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Research Paper

FATIGUE ANALYSIS OF POLYMER COMPOSITE DEEP DRAWING DIE

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Short run production are the current scenario for batch production is of growing importance. When considering metal forming processes in this scenario, die and punch costs play an important role making the processes costlier. Polymer composite material, Renshape 5166 dies made by rapid tooling techniques prove to be good solution in this scenario. Fatigue life estimation of the dies help in planning for the production. FE simulations are carried out to predict the fatigue life of these dies during deep drawing process. The results of the simulation indicate that these dies can be used or softer material like aluminum for 1000 cycles, but when stronger materials like Cu or SS are used, the life is limited to around 100 cycles.

Keywords: Rapid tooling, Polymer composite die, Transient simulation, Fatigue life

INTRODUCTION

Metal forming is a process where metal is styled into necessary shape without adding or removing material. During this process the material is subjected to plastic deformation. Processes like rolling, bending, deep drawing, hydroforming all come under this category. Of these deep drawing is one of the process that is used to make a lot of components like cups, shells, etc. A lot of research has been done to study the flow of metal during this process.

The process of deformation of sheet during rectangular cup drawing operations is discussed by AmraTalic-Cikmiš *et al.* (2010). Peter Ulintz (2007) and Kadhim Abed (2011) presented the equations for calculating the die dimensions and drawing force. The calculated dimensions validity were checked using FEM. Sekhara Reddy *et al.* (2014) discussed an easy way for determining Limiting Drawing Ratio (LDR) in Deep Drawing process. FE Analysis performed by Neto *et al.* (2014) to study the wrinkling of sheet during deep drawing operation and verified the results experimentally. In-plane mesh refinement is suggested by them. FEA is used by Magar *et al.* (2013) to predict the thickness distribution with variation of drawing ratio, yield

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strength and blank holder force, when radial drawing was dominant for cup shaped component without flange and having high punch radius. Pradeep Patil and Prashant Bajaj (2013) used FEA to study the effect of deep drawing parameters like speed of the punch, drawing force etc on the drawing defects that are produced during forming operation. Strain distribution pattern in a plate during cup drawing is studied using FE simulations by Shishir Anwekar and Abhishek Jain (2012). Their results were found to be in excellent agreement with experimental results.

Susheel Madhavrao Magar and Mohan Yashwant Khire (2010) performed numerical simulations to study the change in thickness of the blank during forming operation. Also analytical relationship is suggested to obtain correct initial blank size for cup shaped components with flange on the basis of principal of constancy of volume. Ayari and Bayraktar (2011) did a parametric study to predict accurately the final geometry of the sheet blank and the distribution of strains and stresses and also to control various forming defects, such as thinning as well as parameters affecting strongly the final form of the sheet after forming process. Optimization using Taguchi techniques was performed by Raju *et al.* (2010) to find parameter values to get optimum wall thickness. It is found that the die shoulder radius has the greatest effect on the thickness distribution.

FE analysis results are used by Mathews Kaonga (2009) to predict critical areas during forming process. Using FEA, Yang (2008), studied the mateial flow character during the elliptic cup deep drawing of magnesium alloy sheet at elevated temperatures. Zhang Xiao-Bing *et al.* (2007) investigated into the effect of coating during cup drawing process as well as delamination of coat and substrate during the drawing process discussed. Solid elements used for modeling purposes. Fuh-Kuo Chen *et al.* (2003) studied experimentally and theoretically, the variation in formability of AZ31 (aluminum 3%, zinc 1%) sheet with temperature during a square cup drawing operation. Hong Yao *et al.* (2000) proposed a modified axisymmetric model with a center offset to predict tearing failure in the corner sections of 3D parts.

All of this work involved investigation into the work piece material deformation characteristics only. As per authors preview, very little work has been done so as to predict the die life. Also most of the simulations involved the use of shell elements. The above work can be used in designing the blank dimensions. But when it comes to designing the die, more investigations into the stress distribution and failure mode of dies are required. Study in this region helps in developing rapid tooling for cup drawing operations.

RAPID TOOLING

Short run productions are the need of the day. Most of the current market production is batch production. Low cost tooling is thus an important requirement in the metal forming industry. Tool making using Rapid Prototyping technique, in other words Rapid Tooling, offers an effective solution.

Different rapid tooling techniques for sheet metal forming are reviewed by Du Zhao Hui *et al.* (2000). Rapid tooling for sheet metals can be classified into two types: Direct and

Indirect. The indirect processes involve secondary processes like Selective Laser Sintering (SLS), Stereolithography (SLA), and high-speed Computer Numerical Controlled (CNC) milling for generating mould which is then used to create the tool. The direct approach uses DTM's RapidSteel to produce the metal tooling without going through any secondary process. Comparisons on quality, leading time and cost are presented.

Yucheng Ding *et al.* (2004) presented an integrated system for using Rapid Prototyping techniques for generating tooling for manufacturing using four case studies. Three fabrication methods, suitable for rapid die development schemes, are compared experimentally by Walczyk and Hardt (1999). The comparison is based on cost, lead-time, and shape resolution and flexibility issues. The candidate methods include CNC-machining a solid billet of material (standard method), assembling and clamping an array of Profiled-Edge Laminations (PEL), and configuring and clamping a matrix of closely-packed pins (discrete die). The discrete die method excels over the other two methods in terms of lower cost and faster fabrication time. Juraj Hudák (2012) discussed the Rapid tooling for metal forming using MELATO® (MEtalLAminatedTOoling) technology. Using this technology, punches are prepared using sheets of metals and a polymer coating.

Park and Colton (2005) Polymer composite material usage for die materials is discussed. Renshape 5166 die failure analysis and life prediction is performed using FEA and verified experimentally. Al sheet is simulated during this process and experimentation is performed using this sheet. Deep drawing is discussed in this process.

PROBLEM STATEMENT

When using polymer composite material for sheet metal forming dies and punches, it is quite necessary to predict the effect of various factors on the life of punch and die. The current work aims at studying the effect of different blank materials on the life of the die. Different punch travel speeds are simulated during the process. Table 1 gives the various parameters that are used to define the model during simulations.

Table 1: Model Design Paramters

Quantity	Value
Punch length	50 mm
Punch corner raidus	5 mm
Punch dia	31.8 mm
Sheet thickness	1 mm
Blank dia	50 mm
Blank material	Al/Cu/SS
Die runoff	15 mm
Die corner radius	5 mm
Die height	50.8 mm
Die hole dia	34 mm
Die and punch material	Renshape 5166
Punch travel speeds (mm/min)	90, 120, 150

MESHED MODEL AND BOUNDARY CONDITIONS

Cup drawing simulations is performed as axisymmetric model. Meshed FE model is shown in Figure 1. Figure 2 shows the detailed meshing of the sheet. The sheet is finely meshed so as to simulate the bending realistically. Mesh of both die and punch is inflated along the contact walls so that an accurate prediction of stresses during the

Figure 1: Complete Meshed Model of the Assembly

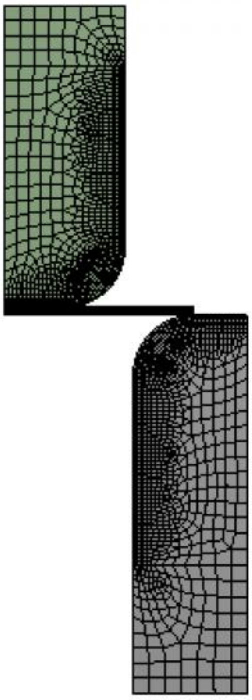
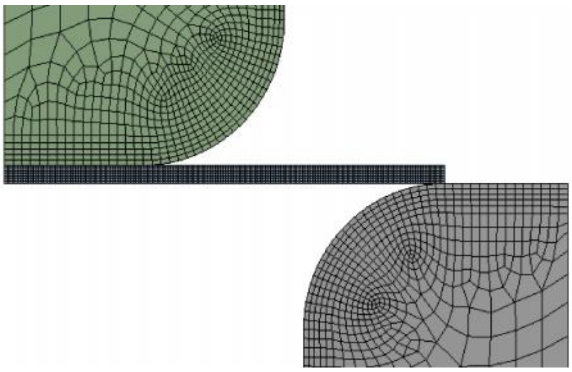


Figure 2: Meshed Model of the Sheet



being process can be predicted. Transient simulation is carried out to simulate a punch displacement of 15 mm with three different travel speeds: 90 mm/min, 120 mm/min and 150 mm/min. Stress distribution in both die and punch are studied during the process. Bottom and outer edges of the die are fixed during this process and punch movement in x direction is constrained.Renshape 5166 material properties and s-N curves are given in Park and Colton (2005).

RESULTS AND DISCUSSION

Figures 3, 4 and 5 compare the drawing force, Min Principal Stress and Max principal stress predicted during the simulation. It may be noted here that the –ve values indicate compressive stresses while the positive values indicate tensile stresses. Also from the plots it can be observed that the compressive stresses are of greater magnitude when compared to that of tensile stresses. Also considering the drawing force, it can be

Figure 3: Drawing Force Variation wrt Draw Speed

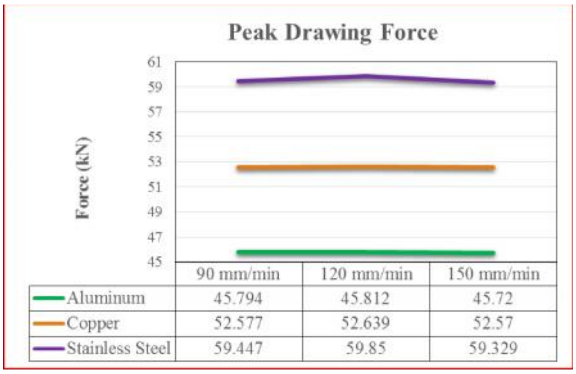


Figure 4: Min Principal Stress Variation wrt Draw Speed

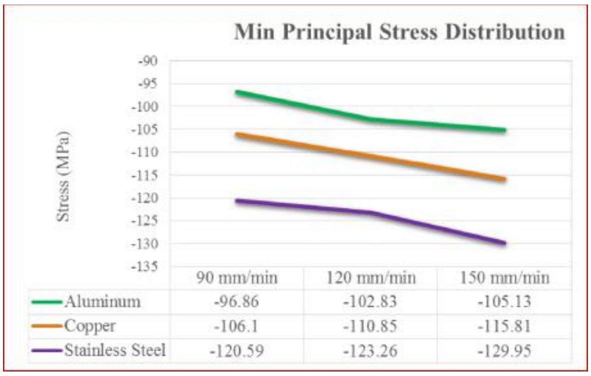
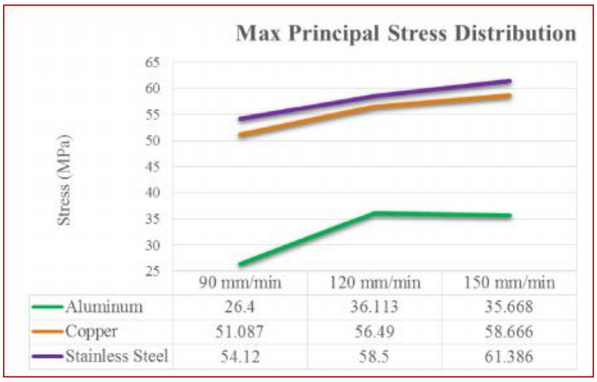


Figure 5: Max Principal Stress Variation wrt Draw Speed



observed that the drawing force is almost constant with the draw speed.

The stress distribution plots for aluminum as blank material and with 90 mm/min are given in Figures 6 and 7. Based on the stress distribution plots, it can be observed that the stress is the punch is quite less and is around 11 MPa. Thus the stress distribution study of die is not given importance. But when considering the die, stress as high as 96 MPa are produced. Thus stresses in die are given importance in all the studies. Plots 8 and 9 detail the stress distribution in when copper and SS materials are used as blank materials.

It may be noted that high compressive stresses are produced, in all cases exactly at the tip of the shoulder radius of the die. And

Figure 6: Stress Distribution in Punch and Die with Al as Blank Material and Draw Rate 90 mm/min

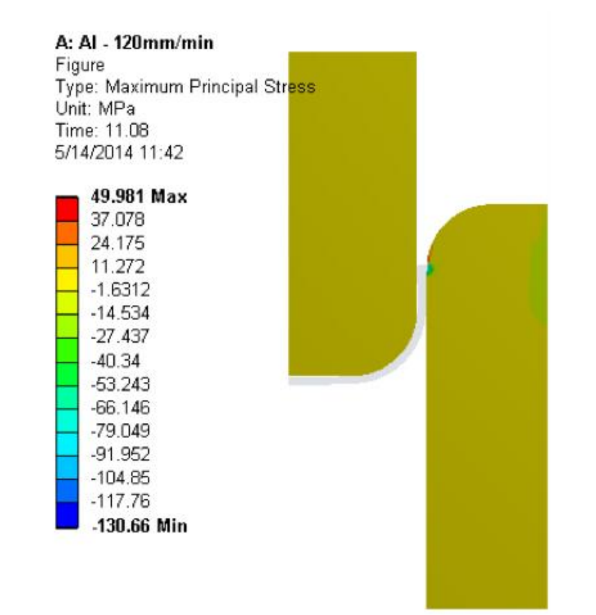


Figure 7: High Stress Region in Die with Al as Blank Material and Draw Rate 90 mm/min

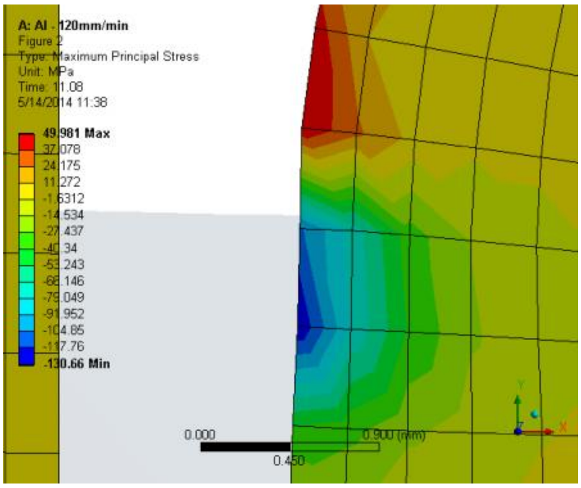


Figure 8: High Stress Region in Die with Cu as Blank Material and Draw Rate 90 mm/min

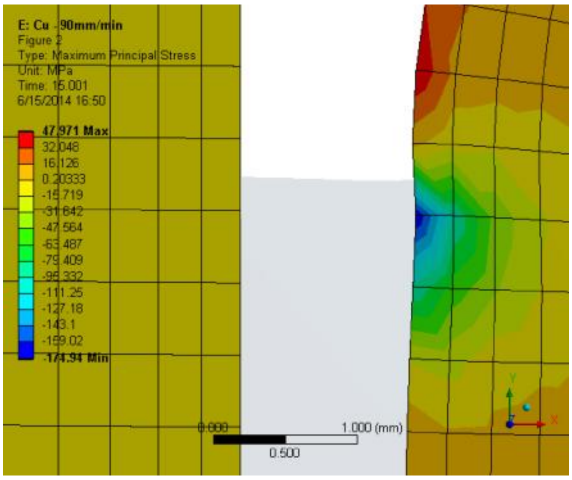
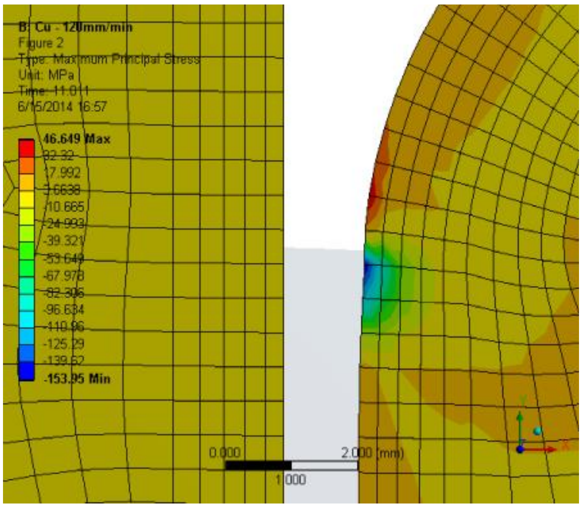


Figure 9: High Stress Region in Die with SS as Blank Material and Draw Rate 90 mm/min



tensile stresses occur just above the tip of the shoulder radius of the die. It is also observed that high stress values are produced when the top of the cup just passes the shoulder of the die. In the plots 4 and 5, the stress values are taken considering the degeneracy of the result. As per Park & Colton, the failure does not occur in the die as long as Equation (1) is satisfied.

$$(\pm_1)_{max} \approx \pm_u = 1.6\pm_{uts} \quad ...(1)$$

It can be noted from the result that in almost all cases of aluminum, the max stresses are quite low. In rest of the cases, Max stresses are nearing 1.6 $\pm_{ut}$ and thus the dies shall be very sensitive to any misalignments and shall fail readily. Thus if the die survives for the first draw, it can be used for the next couple of hundred draws.

CONCLUSION

Transient simulations are executed to study the life of polymer composite Renshape 5166 die during deep drawing operation. For this axisymmetric model of the assembly is used for performing simulations. Blank is finely meshed to model the forming process realistically while dies are inflated along the contact regions so as to study the interactions in a detailed fashion. The results of the simulations indicated that the stresses in the punch are quite low and thus the life of the punch will be very high. But when considering the die, it is observed that the max compressive stresses are being generated at the tip of the shoulder radius and tensile stresses are just above that of the shoulder radius. Based on the results, it is observed that for a sheet thickness of 1 mm with aluminum as sheet material, the die life will be around some 1000 cycles. But for harder materials like Copper and Stainless Steel, based on the magnitude of the stress generated, if the die lasts for the first draw, the die can be used for next 100 cycles.

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