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A Study of New Parameters Effect on the Springback of Aluminum Sheets in Plane Strain Bending

Fathi Al-shamma[1], Hajer M. Issmael[2]

[1]Assistant Professor, Dr. in Mechanical Engineering Department, Baghdad University, Iraq

[2]Student in Mechanical Engineering Department, Baghdad University, Iraq

Abstract: ***In this study a theoretical and experimental analyses of the effect of different parameters on Springback in wide and narrow plate was done for three types of Aluminum alloys: 1100, 5083 and 6061. The study investigated in the effects of material type, plate width and bending angle on springback in narrow and wide plate of Aluminum. In other hand study presented the effects of theses parameters in residual stresses. Experimental part including finding residual stresses and springback. Theoretical part including using analytical equation to calculate strain total and strain final using flow equation of Levy-Mises in order to find springback and residual stresses. Grid deformation theory used to find strain in plate. All equations processed using MATLAB program. Numerical analysis including using both SOLID WORK and ANSYS 18.2 for designing and simulation of bending process to calculate residual stresses .X-ray diffraction method also used to find the amount of residual stresses in all specimen. The results show that the springback amount effected by the variation in material types and material width more than the effect of angle of bending. Numerical and experimental results were compared which gives good agreement.***

Keywords: Residual stresses, Springback, wide plate, Narrow plate, AA6061, AA5083, AA1100

NOMENCLATURE:
ε_x = strain in X-direction
ε_y = strain in Y-direction
F = bending force KN
ds =Ddeformation in mm
$\bar{\sigma}$ =effective stress /MPa
$\bar{\varepsilon}$ = effective strain
K =strength coefficient/MPa
n =strain hardening exponent
$\bar{\varepsilon_t}$ =total effective strain
ε_f = strain final
$S.B$ =springback factor
$R.S$ = residual stresses\MPa

1. Introduction

Springback is known as the elastic recovery of materials after unloading in plastic deformation and this causes changing in the final geometry of the part. This Changes in the geometry after springback are a big and costly problem in the automotive industry, so, springback is One of the most sensitive features of the sheet metal forming. spring back is affected by the factors such as sheet thickness, material properties, tooling geometry One of the main causes that lead and influence the intensity of this instability spring back phenomenon is the state of stresses generated by the forming process in the deformed material.[1]

The residual stresses may have an important effect on the mechanic behavior of the material and we should mention that if there is any other subsequent operation to form the part, residual stresses in bending will affect the stresses formed by this subsequent operation and hence the springback of the part. The residual stresses may have an important effect on the mechanic behavior of the material. Analysis of the residual stresses in a bent specimen is generally very complicated, since the residual stresses induced in the forming process depend not only on the process parameters, but also on material properties[6]. Aljosa and Branko studied the stress state and springback in v-bending operation on three types of steel series using 90 degree bending angle and different thickness. The object of investigation was to measure springback and he found that the angle after bending is smaller than the die angle which means that the negative springback take a place and also he found that the stress distribution in bending zone depending on die stroke. [2]

A.Essa and M.H Ahmed, studied the variation of residual stresses and springback in sheet bending from plane strain to plane stress condition using finite element to simulate three points bending . They concluded that residual stresses and springback in bending effected by loading condition, sheet thickness, sheet width. He found that the residual stresses and springback has maximum value when sheet width is eight times to sheet thickness.[3] Chuantao Wang et. al. has established mathematical models for plane-strain sheet bending to predict springback, strain and stress distributions, and noted that to obtain a reasonable accuracy: the non-linear (true) stress distribution across the sheet thickness, strain hardening, and material anisotropy should be considered in the model[4]. Many researcher like Prabhakar and Fahd Fathiused FEM to study the spring-back in V-bending. The results proved that springback is dependent on punch geometry. [5][8]. Jian et. al. has derived an equation to predict the springback for wide sheet after sheet bending using form dies, and reported that the geometry of the sheet and punch as well as material properties influence the amount of springback[7]. Mohamd and Behrooz, presented in their work the effects of bending force and bending parameters on springback in v-bending of sheet metal. He found that the springback is a function of material thickness, material width, die width, die and punch angle and size of punched hole. [9]

Tekaslan determined experimentally the springback of sheet metals on V-bending dies. The results showed that an increase in the thickness of the sheet and bending angle increase springback values [10]. The effects of residual stresses on springback through various parameters will be presented and discussed on this paper.

2. Theoretical Part

An analytical equation has been derived to calculate the total strain from strain energy and workdoen in specimen after deformation (bending). Strain energy method has been used in this paper to find amount of energy absorbed by the part after bending deformation in wide and narrow plate and through using Grid Deformation theory. Grid deformation probably is the simplest conceptual method to determine strain in the fixed measuring system and is illustrated by the coordinates x -y and x'-y'. The coordinates for a particular grid line on the undeformed plate are shown as (x1,0), (x2,0), (x3,0), and (x4,0). The displacement components in the x and y directions are called u and v. The slopes of these curves are $\partial u/\partial x$ and $\partial v/\partial y$. And the expression for strain is:

$$\varepsilon_x = \frac{\partial u}{\partial x}\ , \qquad \varepsilon_y = \frac{\partial v}{\partial y} \qquad (1)$$

grid is to treat each interval individually and make measurements before and after loading .

$$workdoen = strainenergy$$

$$\int_0^s Fds = \int_0^{\varepsilon 1} \overline{\sigma} \overline{d\varepsilon} \qquad (2)$$

And for strain haredening material $\sigma = K\varepsilon^n$ sub in eq (2)

$$\int_0^s Fds = \int_0^{\varepsilon_t} K\overline{\varepsilon^n}\overline{d\varepsilon} \qquad (3)$$

$$\int_0^s Fds = K\int_0^{\varepsilon_t} \overline{\varepsilon_t^n}\,\overline{d\varepsilon}$$

And by integration both side we get

$$\overline{\varepsilon_t} = \left[\frac{Fs(n+2)}{K}\right]^{1/(n+1)} \qquad (4)$$

Force - deformation integration by using curve fitting and polynomial method using MATLAB 2015. Now strain final can be found from equation (1).

$$\varepsilon_x = \frac{\partial u}{\partial x}$$

$$\varepsilon_f = \ln(1 + \varepsilon_x) \qquad (5)$$

Then springback can be found from :

$$Springback = \frac{\varepsilon_t - \varepsilon_f}{\varepsilon_t} \qquad (6)$$

Now to find residual stresses flow plastic relations was used to find effective stress and effective strain and thin finding the proportional factor $d\lambda$ from

$$d\lambda = \frac{\overline{d\varepsilon}}{\overline{\sigma}} \qquad (7)$$

Residual stresses calculating from

$$R.S = \left(\varepsilon_t - \varepsilon_f\right)/d\lambda \qquad (8)$$

3. Material and Experimental Work Procedure

The material used for the experiments Aluminum AA1100, AA5083 and AA6061 used as a work piece, which is frequently used in industry.Fig.(1) shows the result of a tensile test for materials. Tensile tests were carried out according to ASTM standards. table(1)shows the chemical composition of three materials used in the bending operation.

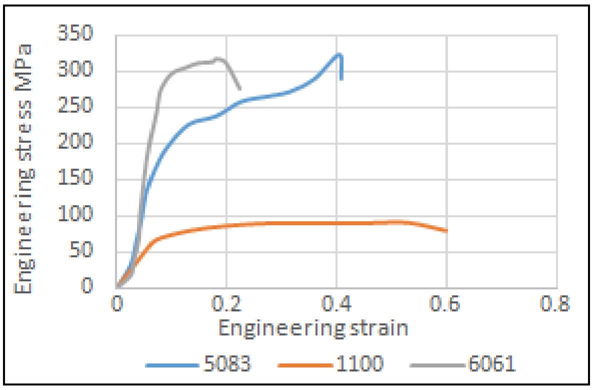


Figure 1: Tensile test for three type of material

In order to perform the experiments work, the specimens must fit the die and punch with a suitable clearance. a rectangular plate of 70 and 30 mm of width and 150 mm of length with (3) mm thickness used in experimental work.Three angles used in bending (90°, 70° and 35°).

Table 1: Chemical composition of Aluminum specimen wt%

element / Aluminum alloy	Si%	Fe%	Zn%	Cr%	Mg%	Mn%	Ti%	Cu%	Al%
AA6061	0.4832	0.2134	0.0032	0.257	0.9043	0.0071	0.005	0.1827	Balance
AA5083	0.129	0.337	0.11	0.061	4.14	0.0102	0.02	0.05	Balance
AA1100	0.1196	0.16	0.11	0.001	0.024	0.02	0.08	0.67	Balance

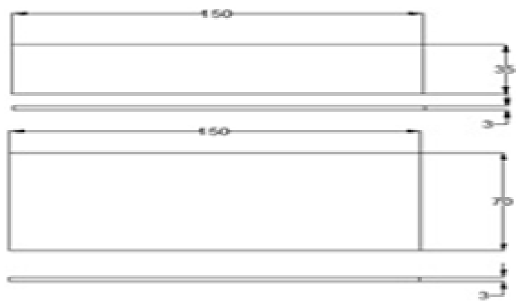


Figure 2: Specimen dimensions

The die designed under standard specification, they consist of two parts, normally punch and die both are made from CK45. Fig (3 & 4).

Figure 3: 35° bending die

Figure 4: 70° bending die

The bending tests comprised of the following steps:
fixing die and punch on press machine; putting the specimen on the die and getting the punch down until contact the specimen.

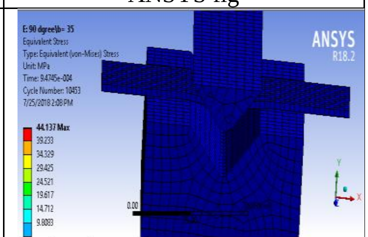
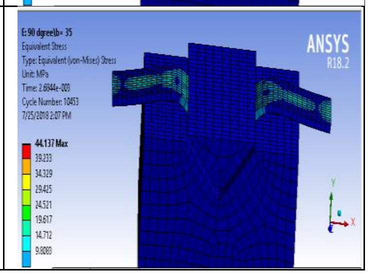
Strat bending operation by moving punch down. Move the punch up. Replacing the specimen and measuring the angle after unloading using protractor. Fig (5).

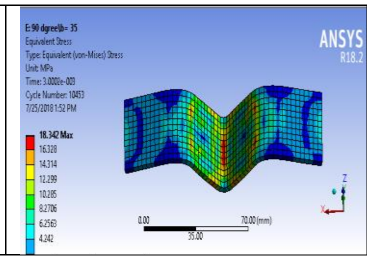
Figure 5: Bending test for specimen

Element Analysis

In this research a FE model of the air bending process was developed in order to predict the value of residual stresses and springback intensity after unloading. FESimulations were conducted in ANSYS 18.2: explicit dynamic forspringback. Modeling for three types of material and three angles. Table (2) shows different position of punch and blank in ANSYS.

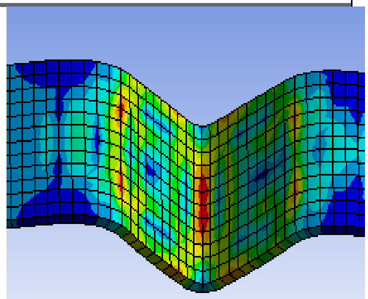
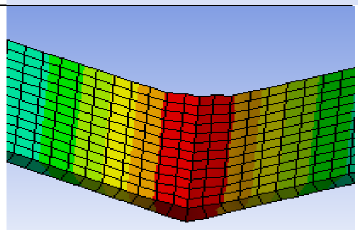
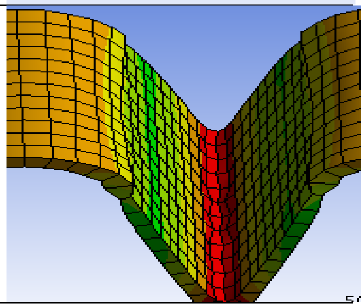
Table 2: Different position of punch using ANSYS

Different position of punch	ANSYS fig
V-bending process setting up	
Start of loading on the Blank material	

Final shape of blank after bending	

Heterogeneous plastic deformation between the core and surface of the part causes different stress distribution in the specimen. The distribution of these stresses can be observed from table (3) are distributed along the width of the sheet in the middle of the specimen surface that is in contact with the punch and lowest values of stresses can be observed on the specimen edges.

Table 3: Stress distribution in different angles

Angle of bending	Fig of stress distribution
Angle 90	
Angle 70	
Angle 35	

Using this model the punch displacements for desired angles of V-shape products were determined using the code ability to stop calculation when contact between two model parts appears. ANSYS showed a variation in value of residual stresses for both wide plate and Narrow plate. For the same angle and same material results of ANSYS showed a higher residual stresses under wide plate than Narrow plate. The FE model for residual stresses contains only deformed sheet part. X-ray diffraction methods was used to calculate residual stresses in all specimen. Fig(6)

Figure 6: X-ray diffraction machine

4. Results and Discussion

4.1 Effect of Sheet Width on the Residual Stresses:

The sheet width has significant effect on the Residual stress and springback has been calculated for different sheet width 70mm and 35mm, The results show When the sheet width increases, the RS increases too. Fig (7) shows the effect of sheet width on residual stresses and springback in sheet metal.

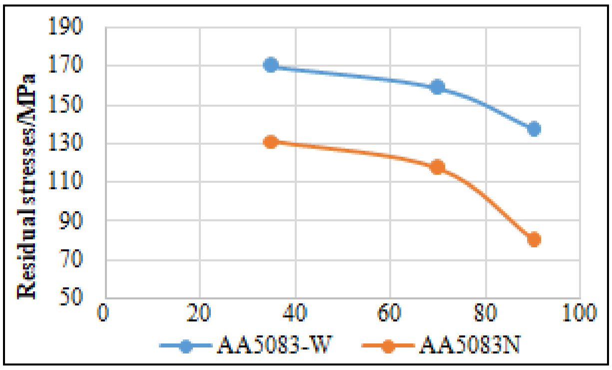


Figure 7: Effect of material width on R.S

Lower plastic zone leads to lower strain energy absorbed in narrow sheet which provided lower residual stresses and lower springback, and higher plastic zone leads to higher residual stresses and springback in wide sheet. Fig.(8) shows the springback in wide and narrow plate.

Table 5: S.B and R.S in wide and Narrow plate

Specimen	Wide plate		Narrow plate	
	S.B	Residual stresses	S.B	Residual stresses
AA6061-35	0.17191	332.377	0.12919	318.782
AA6061-70	0.14399	331.08	0.11791	306.493
AA6061-90	0.09131	308.44	0.10147	246.061
AA5083-35	0.13076	169.63	0.10076	144.506
AA5083-70	0.12403	158.621	0.09903	117.078
AA5083-90	0.07501	136.939	0.0853	79.9088
AA1100-35	0.1102	67.4368	0.092	54.0154
AA1100-70	0.09913	66.3935	0.09913	39.5809
AA1100-90	0.07098	59.6729	0.0744	17.4461

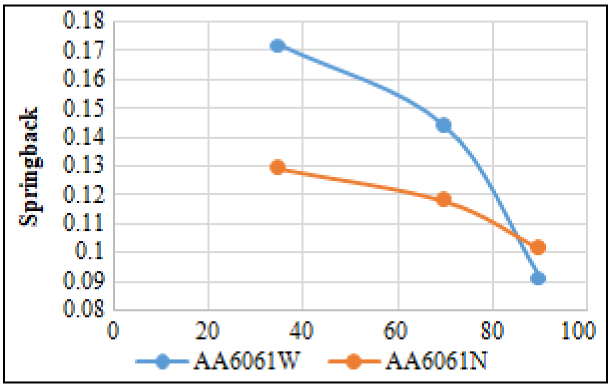


Figure 8: R.S in wide and Narrow plate

4.2 The effects of bending angle on residual stresses and springback

Bending angle in sheet bending processes determines the plastic area created. The lower bending angle means that we need to generate a larger bending stress in forming process for formed material and finally that's means increasing in force because strain hardening will be substitutional. table (5) shows that the experimental and mathematical values presented that springback angle is reduced when moving from lower angle 350 to higher angle 700 and 900 and that's because of residual stresses higher in smaller angle due to higher workdone experienced by the specimen. Residual stresses can be reduced by 9% through using higher bending angle and that's lead to reduce springback angle to 41%. Fig (9) shows the effect of bending angle on RS and SB which can be reduced by 57% in AA5083 while springback can be reduced to 22%.

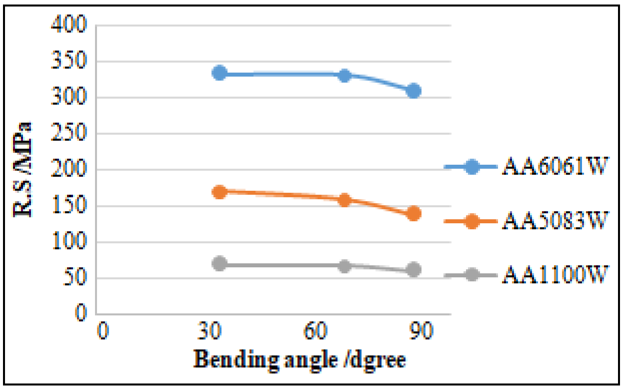


Figure 9: The effect of bending angle on residual stresses

4.3 Effect of type of material on residual stress and springback

Since the production processes can be affected by the material applicability, so the relation betweenthe material properties and springback should be studied. Depending on the ductility and brittleness of the material, three types of Aluminum were used in this paper 6061,5083 and 1100 in order to study the amount of effect of material on residual stresses and springback. Results shows that the brittle materials 6061 have a large value of RS and SB due to higher applicability of ductile material to be deformed than Brittle material. Results also indicated that residual stresses have smaller values when moving from AA6061 to AA5083 and AA1100 which can reduced by 57% in AA5083 while springback can be reduced to 22% Fig (10 &11) shows the effect of type of material on residual stress and spring back.

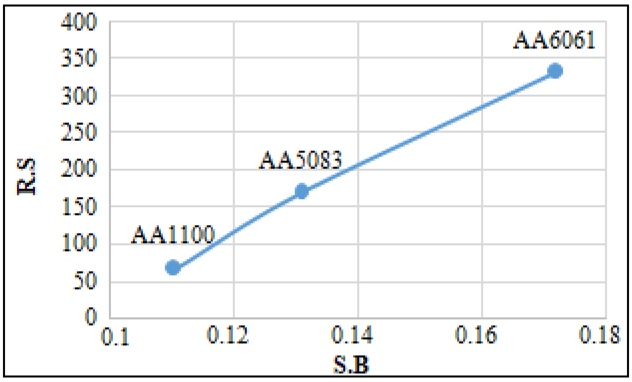


Figure 10: Effects of types of material on residual stresses and springback

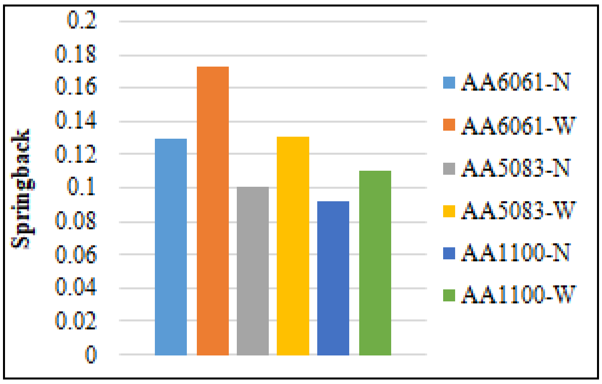


Figure 11: Springback in Three types of material

Finally, we should mention that all residual stresses theoretical results where compared to the experimental results (X-ray diffraction) and it showed a good agreement.

5. Summary and Conclusions

Springback in bent part is a function of different parameters such as: plate width, punch and bending angle, type of material of the bent part and the material properties.

Sheet width has important effects on the residual stresses and springback values:Increasing plate width causes increasing in residual stresses. In this paper results shows that increasing sheet width to double leads to an increasing in residual stresses by 9% for the same thickness, bending angle and material type.Increasing plate width increases springback angle due to higher residual stresses. Increasing sheet width to double causes increasing in springback by 28%.Springback and residual stresses are greatly affected by bending angle. Lower bending angle means larger force needed and that's mean larger stresses generated to get the final shape and that's all resulted in large amount of energy and stresses absorbed and stored in the part to be bent and finally higher springback. Increasing bending angle causes decreasing in residual stresses by 9.5%.Increasing bending angle decreases springback by 41.2% for the same material and same width.Type of material has a major effect in springback and residual stresses in part bending due to material applicability to be bent and deformed pure and ductile material has large ability of deformation before cracking or fracturing.Residual stresses by x-ray diffraction and Experimental results is about 70-95% of the yield stress in AA6061 and about 60% for 5083 and finally about 47% in AA1100.

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