Experimental and Numerical Study the Effect of Process Parameters on Spring Back of Al/Cu Bimetallic Sheet in V- Bending Process

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Abstract-- Now a day, the bimetallic sheet in metal forming processes are highly requested due to their characteristics and better mechanical properties than a single sheet. Unfortunately, the spring back phenomenon is one of the most phenomena that greatly affecting the dimensions and geometry of the V-bending process of the bimetallic sheets. For this purpose, the present work was conducted to study experimentally and numerically the effect of process parameters on spring back of Al/Cu bimetallic sheet in V-bending process includes the sheet thicknesses, equal punch and die radii, and strain rates. Firstly, it was proved that experimentally and numerically the setting position of Al die face/ Cu punch face setting condition experienced a smaller spring back value. In general, good agreement between experimental and numerical results was observed. Both results illustrated that positive and negative spring back are occurred due to changes in punch and die radii and sheet thickness, and with increasing their values the negative spring back is changed to the positive one as well as increasing the amount of spring back too. Also, with increasing the strain rates the amount of the spring back has either increased or decreased are greatly affected by sheet thicknesses and radii of the punch and die. Moreover, ANOVA analysis was conducted to determine the relative contribution and main effect of the process parameters on spring back. The ANOVA analysis shows that the bimetallic sheet thickness and punch and die radii are the significant parameters with P-value less than 0.05, while the strain rate is not a significant parameter, and has less influence on spring back than the other two parameters. Furthermore, a validated simulation model was developed to study the effect of using the die with a circular groove and the process temperature on spring back of the Al/ Cu bimetallic sheet. The simulation result provided that a die with a circular groove was experienced a less amount of spring back compare with simple V-die process and results in reducing the spring back amount in V-bending process of the bimetallic sheet. Also, the spring back amount is decreased by increasing the temperature in the V-bending process.

Index Term-- V-bending, Al/Cu bimetallic sheet, spring back, process parameters, FE simulation, ANOVA analysis.

1. INTRODUCTIONS

Sheet metal forming is a special class of deformation processes which is one of the conventional metal working processes and are highly adopted in the automotive industry to fabricate many components such as body panels, the structural members of the chassis and so on. The sheet metal forming includes bending, flanging, stretching, punching, deep drawing and some other processes, the bending process is widely applied in sheet metal forming operations [1]. Also, generally in sheet metal forming process highly in the bending process during or after process, many defects are occurring and the most one is spring back. The spring back phenomenon is generally referred to as undesirable change of part shape that occurs upon removal of constraints after forming. It can be considered as a dimensional change which happens during unloading, due to the occurrence of primarily elastic recovery of the part which affects the accuracy of bent parts, particularly the bent angle [2].

Moreover, clad metal or laminated sheets consist of two or more layers of dissimilar metals of different thicknesses such as Al/Cu, Steel/Al, Cu/Ag, Al/Ni, Steel/Ti, etc. which are fabricated and formed by different joining and techniques such as explosive welding, rolling bonding, diffusion bonding, extrusion and friction-stir welding methods and they combine the mechanical, chemical and physical properties obsessed by the base materials. They developed as multifunctional material which provides a new function that monolithic metal sheet could not. In present days, there is a rising need of laminated sheets and have become increasingly popular due to their special properties and advantageous characteristics such as good thermal conductivity, high wear resistance, corrosion resistance, stiffness/ weight ratio, surface quality, and light weight[3]. Hence, because of different amount of elastic recovery of each layer due to difference of chemical composition, mechanical characteristics, and the elastic-plastic deformation of each layer, which makes a bimetallic sheet possesses owns a different bending behavior than a single sheet. In recent years, a limit amount of research work has been studying the behavior of bending and spring back. Yoshida et al. [4, 5] they numerically investigated the effect of stretching force on spring back of clad sheet metals under uniform stretch bending. It appears that the re-yielding occurs in the low-strength layer which is laminated with the high-strength layer during the spring back. Beyond, some researchers experimentally and analytically studied the spring back effect in bending process focused on aluminum/steel laminated sheet. For instance, Hino et al. [6] and Patel [7] they experimentally and analytically studied the bending characteristics for aluminum and ferritic stainless-steel laminated sheet. The result shows that the
spring back is highly affected by setting condition of strong/weak layers. Also, the thickness ratio of each layer and the stretching force acting on the laminates are the factors that strongly affect on spring back, when the thickness of stainless steel (strong layer) is less than aluminum (weak layer) the spring back and the ratio of thickness were reduced. Additionally, Yilamu et al. [8] they investigated the bending behavior of Aluminum (Al) /stainless steel (SS) in air bending process experimentally and numerically. The thickness variation and spring back have been studied and the results illustrated that the position of the strong and the weak layer of the clad sheet has highly affected of bending behavior but has low effect on spring back bending. While Kagzi et al. [9] were analytically studied the bending of the laminated sheet of the case adopted by the previous author and comparison of their results showed that there are good agreements between both results. Further, Govindasamy and Jain [10] for same bimetallic sheet but after the U- bending they experimentally and numerically developed a bending model to determine the change in relative thickness as a function of bending curvature. From the result, it was indicated that the relative thickness of the sheet after bending is affected by the thickness and position of the softer material of the clad. Besides, in different study Yilamu et al. [11] for same material Al/SS bimetal sheet under draw bending they achieved a numerical prediction of spring back by the Bauschinger effect and their influence on spring back was studied. For this purpose, they employing two types of model in their numerical solution, which are the kinematic hardening and the classical isotropic hardening models. According to their experimental and finite element simulation result, they concluded that an accurate prediction of spring back is obtained by considering the Bauschinger effect. In the other hand, among those studied that done for cladding steel with other material, a few studies done for other types of metal cladding with aluminum. For instance, Mohammad and et al. [12] investigated the effect of different process parameters on the spring back of Aluminum/copper clad sheets in the air bending process. The effect of punch stock, punch radius and die opening on spring back are studied experimentally, numerically and analytically. Also, analytically for each setting conditions, the changing of the thickness for each layer is studied. The results showed that the spring back will increase with increasing the punch radius and die opening and reversely is true. Also, the result appeared that setting condition effect on changing thickness. Additionally, Nikhare [13] has studied the analysis of spring back under bending for aluminum alloy 2024 and composite. Were the setting condition for the weak/strong layer and two banking holding forces were analyzed. So, the result observed that to provide lower spring back its recommended to use a combination between adjusting the bottom layer as metal with higher blank holding force. Therefore, a considerable amount of work has been analyzed in the literature to study the behavior of bending and spring back of the bimetallic sheet. However, there have been very few studies conducted on behavior of bending and spring back of the Al/Cu bimetallic sheet which is not extensively studied. So, the focus of the current paper is to study the effect of process parameters includes (thickness of the bimetallic sheet, punch and die radius, strain rate, and temperature) on spring back characteristics. Besides, the majority of this studies is that the punch and die radius are equal and individually in the part of the study V- die with circular groove was used which give the idea of combination between v and air bending, also the thickness ratio equally change for each Al and Cu with all thickness of the bimetallic sheet.

2. TAGUCHI METHOD WITH EXPERIMENTAL AND FINITE ELEMENT SIMULATION PROCEDURE.

2.1 Taguchi method

In the current study, the commercial software (MINITAB) as a statistical tool was utilized to design parameters for experimental and simulation test and to analyze parameters that effect on product quality. As listed in the table (1) for three levels of three process parameters (factors) including sheet thickness, punch & die radius and strain rate the standard Taguchi L27 (3^n) orthogonal array were designed. To design the experiments for three factors with three levels using this type of orthogonal array gives a greater number of experiments, and this proposed in this study because more experiments are needed in order to estimate and analyze all process parameters also to cover all possible combinations. General signal-to-noise (S/N) ratio in the Taguchi method was used to identify the control factors, this makes a reduction in errors on product quality. So, for experimental results, the S/N response table can be constructed which give the S/N ratio with combination levels for each process parameters, and the optimal design value of each process parameters are indicated by the greatest S/N ratio for each parameter. In this analysis, the spring-back angle result selected as process response and for signal-to-noise ratio (S/N) the “Smaller is better” characteristics were considered. In addition, the ANOVA technique was also applied to the spring-back results to determine the significant degree of each process parameter which effect on spring back in the V-bending process. The significant level of the factor based on the p-value. For this case the p-value is 0.05 (confidence level 95%), the factor is indicated as a significant factor on the result if the p-value of the factor is less than 0.05.
2.2 Experimental procedure

The bimetallic sheet materials used in this study are Aluminum (Al 1060) and Copper (Cu C1100) materials which are joined together by a hot rolling process. The bimetallic sheets produced with a fixed volume composition (80:20) for all thicknesses of Al/Cu clad sheet. Samples of different thicknesses (1, 3 and 5) mm are used in an attempt to study the effect of the sheet thickness on spring back. The material properties and their chemical composition are shown in table (2). Also, to ignore the effect of width and length on spring back of the bimetallic sheet, all samples were cut in a rectangular shape with dimensions of (30) mm width, (100) mm length with three different thickness. The V-dies fabricated with a fixed angle (90°) and with fixed die opening 36 mm. Both die and punch have different radii such as (1, 3 and 5) mm, all set of the punch and die are presented in figure (1) and their dimensions in the table (3). Also, to prevent siding bimetallic sheet samples during bending test on the top of die faces an additional groove were provided. For carrying out the experimental work a Hydraulic universal material tester (WP 310) was used. The range of the machine capacity is between 1 to 50 KN, and the speed of the cross-head is between 5 to 425 mm/min. Also, all sets of the die and punch were designed and fabricated to be easily installed and mounted on the hydraulic universal tester machine. Furthermore, before starting the bending process according to the experiment table design the setting condition (Al/Cu, Cu/Al) was tested with constant all other parameters to determine their effect on spring back.

Table I
Factors and their levels

<table>
<thead>
<tr>
<th>Factors</th>
<th>Thickness (mm)</th>
<th>Punch and die radius (mm)</th>
<th>Strain rate (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>1</td>
<td>1</td>
<td>0.0043</td>
</tr>
<tr>
<td>Level 2</td>
<td>3</td>
<td>3</td>
<td>0.0217</td>
</tr>
<tr>
<td>Level 3</td>
<td>5</td>
<td>5</td>
<td>0.0458</td>
</tr>
</tbody>
</table>

Table II
Properties and chemical compositions of Al and Cu materials.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density kg/m³</th>
<th>Poisson’s ratio</th>
<th>Young’s modulus GPa</th>
<th>Tangent modulus MPa</th>
<th>Yield strength MPa</th>
<th>Chemical composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 1060</td>
<td>2710</td>
<td>0.33</td>
<td>89</td>
<td>500</td>
<td>95</td>
<td>99.6Al, 0.22Si, 0.32Fe, 0.025Mn, 0.05Zn, 0.03Ti.</td>
</tr>
<tr>
<td>Cu C1100</td>
<td>8900</td>
<td>0.34</td>
<td>110</td>
<td>1150</td>
<td>170</td>
<td>99.9Cu, 0.001Bi, 0.002Sb, 0.002As, 0.001Fe, 0.005Pb, 0.005S.</td>
</tr>
</tbody>
</table>

Table III
Dimensions of die and punch.

<table>
<thead>
<tr>
<th>Die part</th>
<th>Dimensions (mm)</th>
<th>Punch part</th>
<th>Dimensions (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>100</td>
<td>Length</td>
<td>100</td>
</tr>
<tr>
<td>Height</td>
<td>40</td>
<td>Height</td>
<td>60</td>
</tr>
<tr>
<td>Width</td>
<td>34</td>
<td>Width</td>
<td>34</td>
</tr>
<tr>
<td>Die angle</td>
<td>90 degree</td>
<td>Punch angle</td>
<td>90 degree</td>
</tr>
<tr>
<td>Die radii</td>
<td>1, 3, 5</td>
<td>Punch radii</td>
<td>1, 3, 5</td>
</tr>
<tr>
<td>Die opening</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
which in turn imparting the control of the strain rate of the deformation process. The bending process starts after the hydraulic pump turned on and the header of the machine will come down to bend the bimetallic sheet and the head travelled distance is presented digitally on the machine control unit. When all the required tests for all specimens are carried out, the amount of the spring back of each specimen of the bimetallic sheet is measured experimentally by using Mitutoyo profile projector with an accuracy of 2 min (0.03333 degrees). As shown in figure (2) the measurement process including the placement of the specimen on the V-block jaw on the table of the projector, turn on the projector and by adjusting the end of the specimen on the projector screen the angle of the bent specimen can be measured. The amount of spring back can be calculated by the differences between the designed punch and die angle (90 degrees) and the final bent angle.

2.3 Finite Element simulation
In the present work the finite element analysis of V- die bending process is carried out using developed simulation model based on ANSYS (release 19.1) software to analyze and understand the effects of process parameters on spring back of the bimetallic sheet of Al/Cu materials. This study was carried out to validate the simulation model and then used as an alternative method to study the effect of other process parameters such as temperature and to determine the effect of using V- die bending with a circular groove on spring back.

In the simulation modeling of V- bending process the tooling (punch and die) was defined as rigid bodies to reduce the calculation time. The sheet was represented as a flexible body i.e. deformable body, and 4-node plane-stress 3D solid element was adopted to construct and develop the meshing process. As in experimental bending tests, the same dimensions of the model (tool and specimen), loading conditions (strain rate) were used for the finite element simulation model of the V-bending process of the bimetallic sheet, as shown in figure (3). The 3D solid element type was selected according to the ratio of punch radius/ sheet thickness. In other words, when this ratio is equal or less than 5 the element type should be 3D solid element[14]. The appropriate selection of the material models and property of the bimetallic sheet play an important role in obtaining an accurate prediction of the spring back in the V- bending process. For this reason, the nonlinear behavior of the material model is presented, and the material properties for both metals of the bimetallic sheet as given in table (1) were inserted in engineering data. For contact between (Al and Cu) sheets the bonded type with multi-point contact formula was adopted, to be closer to the actual behavior of the bimetallic sheet and for the contact between sheet and tools, the augmented Lagrange formula and frictional type with a constant value (0.1) of the coefficient of fiction were used. Additionally, different types and sizes of meshing elements are tested until getting the convergence solution of the
process compared with the experimental one. Accordingly, the number of nodes and elements for meshing of the bimetallic sheet changed due to the thickness of the sheet are ranged between (37957-54972) for nodes and (16716-29139) for elements. The final step in modelling of the finite simulation model is the loading and unloading conditions. In loading condition, the rate of deformation of the bimetallic sheet is determined by specifying the punch travel distance in a certain interval period of time which results in controlling the speed of the punch through the deformation zone. For the unloading condition, it is found that the gradual release method is the appropriate one and it is adopted to simulate the tool unloading condition in the present work.

Fig. 3. 2D and 3D model of V-bending process

3 Result and Discussion

3.1 Effect of the bimetallic sheet thickness on spring back

Figures (4) shows the variation of the spring back (in terms of the final angle of the sheet after bending) with respect to the bimetallic sheet thickness, at each die and punch radius, for three different strain rates respectively. From these figures, it can be seen that the bimetallic sheet thickness is greatly affecting and controlling the amount of spring back and it is variation. Also, it is clear that there is a critical bimetallic sheet thickness at which a transition or change in the variation of the spring back with the sheet thickness it occurs. Accordingly, due to this transition thickness, the general trend which revealed the increase or decreases in the amount of the spring back occurs and the two types of the spring back (positive spring back and negative spring back) appear. The change in the amount of the spring back with increasing the bimetallic sheet thickness attributed to the change of the elastic modulus of the sheet which in turn increases with increasing the thickness ratio of the aluminium-copper materials of the bimetallic sheet [15]. Consequently, the increase in the elastic modulus of the bimetallic sheet results in increasing the elastic recovery of the sheet metal which in turn experience a positive spring back in the bending process with increasing the sheet thicknesses especially for bimetallic sheet thickness of 5 mm.
3.2 Effect of the punch and die radii on spring back
Figures (5) present the variation of the spring back with respect to the die radius and punch radius, at each strain rate with different bimetallic sheet thicknesses respectively. From these figures it can be seen that generally with a small punch and die radii a negative spring back is occurred and with increasing the punch and die radii the negative spring back is changed to the positive spring back. This behavior is may be attributed to what is called the conformity between the punch and the sheet. If close conformity between the
punch and the sheet is required, the die is made with a radius at the bottom to match the punch, and a large force is applied at the end of the process [2]. Consequently, inducing of the large force due to a small contact area with small punch radius results in experiencing an elastic-plastic deformation during the loading and unloading conditions and producing a negative spring back [16]. Alternatively, with increasing the punch and die radii the bending zone increased because the sheet comes into contact with the sides of the punch tip and the contact region extends. This reduces the contact pressure and the stresses are distributed for a larger area, which in turn results in increasing the spring back and the bent sheet experiencing a positive spring back [17].
3.3 Effect of the strain rate on spring back

Figures (6) demonstrate the variation of the spring back with respect to the strain rate at each bimetallic sheet thickness with different die and punch radii respectively. These figures reflect that there is a strain rate sensitivity of the bimetallic sheet to the rate of deformation in the V-bending process. This strain rate sensitivity is characterized by changing the behavior (trend) of the spring back with increasing or decreasing the strain rate. Accordingly, the rate of deformation should be chosen carefully to control the spring back. Also, it can be seen that with increasing the strain rate, the spring back is increased or decreased greatly affected by the die and punch radii and the bimetallic sheet thickness. In other words, the strain rate has less effect on spring back compared with the metallic sheet thickness and tool geometry [18].

(c). strain rate of (0.0458 s⁻¹).

Fig. 5. Experimental result with simulation result shows the effect of punch and die radius on a final angle (spring back) at different sheet thickness.
3.4 Analysis of variance (ANOVA).

In the current study, the result of each process parameters and their levels that effect on finale angle in the V-bending process of the bimetallic sheet are arranged according to the L27 Taguchi orthogonal array. The data is analyzed using a signal to noise ratio (S/N ratio). The “Smaller is better” (S/N) characteristics which combine information between variance and mean to explain the results of spring back (response) which is desired to be minimum. The average of S/N ratio for all parameter of each level are given in the response table (4). The table shows the delta value for the variations in the S/N ratio within the levels and the rank for each control factor. It can be seen that the delta values indicate that the thickness of the bimetallic sheet, which is maximum, has a strong effect on the spring back. Also, with a rank value of 1, it can be estimated that the sheet thickness is the most control parameter influencing the spring back of the V-bending process of bimetallic materials. The next delta value refers to the tool geometry (punch and die radii) with rank 2. In other words, this parameter represents the second parameter that influences and control the spring back in the V-bending process. The last parameter affecting and influencing the spring back in the V-bending process of the bimetallic sheet is the strain rate with rank 3.

![Graph](image1.png)

(b). sheet thickness of (3mm).

![Graph](image2.png)

(c). sheet thickness of (5mm).

Fig. 6. Experimental result with simulation result shows the effect of strain rates on a final angle (spring back) at different punch and die radii.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Thickness</th>
<th>Punch and die radius</th>
<th>Strain rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>1</td>
<td>-39.04</td>
<td>-39.08</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-39.25</td>
<td>-39.18</td>
</tr>
<tr>
<td>Delta</td>
<td>0.25</td>
<td>0.22</td>
<td>0.05</td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
In addition, the main effects plot which represents the effect of factors for S/N ratio is shown in figure (7). The figures show that for the combination of process parameters of bimetallic sheet thickness of 1 mm, with punch and die radii of 1 mm, and strain rate of (0.0458 s⁻¹) minimum spring back is obtained, and this may be an optimal one and can be adopted for minimizing the spring back in V-bending process of bimetallic sheet.

Fig. 7. Main effects plot for S/N ratios for spring back angle.

Furthermore, for more accurate determination of the optimum process parameter level, ANOVA analysis based on S/N ratio was adopted and using the confidence level at 95% which explain that the significant level equal to or more than 0.05 is not significant. Thus, the analysis of variances of the differences in parameters was also calculated to evaluate the significance of each process parameters on the spring back. In the ANOVA analysis, the (degree of freedom, sum square, variance, p-value, and the error of the process) are evaluated for all three process parameters. The results are summarized in table (5) as shown below. The ANOVA results illustrated that the value of the F factor, for the sheet thickness parameter is greater than the other two parameters which are punch and die radii and strain rate. Also, the bimetallic sheet thickness and punch and die radii are statistically significant with P-value less than 0.05, while the strain rate is not a significant parameter, and has less influence on spring back prediction than the other two parameters. In other words, for a V– the bending process of the bimetallic sheet it is clear that the bimetallic sheet thickness represents the most significant parameter that can be controlled to reduce the spring back depicted in V-bending process of Bimetallic materials.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F- Value</th>
<th>P- Value</th>
<th>significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mm)</td>
<td>2</td>
<td>0.317</td>
<td>0.159</td>
<td>11.05</td>
<td>0.001</td>
<td>Yes</td>
</tr>
<tr>
<td>Punch &amp; die radius (mm)</td>
<td>2</td>
<td>0.217</td>
<td>0.108</td>
<td>7.56</td>
<td>0.004</td>
<td>Yes</td>
</tr>
<tr>
<td>Strain rate (s⁻¹)</td>
<td>2</td>
<td>0.015</td>
<td>0.007</td>
<td>0.51</td>
<td>0.0609</td>
<td>No</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>0.287</td>
<td>0.014</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>0.835</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.5 Verification of the simulation result

Comparing the results of the developed simulation model of the bimetallic sheet at different thickness, tool geometry (punch and die radii), and the strain rates showed a good agreement with those obtained by the experimental one. These results indicated that the finite element simulation model could be used to predict the effects of other process parameters on spring back especially for those parameters difficulty to be carried out experimentally. Also, from the result, it can be seen that the minimum and maximum differences between the finite element prediction results and the experimental of the spring back for the same process.
parameters are % 0.055 and % 0.89. The comparison of simulation result as refereed in figures (4), (5), and (6).

3.6 Effect of using V-die with circular groove on a spring back: simulation results

A circular groove along the bottom face of the die part faced toward the tip of the punch part was proposed as a modification of the tool geometry. The effect of this geometrical modification on a spring back behavior was studied numerically. The numerical study of the die part with a circular groove of (3) mm radius is carried out for the six cases where the spring back has a minimum and maximum value in a traditional V-die bending process (die without groove). The effect of the using die without groove and with a circular groove on the spring back of the bimetallic sheet are presented in figure (7). From the results, it was absorbed that the reduction of the spring back has occurred. It was appeared that samples with minimum spring back for the die without groove the percentage difference between the die angle with bent angle sheet are (0.88, 0.61 and 0.39) for thickness (1, 3, and 5) respectively and these values are reduced to (0.71, 0.49 and 0.32) for the die with groove as shown in figure (15-a). Also, for samples with minimum spring back for the die without groove, the percentage difference between the die angle with bent angle sheet are (2.67, 3.44, and 3.47) for thickness (1, 3, and 5) respectively and these values are reduced to (2.07, 1.51, and 1.71) for the die with groove as shown in figure (15-b). Hence, it can be seen that the presence of the groove results in producing a bent sheet with a bent angle closer to the designed one in both cases of the minimum and maximum spring backs. This effect may be attributed to the fact that the presence of the die groove leads to produce a bent sheet free of an overstraining which is occurred at the last stage of the V-bending process. In other words, the free of overstraining bend area of bimetallic sheet tend to minimize and relieving of the residual stresses and eliminating the thinning of the sheet that may be occurred at the end of the loading condition. Also, when three samples of minimum spring back were taking it appears that all three of them has the same punch and die radius which is 1mm but has different strain rates and thickness also all three samples have negative spring back which is less than die angle which (90 degrees). But in three samples which have maximum spring back all of them has same strain rate which is (0.0043) but different in thickness and punch and die radius and also at thin sheet negative spring back but after increasing thickness, it changed to spring back which is greater than die angle.

![Fig. 7. Effect of using V-die with circular groove on final angle for samples with: (a) minimum spring back, and (b) maximum spring back.](image)

3.7 Effect of temperature on spring back: simulation result

In general, any combination of tool-sheet temperature that can reduce elastic recovery can be effective in reducing the amount of spring back. It is worthy to mention that, in the previous section, all the simulation results of the effect of different process parameters on a spring back were studied at room temperature. Accordingly, an attempt was made to study the effect of temperature on the spring back of V-bending process of bimetallic based on the validated simulation model. The simulation results of the maximum and minimum spring back at room temperature are repeated at different forming temperature. Two forming temperatures are adopted (65, 125) °C, whereas at these temperatures the mechanical properties of Al/Cu bimetallic sheet are changed. The new mechanical properties of Al/Cu bimetallic sheet such as yield stress, tangent modulus and modulus of elasticity are inserted into the material data of the finite element simulation model. The result of the simulation study for all three temperature are presented in figures (8). From the results, the reduction of spring backs at elevated temperatures was demonstrated sheet and this spring back reduction of the bimetallic it based on the fact that with increasing the temperature, the yield strength of
the materials is reduced, which is lead to reduce the elastic recovery of the bimetallic sheet material [19]. So, as seen from figure (16-a) by increasing temperature from 22 °C to 65 °C then to 125 °C for samples with minimum spring back the difference percentage between die angle (90 degree) and final angle of bent sheet are reduced from 0.88 to 0.47 then to 0.26 when sheet thickness is 1 mm, for 3 mm thickness are reduced from 0.61 to 0.38 then to 0.21 and for 5mm thickness are reduced from 0.39 to 0.30 then reduced to 0.13. Also, the difference percentage for samples with maximum spring back is reduced as shown in figure (15-b). Again, for 1 mm sheet thickness is reduced from 2.67 to 1.62 then to 1.27, for 3 mm thickness are reduced from 3.44 to 2.13 then 1.76 and for 5mm thickness are reduced from 3.47 to 2.38 then reduced to 1.99.

![Fig. 8. Effect of temperature on spring back for samples with: (a) minimum spring back, and (b) maximum spring back.](image)

4. CONCLUSIONS
Due to highly using of the bimetallic sheet in sheet metal forming because of their characteristics and better mechanical properties. Also, because each layer has a different chemical composition and mechanical characteristics, this makes a manufacturing process to be complicated and need to correct prediction and decreasing the defect (spring back) which is affecting of assessing the accuracy of part geometry. For this purpose, this work was carried out to study the effect of process parameters which includes (thickness, punch and die radius, and strain rate) on spring back of Al/Cu bimetallic sheet in V-bending process experimentally and numerically. For both circumstances, the spring back amount was determined then analyzed and compared. Moreover, by using ANOVA and S/N ratio analysis the relative contribution and main effect of process parameter on spring back were evaluated. In another hand, after verification of the simulation result with the experimental result. Individually the effect of using the die with circular groove and temperature on spring back in Al/ Cu bimetallic sheet in V bending process is also studied. The numerical test is done for three samples with minimum spring back and three samples with maximum spring back. Hence, from these results the following conclusions were stated:

1- Different setting conditions (Al/Cu and Cu/Al) have effect on spring back, and Al die face/ Cu punch face experienced a smaller spring back with fixing all others parameters.
2- Bimetallic sheet thickness is greatly affecting the spring back amount, but this amount varied due to a transition that occurs where the sheet thickness increases.
3- The positive and negative spring back occurs in the V-bending process of Al/Cu bimetallic.
4- By increasing the punch and die radii the bending zone increased which lead to increasing the spring back and the negative spring back is changed to the positive one.
5- With increasing the strain rate the spring back has either increased or decreased and this trend is highly affected by sheet thickness and radii of the punch and die.
6- The ANOVA analysis shows that the bimetallic sheet thickness and punch and die radii are statistically significant with P-value less than 0.05, while the strain rate is not a significant parameter, and has less influence on a spring back amount than the other two parameters.
7- The result of the simulation model has a good agreement compared with the experimental one.
with minimum and maximum differences between both result for the same process parameters not exceed % 0.055 and % 0.89 respectively.

8- The validated simulation results show that a die with circular groove results in reducing the spring back amount in V- bending of the bimetallic sheet.

9- With a circular groove die, specimens with minimum and maximum spring backs, show a reduction in the range of 17- 20 % and 23- 56% respectively compared with that without groove.

10- The spring back amount is decreased by increasing the process temperature of Al/Cu bimetallic sheet, and specimens with minimum and maximum spring backs show a reduction between 55- 66% and 42- 53% respectively when bending carried out at 125 °C.

5. RECOMMENDATIONS FOR FUTURE WORKS
Describing the work with drawn of conclusions, which makes suggestions for some of areas of further work will guide to additional understanding of the subject. These recommendations are summarized as follows:

1- The experimental work can be extended to study the effect of increasing thickness ratio for both AL and Cu on spring back.

2- Studying the effect of joining type of Al/Cu bimetallic sheet on spring back for all type of bending process.

3- Investigating of the vibration influence on spring back of the bimetallic sheet during and post the V- bending process.

REFERENCES