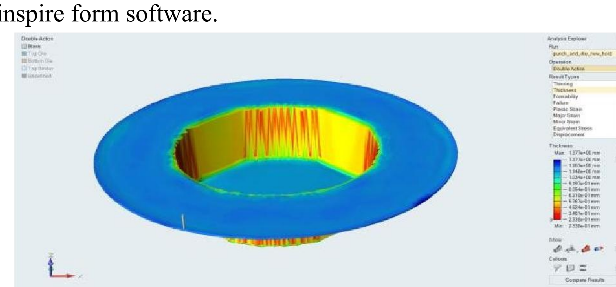

Figure 6: Thickness of cup at various regions

III. Result And Discussion

Below table shows the strain stress and resultant punch force generated as particular deformation value.

Total Deformation (mm)	Equivalent Elastic Strain x10^{-3}	Equivalent Stress (MPa)	Shear Stress (MPa)	Total Force (Ton)
0.1258	1.51	281.64	85.852	0.976
12.492	6.45	1338.2	539.9	19.257
20.310	7.75	1591.6	636.99	23.942
31.238	9.57	1874.5	645.51	28.522
33.989	9.62	1953.4	676.78	31.02
36.270	9.92	2096.2	704.68	32.437

Table V: Result Table

The main finding of this paper is to find the punch force required in forming operation like deep drawing which is calculated by using ansys force probe tool. Below graph shows the as increase in deformation punch force also increases. It increases up to the tearing of component wall then it decrease. Next graph shows the force values in tones for specific deformation.

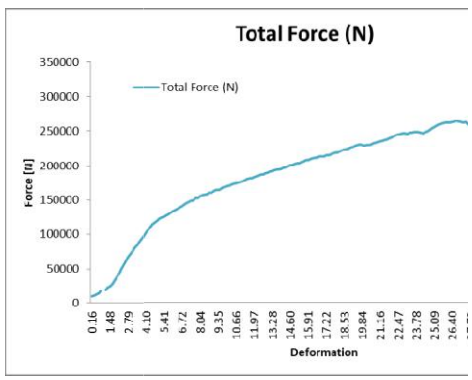

Figure 7 (a): Required force as deformation increases

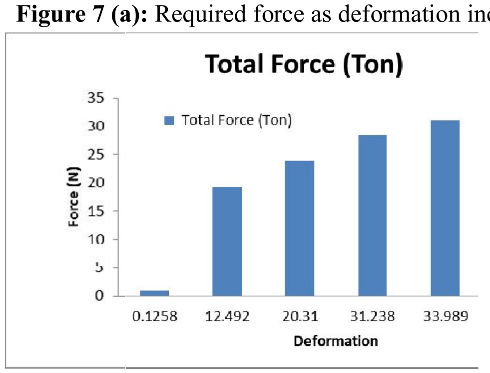

Figure 7 (b): Force values for specific deformation

Joint probe table and chart shows the required force to draw blank into required shape, i.e. Required Punch Force is $2.978 * 10^5$ Newton which is nothing but 30.87ton

This punch force is calculated from Ansys transient structural simulation solver. we required punch force 31 ton. Factor of safety should be taken 1.5, Therefore,

Draw Force

(P) = 46 ton

Press Tonnage = Draw Force + (B.H.F.) = 56ton- (8)

From the theoretical calculation the required force is 36 ton and from the Ansys simulation we get required force as 56 ton. In actual production the required machine force is in the range of 56 to 60 ton. This difference can be attributed to the average value of the constant *C,* used in the equation (4) which is dependent on die angle, friction and lubrication.[5] The problem areas such as wrinkling, tearing thinning are the biggest challenges in the industry now a days but these problems is minimized and sorted out in the initial stages of the design by using simulation techniques. In this simulation there is no single evidence is found about wrinkle. In case of tearing as shown in fig 6, shear stress is maximum on the neck of cup but it indicates the initial stage of tearing not a proper teardown on neck. Fig 8 shows the thickness of cup which is 1.2mm max i.e. original sheet thickness and 0.7mm minimum thickness. From this value thinning is approximately 41percentages.

IV. Conclusion

The maximum force recorded in the simulation deep drawing processes (Equation 8) is calculated as 56ton, and this force is validate by conducting experimental process at 55ton force (shown in table VI). The experimental and computational value of force obtained matches well with each other. From the results it can also be concluded that the computational method used in this paper is much acceptable for deep drawing.

From the experimental results it is observed that the part manufactured is wrinkle free hence equation (5) provides correct blank holding force to produce defect free production of deep drawing forming parts. Tearing defect is also absent in whole experimentation process. Maximum thinning of cup is 33 percentages i.e. wall thickness is 0.8mm which is acceptable. Therefore press machine up to 60 ton capacity can be used for the required process.

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