AN EXPERIMENTAL INVESTIGATION ON THE DEEP DRAWING PROCESS OF STEEL-BRASS BIMETAL SHEETS

Faramarz Fereshteh-Saniee, Ali Alavi-Nia, Amir Atrian-Afyani

Mechanical Engineering Department, School of Engineering,
Bu-Ali Sina University, Hamedan 65178, Iran.

ABSTRACT
Deep drawing, as an important sheet metal forming process, is widely used in different industries. In this research work, the deep drawing process of laminated sheets is experimentally studied. Composite blanks, made of stainless steel and brass sheets, were deep drawn by means of a 600 kN Instron testing machine. With this regard, the effects of various parameters such as blank holder force, blank diameter, blank stacking sequence, frictional and connection conditions of two layers on the forming load and material flow were investigated. The distribution of thickness strain in each layer of the deep drawn component was also calculated.

Keywords: Deep drawing, composite sheets

1. INTRODUCTION
The deep drawing process is one of the sheet metal forming process, which is widely used in different industries. In this process a sheet of metal, which is held on its periphery by a blank holder on the upper face of the lower die, is drawn into the matrix, producing a cup shape component. Many experimental, analytical and numerical researches have been carried out regarding this and other sheet forming processes in order to predict required load and energy prevent any possible defect and study the course of material flow [1-5]. In order to take the advantages of different materials, such as strength, low density and corrosion resistibility, at the same time and in a single component, it is beneficial to carry out the deep drawing process of bimetal sheets. With this regard, it is possible to take the benefits of the forming processes, such as low waste of material and high directional strength of the components. However, different material properties of various layers of the blank make the material flow and the process more complicated. That is why not so many investigations have been carried out in this field of research. Kapinski [6] studied the drawability and springback in deep drawing process of bimetal sheets. He considered the inertial effects and strain hardening in his research. Habibi Parsa et al. [7] investigated redrawing of components made of stainless steel and aluminum by means of finite-element simulations and practical experiments. Other researches were also carried out relating sheet metal forming of laminated blanks [8,9].

The present research work is concerned with the experimental study of deep drawing process of laminated sheets. With this regard, bimetal sheets made of brass and steel sheets were deep drawn using a special die set on an Instron testing machine. Several tests were conducted in order to investigate the influences of some variables, such as the stacking sequence of the layers, interfacial condition between the layers, frictional condition between the tool and workpiece, the blank holder force and the diameter of the composite blank, on the load-displacement curve and the final shape of the produced component. Some preliminary experiments were also performed. These involved tensile tests for determination of the stress-strain curves of different materials and friction tests for evaluation of interfacial friction coefficients. The main parameters studied in this research work were the material flow
(occurrence of defects such as wrinkling or fracture) of the component and the required drawing force. In some cases, the variation of thickness strain in each layer of the component was also determined. Based on the observations made in this investigation some conclusions are drawn, which are explained at the end of this paper.

2. EXPERIMENTAL PROCEDURE

2.1 Preliminary tests
The preliminary experiments involved the tensile tests and friction tests. The tensile tests were carried out in order to obtain the stress-strain curves of the materials under consideration. This type of test is usually adopted for sheet metal forming processes, because of the stress state involved. It is very important to examine the suitability of selected materials before doing the deep drawing process of laminated sheets. For this reason, the tensile tests were conducted for four different alloys, namely brass, stainless steel, aluminum and copper. Figure 1 shows the test samples made based on ASTM (E8M-98) standard. For more precise evaluation of strain, all the tensile tests were conducted using an extensometer. Based on the stress-strain curves obtained from the tensile tests, it was found that combination of stainless steel and brass is suitable for doing the main deep drawing experiments.

Figure 1. ASTM samples for the tensile tests. From top to bottom: stainless steel, brass, copper and aluminum.

With this regard it is notable that brass possesses extensive decorative applications and its thermal and electrical conductivities are much better and its specific heat is considerably lower than those of stainless steel. However, strain hardening, tarnish resistibility, strength/density ratio and surface quality of stainless steel are higher than brass. Therefore, by making a component made of brass and stainless steel, one can take different advantages of these metals at the same time. The true and engineering stress-strain curves of these alloys are given in Figures 2 and 3. The engineering stress-strain curves are also given in order to compare the ultimate strengths of these materials.

![Figure 2. True and engineering stress-strain curves of stainless steel.](image)

![Figure 3. True and engineering stress-strain curves of brass.](image)

The thicknesses of steel and brass sheets used in both the tensile and main drawing tests were 0.39 and 0.62 mm, respectively. Tables 1 and 2 contain the compositions of these materials obtained from the analyzer machine (quantumeter). The friction tests were also conducted in order to determine coulomb friction coefficients under various conditions. For each frictional condition, a specified normal
force was applied to the sheet by the press and, then, the horizontal force needed for initiation of motion of the sheet between the die faces was measured. Afterwards, using the coulomb friction formula, the friction coefficient was calculated. Three different frictional conditions were tried for both the steel and brass sheets. Average friction coefficients of 0.3, 0.25 and 0.22 were specified for dry condition, nylon sheet and grease as lubricants, respectively.

Table 1. Chemical composition of stainless steel in percent.

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Cr</th>
<th>Ni</th>
<th>Mn</th>
<th>Si</th>
<th>Cu</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70.55</td>
<td>19.57</td>
<td>7.00</td>
<td>1.38</td>
<td>0.44</td>
<td>0.14</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table 2. Chemical composition of brass in percent.

<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Zn</th>
<th>Nb</th>
<th>Fe</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70.71</td>
<td>20.28</td>
<td>8.86</td>
<td>991ppm</td>
<td>469ppm</td>
</tr>
</tbody>
</table>

2.2 Deep drawing tests

After selection of two appropriate metals, the important variables were selected for parameter studies. These involved blank diameter, blank holder force, lubrication, stacking sequence and connection condition of two layers. Based on the die set designed, the blank diameters were selected to be 7.5, 8.5 and 10 cm. Stainless steel and brass sheets with these diameters were punched in order to provide flat circular edge and better attachment of the layers in the composite blank (Figure 4).

The blank holder force was adopted with three levels, namely 0.71, 2.14 and 3.56 kN. These values were selected considering the guidelines suggested in [10,11]. The blank holder force was exerted by means of eight B-16/76 standard springs. This force was kept constant during each drawing experiment.

Dry condition and nylon sheet as a lubricant were considered for tool-workpiece interface. Complete bonding, lubrication with grease and dry separation were also three different contact conditions maintained between two layers of various composite blanks. Complete bonding of the layers was achieved by applying special strong industrial glue. It was found that after finishing the drawing process with this condition, the layers were still strongly connected to each other, excepting for the edges of wrinkled components.

The stacking sequence involved two cases, namely BS and SB. In BS case, the stainless steel layer was in contact with the punch and the brass sheet was positioned underneath. In SB state, there was a reverse situation, i.e. the brass layer of the composite blank was in contact with the punch.

The drawing die set contained three main parts. These were the punch, the matrix and the blank holder. The punch and matrix were made of SPK steel, whereas the other parts were manufactured from St37 steel. Table 3 contains dimensions of major parts of the die set and Figure 5 shows the assembled matrix and blank holder together with the punch. After preparation of the double-layer blank and applying the relevant lubricant, the deep drawing experiment was conducted by means of a 600 kN Instron testing machine (Figure 6). The load-displacement curve was obtained for each test to carry out the comparisons.

3. RESULTS AND DISCUSSIONS

Almost in all of the metal forming investigations, one of the main objectives is determination of the maximum load required for a successful process.
Therefore, in the present research, the effects of various parameters mentioned in the previous section on the load-displacement curve are studied.

Table 3. Dimensions of various geometrical parameters of deep drawing die set.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch Diameter</td>
<td>46.0</td>
</tr>
<tr>
<td>Punch Profile Radius</td>
<td>10.0</td>
</tr>
<tr>
<td>Die Diameter</td>
<td>48.5</td>
</tr>
<tr>
<td>Die Profile Radius</td>
<td>8.0</td>
</tr>
<tr>
<td>Blank holder Outer Diameter</td>
<td>100.0</td>
</tr>
<tr>
<td>Blank holder Inner Diameter</td>
<td>49.5</td>
</tr>
<tr>
<td>Clearance between Punch and Die</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Figure 5. The assembled matrix and blank holder (top) together with the punch (bottom).

Figure 7 typically compares the load-displacement curves obtained from two different tool-workpiece interfacial conditions, namely nylon lubricant and dry condition. These results are obtained for bimetal blanks with 7.5 cm diameter and under a blank holder force of 3.56 kN. This figure illustrates that the nylon sheet does not affect the early part of the curve, because at this stage of the process, the contact pressure is not sufficiently high. Generally, the influence of friction can more apparently be observed at large deformation [12]. However, the maximum load required decreased by about 13.5%. Moreover, the composite cups produced with nylon lubricant have higher surface quality, compared with dry condition.

Figure 6. The Instron testing machine with the deep drawing set mounted.

Figure 7. The effect of friction condition at the tool-workpiece interface. The diameter of the blanks was 7.5 cm with a blank holder force of 3.56 kN.

The stacking sequence is also one of variables investigated in this research. Since the material properties and the thicknesses of two layers are different, the stacking sequence might involve certain effects on the process. For example, Figure 8 shows how the stacking sequence affects the load-displacement. Despite the friction, the early part of the curve is also changed. It was observed that the friction condition can change the influence of stacking sequence.
For instance for dry condition, when the steel layer was in contact with the punch (BS), the maximum load was about 7% greater than the similar situation with SB case. But when nylon sheet was employed as lubricant, the SB condition needed nearly 14% greater force, compared with the BS case under similar conditions.

![Graph](image)

Figure 8. The influence of stacking sequence under dry condition, with a blank holder force of 3.56 kN and for composite blanks with 8.5 cm diameter.

Contact states between two layers of the blank included dry, greased and bonded conditions. Comparing dry and greased cases, it was found that the maximum load of latter case is about 6% less than the other case. However, the most significant influence belongs to sticking condition. As shown in Figure 9, the load-stroke curve of this case is much different from those of the other two cases. With this regard, it can be claimed that when two layers are bonded to each other, the strain and deformation at the contact surface are the same, whereas the material properties of two layers, such as flow stress and strain hardening behavior, are different. Another probable reason could be sudden separation of the bonded layers during the process. These could induce a knee in the load-displacement curve of the process (gray curve in Figure 9).

According to many researchers [1,2,10,11], one of the important variables affecting the deep drawing process is the blank holder force. For deep drawing of composite blanks, the selection of appropriate blank holder force is also critical. Figure 10 illustrates how wrinkling occurs when the blank holder force is insufficient. However, when this force is too much, tearing of one of the layers may take place. In Figure 11 the brass sheet is torn because of a high blank holder force. Higher blank holder forces provide more constraints for circumferential shrinkage of the blank edge and this prevents wrinkling. However, the greater the blank holder force, the greater is the required maximum load. Figure 12 indicates that, in the range under consideration, there is almost a linear relationship between the maximum drawing load and the blank holder force. Under the same conditions, the experimental results showed an increase of 13% in maximum drawing force when the blank holder force increased.

![Graph](image)

Figure 9. The influence of contact condition of two layers for a blank holder force of 3.56 kN and composite blanks with 8.5 cm diameter.

![Images](image)

Figure 10. The effect of decreasing the blank holder force (from left to right) on occurrence of wrinkling at the edges of composite blanks with 8.5 cm diameter.
blanks with larger diameter, the peak of the load-stroke curve is shifted to the right. Figure 14 also typically illustrates that assuming a linear relation between the maximum drawing force and the initial blank diameter is quite reasonable and does not involve significant errors.

In order to quantitatively study the effect of blank diameter on the forming load, several experiments were carried out. When the diameter of the composite blank increased, since the blank holder force was kept constant, the contact pressure at the edge of the blank was decreased, and a tendency for wrinkling was observed at this region of the component. Looking at Figure 13, one can find out that, when the diameter of the bimetal blanks increases from 7.5 cm to 10 cm, the maximum drawing force increases about 100%. According to Sieble and Beisswanger [1], in single layer deep drawing, the maximum punch force occurs when the outer diameter of the drawn component reaches 0.77 of the initial blank diameter \( d_{F,\text{max}} \approx 0.77d_0 \). Going through the experimental results obtained in the present research work, it was found that there was a similar situation in deep drawing of composite blanks. It is typically clear from Figure 13 that, for double-layer

Figure 11. Tearing takes place when the blank holder force is too great. In this case, the brass layer is fractured.

Figure 12. Variation of maximum drawing load with the blank holder force for composite blanks with 7.5 cm diameter.

Figure 13. The effects of initial blank diameter on required drawing load for a blank holder force of 3.56 kN and greased condition at the interface of two layers.

Figure 14. Variation of maximum drawing force with initial blank diameter for a blank holder force of 2.14 kN.

In sheet metal forming processes, the governing stress state is usually tensile. Therefore, the maximum achievable tensile strain is restricted by the maximum tensile stress, which should not exceed the ultimate strength of the material [1]. Because of necking caused by a tensile stress state, some regions of the deformed component may be in danger of tearing and fracture. Hence, the study of stress and strain distributions in the drawn component could be very beneficial for preventing the occurrence of possible fracture and defects.
With this regard, by calculation of thickness strain of the drawn cup in the radial direction, one can assess the possibility of fracture.

In this research work, in order to determine the variation of thicknesses of both the layers, the drawn component was sectioned diametrically by means of a wire-cut machine (Figure 15). By measuring the thickness of each layer at various positions from the centerline of the component, the variation of thickness strain of each layer is specified in the radial direction. Figure 16 illustrates the total and individual distributions of thickness strain for a typical laminated drawn cup. It can be seen in these experimental results that at the edge radius of the punch, there is the maximum possibility of fracture of one or both of the layers of the component. Figure 11 also agrees this conclusion.

![Figure 15. The drawn bimetal component sectioned diametrically using a wire-cut machine for evaluation of thickness strain.](image)

![Figure 16. The total and individual distributions of thickness strain for a typical composite drawn component.](image)

1. By means of deep drawing process of composite blanks, one can take the advantages of different material properties and the benefits of the forming operation at the same time.
2. Regarding the occasion of peak load during the process, the formula suggested by Sieble and Beisswanger for deep drawing of single-layer sheets is approximately valid for similar operation on bimetal blanks.
3. The present investigation showed that the diameter of the blank, the blank holder force, frictional condition at tool-workpiece interface, contact condition of two layers and the stacking sequence had certain influences on the drawing process of composite sheets. However, among these, the blank diameter and the blank holder force possessed the most significant effects.
4. Variation of the maximum punch load with the blank holder force, and also, the relation between the maximum drawing force and the initial blank diameter, with good approximations, can be assumed to be linear.
5. Distributions of thickness strain as well as some failed deep drawing tests with double-layer blanks indicated that the maximum risk of fracture for one or both of the layers is around the edge radius of the punch.

**4. CONCLUSIONS**

Based on the deep drawing tests of composite blanks carried out in the present research work and the results obtained, the conclusions can be summarized as follow:

**LIST OF REFERENCES**