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COMPARISON OF CONVENTIONAL DRAWING, INVERTED DRAWING AND WARM FORMING PROCESSES FOR DEEP DRAWING OF ALUMINIUM CUPS

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Abstract- Cup drawing is one of the important operations in sheet metal forming. Manufacturing of the aluminium base cup involves several stages such as blanking, first drawing, second drawing, taper formation and trimming. This increases the process time. An attempt has therefore, been made to develop a comprehensive, rigorous, yet easily-workable method of analysis for designing a die set to combine the intermediate stages of drawing process. Conventional drawing, inverted drawing and warm forming processes are experimented for yielding successful drawing in single setup. Die sets are separately designed for above said processes. The die sets, thus designed is simulated using DEFORM-F2 to analyze the successful Drawability of the die sets. From the simulations conducted, the die set designed for warm forming process yields greater Limiting Draw Ratio (LDR). Using warm forming process, the LDR of 2.0 was achieved which is much higher when compared with the conventional drawing.

***Keywords** - component; Limiting Draw Ratio, Deep Drawing, Finite element analysis, warm formin.*

I. INTRODUCTION

Drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. It is thus a shape transformation process with material retention. The flange region experiences a radial drawing stress and a tangential compressive stress due to the material retention property. These compressive stresses result in flange wrinkles. Wrinkles can be prevented by using a blank holder, the function of which is to facilitate controlled material flow into the die radius [1,2]. Due to tensile forces acting in the part wall, wall thinning is prominent and results in an uneven part wall thickness. It can be observed that the part wall thickness is lowest at the point where the part wall loses contact with the punch, i.e. at the punch radius. The thinnest part thickness determines the maximum stress that can be transferred to the deformation zone. An indicator of material formability is the limiting drawing ratio (LDR), defined as the ratio of the maximum blank diameter that can be safely drawn into a cup without flange to the punch diameter [3]. Determination of the LDR for complex components is difficult and hence the part is inspected for critical areas for which an approximation is possible [4].

Drawability of a metal depends on two factors. They are the ability of the material in a flange region to flow easily in the plane of the sheet under shear, the ability of side wall material to resist deformation in the thickness direction. The ability of sidewall material to withstand the load imposed by drawing down the flange is determined by its resistance to thinning, and high flow strength in the thickness direction of the sheet is desirable.

During deep drawing of aluminium parts, particles of the work piece material stick to the working surface of the die and cause longitudinal scratches on the surface of the drawn parts [5]. Usually deep drawing is done with a number of processes. Therefore, during conventional drawing, number of scratches increases after each draw and the surface quality of the part deteriorates. The main aim of any unconventional deep drawing process is to extend the formability limits of the process and also to avoid the scratches [6]. The use of the inverted drawing method has considerably improved the surface quality. Warm forming is a method for improving the formability of aluminium. In warm forming of aluminium, the die and the blank holder usually are heated to a temperature in the range of 200 to 300º C [7, 8].

II. MATERIAL MODEL

2.1 Material Model for Blank

Plastic objects are modeled as rigid-plastic material depending on characteristics of materials. The formulation assumes that the material stress increases linearly with strain rate until a threshold strain rate, referred to as the limiting strain rate (LMTSTR). The material deforms plastically beyond the limiting strain rate. The plastic material behavior of the object is specified with a material flow stress function or flow stress data (FSTRES). In DEFORM-F2, work piece is automatically switched to plastic, as they are deformable objects

2.2 Die Set Model

Rigid material model was chosen for die, punch and blank holder. All the displacement and rotational parameters were constrained for die and blank holder. In case of punch, all rotational and X, Z displacement parameters were constrained. Since the punch was not constrained in Y direction, it was allowed to displace along Y direction alone. Rigid objects are modeled as non-deformable materials. In the deformation analysis, the object geometry is represented by a geometric profile (DIEGEO). Deformation solution data available for rigid objects include object stroke, load, and velocity. The geometric profile is used for all deformation analysis and the mesh for the rigid object is used for all thermal, transformation, and diffusion calculations. Here dies or tools are automatically assigned to Rigid as they are non-deformable objects.

2.3 Finite Element Model of Die Set

The die sets for warm forming is modelled using primitive geometries in Deform F2

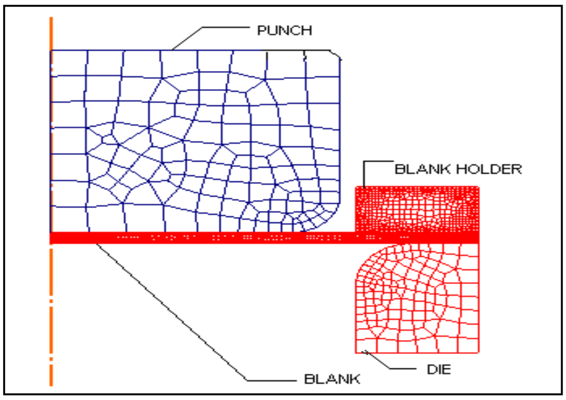

Fig 1- Meshed model

PARAMETER	VALUE
Radius on punch (R_1)	4.75mm
Radius on die (R_2)	4.75mm
Clearance between die and punch (c)	1.5mm

Table 1: Process Parameter Values

III. LOADING AND BOUNDARY CONDITIONS

The material properties are specified individually for die, punch and blank. Then the materials are meshed for loading. The movement of punch is defined in negative Y direction at a rate of 10mm/sec.For die and blank holder all the rotational and translational degrees of freedom are arrested. After the model has been built and loading and boundary conditions are defined, solution process is started. The dies and blank holder are heated with electrical heating rods that are located in the dies. It is necessary to heat up the corners of the dies, because the corners are critical in controlling the metal flow. So, it is not necessary to heat up the entire die in most cases. Straight sides can be cooled by using water or oil. This reduces material flow, similar to the effect of a draw bead.

]In DEFORM- F2, Process type --- warm forming --- calculate temperature in workpiece and dies --- shape complexity --- die temperature = 2500c

C as shown in fig 3. Also, the movement of punch is defined in negative Y direction at a rate of 10mm/sec.

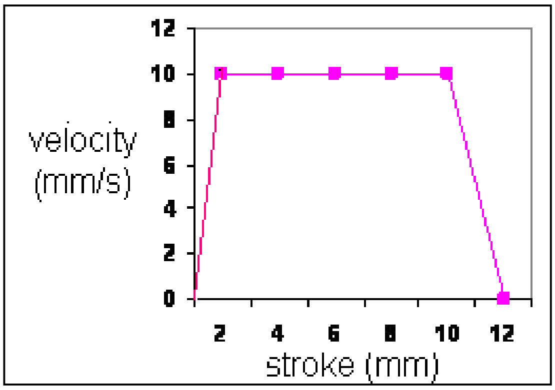

Fig 2- stroke Vs velocity graph

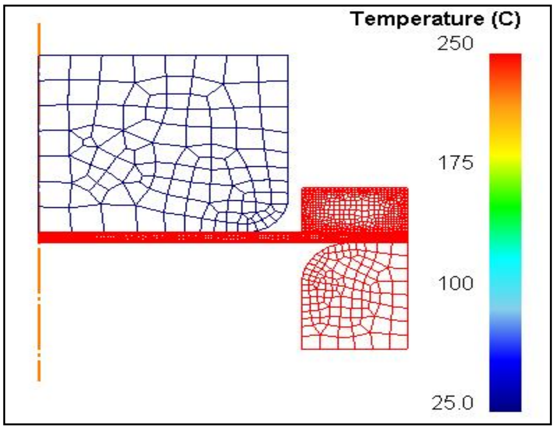

Fig 3- Boundary Condition for Warm Forming

Velocity reaches 10mm/s at the stroke of 1mm. after that velocity is constant up to 10mm of stroke, then it gradually reduces to 0 at the stroke of 12mm. the shape of the curve is trapezoidal as shown in fig 2.

IV. RESULTS AND DISCUSSIONS

4.1 Limiting Draw Ratio

Limiting drawing ratio decides the successful drawability of the deep drawing process. If LDR exceeds the range, formability problems such as fracturing takes place. This occurs when a sheet metal blank is subjected to stretching or shearing forces that exceed the failure limits of the material for a given strain history, strain state, strain rate and temperature.

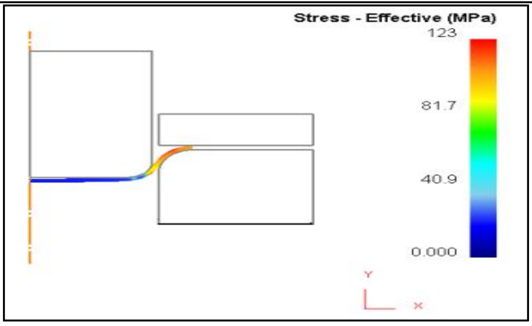

Fig 4 - LDR for single draw

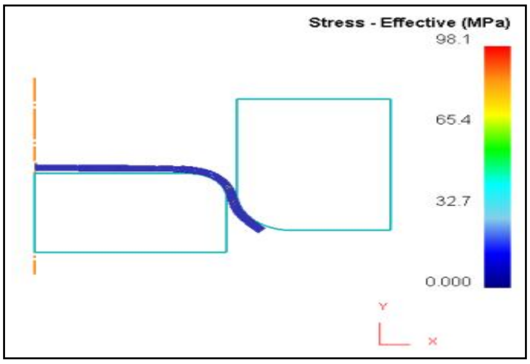

Fig 5 - LDR for inverted drawing

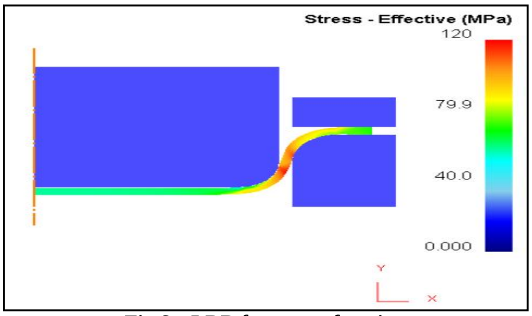

Fig 6 – LDR for warm forming

In above comparison common LDR 1.4 is taken for all three processes. Maximum stress value 123 Mpa is found in single step drawing process as shown in fig 4. So that tear starts after reaching the LDR value 1.4. Inverted drawing yielded succesful forming at Limiting Drawing Ratio of 1.46 for the aluminium material as shown in fig 5. As the stress value is minimum the surface quality can be maintained with no scratches.from the fig 6 in warm forming process the LDR value of 2 can be achived due to metal reaching recrystalisation temperature.

Table 2- maximum LDR for various process

Process	**Maximum LDR**
Conventional drawing	1.4
Inverted drawing	1.46
Warm forming	2

4.2 Punch Load

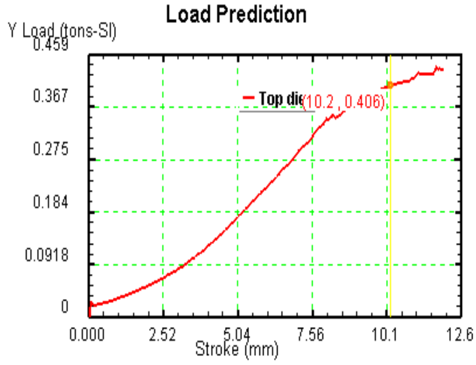

Fig 7 – Load Curve For Single Draw

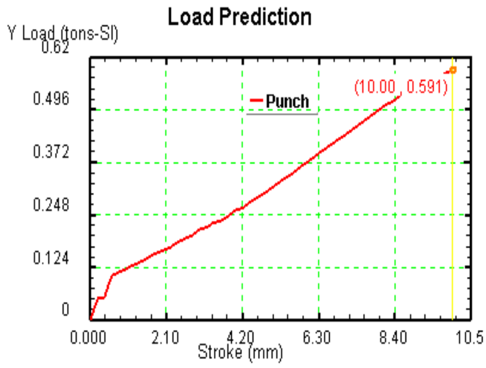

Fig 8 – Load Curve For Inverted Draw

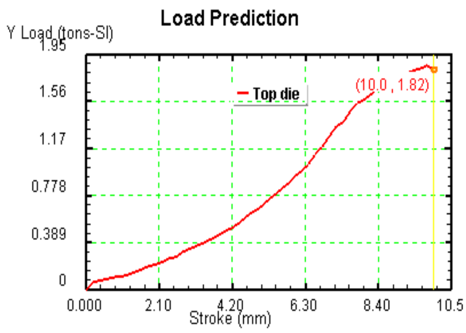

Fig 9 - load curve for warm forming

Table 3: Maximum punch load for various process

In conventional drawing process from the fig 7 for 10mm stroke 0.406 tons of punch load is needed, this is the minimum load of all the three processes. After reaching 1.4 LDR tear will start because it has reached its yield stress value. In inverted drawing from the fig 8 for 10mm stroke 0.591 tons of punch load is needed. In warm forming process as shown in fig 9, 10mm stroke is obtained from 1.82 tons of load, the stress value is reduced due to maintaining of die at 250^0c.

4.3 Thinning Distribution

The thinning distribution across the drawn cup is plotted graphically for all the three process as shown in fig 10. Initially thickness of the blank is kept at 1.2 mm. After the single draw process the thickness is reduced to 0.72 mm; this is the maximum thinning among the three processes. In inverted drawing the thickness value of 0.79 mm is found. In warm forming process the thickness is found as 0.87mm, which is the minimum thinning when compared to other two processes In order to reduce thinning the draw radius has to be kept at low temperature and also avoid heating up the blank homogenously

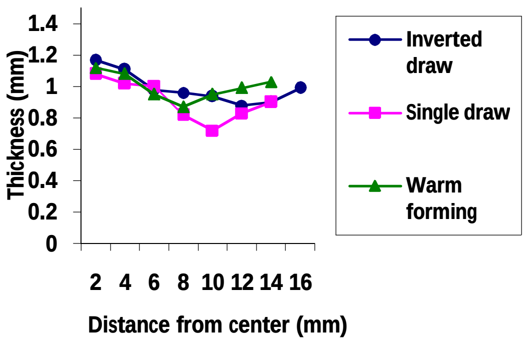

Fig 10- comparison of thinning distribution

V. CONCLUSION

In this paper, aluminium sheet metal has been numerically analyzed and compared for conventional drawing, inverted drawing and warm forming processes. DEFORM- F2 is conveniently used for the simulation of aluminium sheet metal deep drawing processes at elevated temperatures from this comparison LDR of 1.4 can only be achieved in single drawing process. In inverted drawing thinning is maximum with minimum punch load. So both single draw and inverted drawing process are not suitable for aluminum material if its LDR value is beyond 1.46. In warm forming process Even the punch load is maximum the thinning distribution is found to be minimum; also LDR value up to 2.0 can be achieved. The warm forming process is beneficial in terms of formability.

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