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## **Design and Analysis of Deep Drawing Process on angular Deep Drawing Dies for Different Anisotropic Materials**

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Abstract. Deep drawing process is a significant metal forming process used in the sheet metal forming operations. From this process, complex shapes can be manufactured with fewer defects. Deep drawing process has different effectible process parameters from which an optimum level of parameters can be identified so that an efficient final product with required mechanical properties will be obtained. The present work is to evaluate the formability of different metal sheets using deep drawing process. In which effects of different sheets and die/blank holder angle on deep drawing process observed for sheet metal of 0.8mm of SS304 and Brass and 0.9 mm of Al. The experiments were performed by designing the deep drawing tools such as die, blank holder, and punch. In addition, the numerical simulations are performed for deep drawing of cylindrical cups using three levels of previously mentioned. Punch forces and dome heights are evaluated for all the conditions. From this work, the formability for different metal sheets is observed for angular geometries of deep drawing tools. Moreover, it is observed that strain formation is more for the brass sheet and stress is more for aluminium sheets.

#### **1. Introduction**

Sheet metal forming is one of the most widely used manufacturing processes for the fabrication of a wide range of products in many industries. The deep drawing process is adapted for manufacturing a product of required shape with no failures. The ability to design a deep drawing product with required blank material, size, shape along with its tool design and choice of lubrication significantly depends on the study of influence of the failures occurring in the process. Yoshihara et al [2] investigated deepdrawing process of a circular cup using magnesium alloy, the study is to estimate the LDR using variable BHF control and to understand the fracture mechanism of magnesium alloy sheet using FEM simulation. Hassan et al [1] newly proposed a two-layered tapered blank holder divided into four segments to eliminate the defects of localized wrinkling and intensive shear deformation regions. Cui

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et al [3] applied the optimization method and numerical simulation technology in the sheet metal forming process to improve design quality and shorten design cycle. Chen and Lin [4] investigated the effects of process parameters on the formability of deep drawing of rectangular cups of SUS304 stainless steel using both the simulations and the experiments. Dong and Prasad [5] carried out experiments by varying profile radii of die, punch to measure the punch load variations for elliptical forming processes, and reported the influence of the profile radii of blank shape, die and punch on punch load distribution of elliptical deep drawing product. Tommerup and Endelt [6] demonstrated a method in which using prescribed tool geometry; the process parameters, which provide the highest quality to the drawn parts, can be identified. It was also shown that during forming process the blank holder force distribution had significant influence on the final drawn part. Hassan et al [7] proposed a friction aided deep drawing process for thin sheets and metal foils to increase the deep drawability. A finite element model was developed using the Taguchi and Pareto ANOVA statistical methods and the simulation values obtained were evaluated with the experimental values of square cup deep drawing process to obtain the optimum values. Jayahari et al [8] investigated the aluminum alloy graded IS 737 at elevated temperature and showed that the commercial pure aluminum has substantial increase in the formability at 350°C. Farhang et al [9] analysed numerically and experimentally the formability of AA5754 aluminum sheet metal subjected to stamping, warm forming, sheet hydro-forming and warm sheet hydro-forming by quantifying the maximum draw depth using cylindrical cup forming die set. Javier et al [10] developed a computer-aided deep-drawing tool combining the resolution of both deep drawing and the ironing process. Various parameters were considered in the process to optimize for the material waste, total process time and manufacturing cost. Mostafapur et al [11] conducted investigation to examine the effect on the formability and drawing depth of Al 1050 alloy using the new pulsating blank holder system.

## 2. Methodology

In this research modelling of deep drawing process setup both in real time and by using computer aided design tool, CATIA V5 were carried first. Different sheet metals of 0.8mm brass and stainless steel and 0.9mm of aluminium is considered. The process setup is attached to a universal testing machine to perform the experiments and for simulations the tools are imported into finite element analysis tool, PAM STAMP 2G where sheet metal blank was modelled and simulations were carried out.



Figure 1. Deep drawing process setup

Table 1 Tool dimensions and varied process parameters				
Punch	Diameter	30mm		
	Nose radius	6mm		
Draw die	Die diameter	32.3mm		
	Die profile radius	5mm		
Blank	Thickness	0.8mm/0.9mm		
	Diameter	55x55mm		
Process parameters	Blank holder/Die angle Lubrication	12.5° With and without		
	Material	Al-AA6111,SS304,Brass		

Figure 2. 3D modelled Die and blank holder in CATIA

## 2.1 Base Materials and their mechanical properties

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Table 2Mechanical Properties of AA 6111 sheet [12]										
	Base	E(GPa)	N	σ (MPa)	K(MPa)	n	$R_0$	$R_{45}$	$R_{90}$	t (mm)
	AA 6111	66	0.33	289	543	0.265	0.63	0.61	0.74	0.9
	Table 3       Mechanical Properties of SS 304 sheet [13]									
-	Base	E(GPa)	N .	σ (MPa)	K(MPa)	N	$R_0$	$R_{45}$	$R_{90}$ =	t (mm)
	SS 304	210	0.33	307	1069.8	0.229	1.08	0.92	1.05	0.8
_	Table 4 Mechanical Properties of 70-30 Brass sheet [14]									
	Base	E(GPa)	) v	σ (MPa)	) K(MPa	) n	$R_0$	$R_{45}$	$R_{90}$	t (mm)
7	0-30 Brass	s <u>112</u>	0.33	420	880.5	0.321	1.22	0.76	0.96	0.8

	Tuble e Materials and their corresponding Earls					
S. No	Material	Yield Criteria	Hardening law			
1	Aluminum AA6111	Hill's 1948	Hollomon law			
2	SS304	Hill's 1948	Krupowski law			
3	70-30 Brass	Hill's 1948	Hollomon law			

 Table 5
 Materials and their corresponding Laws

## **3. Results and Discussion**

Various process parameters like die punch clearance, punch radius; die radius and lubrication affect the formability of the blank. Also the thickness of the sheet metal, along with its mechanical properties and the shape of the blank created, affect the formability of the blank. The present study observed the variations at three different materials. The punch force and dome height for the Aluminum alloy, AA 6111, SS304 and brass sheets were effectively evaluated from the reliable results obtained from experiments and simulations in PAM STAMP 2G.

## 3.1 Dome Height Evaluation



Figure 3. Aluminum AA6111 [a], SS304 [b] and Brass [c] deep drawn cups sheet

The variation of cups formation for three different materials namely Aluminum AA6111, SS304 and Brass of size 55x55mm is shown. From the above drawn cups, it is observed that the dome is more for SS304 sheet and then it is for Brass sheet, but the wrinkles formation is more for SS304, so the punch force is also more for SS304.



**Figure 4.** Stress formation for Aluminum AA6111 [a], SS304 [b] and Brass [c] deep drawn cup respectively

The variation of stress for three different materials namely Aluminum AA6111, SS304 and Brass of size 55x55mm are observed. The numerical simulations are carried out and the stress formation zones are seen for all the three materials. From the above drawn cups through simulations, it is observed that

the stress is more for AA6111 sheet and then it is same for both SS304 and Brass sheets, highly stress formation zones is formed around the neck region for all the materials.

#### 3.3 Strain Evaluation



Figure 5. Strains formation for Aluminum AA6111 [a], SS304 [b] and Brass [c] deep drawn cup respectively

The variation of strain for three different materials namely Aluminum AA6111, SS304 and Brass of size 55x55mm are observed. The numerical simulations are carried out and the strain formation zones are noticed. From the above drawn cups through simulations, it is observed that the strain is more for Brass sheet and then it is almost same for both SS304 and AA6111 sheets; highly strain formation zone is formed for Brass sheet around the cup.

## 3.4 Punch Force Evaluation

The variation of punch force for three different materials namely Aluminum AA6111, SS304 and Brass of size 55x55mm are observed. The analysis is carried out by comparing the experimental results with the simulation results.





**Figure 6.** Punch force comparison of experimental and simulation data for AA6111 [a], SS304 [b] and Brass [c] materials

For all the three materials the graphs is plotted between Punch force vs Displacement and the force required to draw a particular sheet is observed and the results were tabulated below. The punch force required is more for SS304 when compared to other materials since wrinkles formation is more for SS304. So from this it can be observed that as the wrinkles formation is more punch force required is more and vice versa.

	Table 6         Materials and their results						
S. No	Material	Max. Strain	Max. Stress	Experimental Punch Force	Simulation Punch Force		
				I unen I oree	I ullell I blee		
1	Aluminum	0.38	0.54	17.6	17.6		
	AA-6111						
2	SS304	0.36	0.49	27.2	26.9		
3	70-30 Brass	0.79	0.49	27.2	26.7		

## 4. Conclusions

The results obtained by varying all the above parameters are evaluated for the punch force. It is concluded that the punch force required is same for brass and stainless steel, aluminium requires less force. For aluminium and Brass Hollomon hardening law suits the best and for Stainless Steel Krupowski law suits the best.

- The Strain formation is more for the brass sheet metal when compared to Stainless steel sheets and Aluminum sheets.
- The Stress formation is high for aluminium sheet when compared to Stainless Steel sheets and Brass sheets.
- The dome is more for SS304 sheet and then it is for Brass sheet, but the wrinkles formation is more for SS304, so the punch force is also more for SS304.
- When compared to flat dies with angular dies results like punch force and formability is better for angular dies.

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