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Effects of Holding Force on the Springback Behavior of Annealed Aluminum Plates

Muhammed Emin Erdin[a,]*, Alper Atmaca[b]

[a]Hitit University, Çevre Yolu Bulvarı No: 8, Çorum 19030, Turkey
[b]Hitit University, Samsun Caddesi No: 99 Çorum 19169, Turkey

Abstract

Typical V-bending process was performed to investigate the effects of holding force on springback behavior of 1050-H14 aluminum alloy plates annealed at 120 °C for 20 minutes. Tests were conducted on a universal testing machine with 60° V-bending mold. Various holding forces (2.25 kN which is slightly higher than the required force for bending operation, 5 kN, 10 kN and 15 kN) were applied at the end of the bending processes to investigate the hardening effect on springback values. The test results showed that annealing decreases springback values in all anisotropy directions. It is also clear from the test data that application of holding force has a significant affirmative effect on springback values.

Keywords: V-bending; springback; annealing; holding force

1. Introduction

Plastic forming of metal sheets/plates has a wide application area in industry. Bending is one of the most widely used sheet metal forming processes [1, 2], especially for aluminum components [3]. Common products obtained by bending are hoods of automotive and aerospace vehicles, wheelhouse panels, machine housings, pressure vessels, medical equipment, etc. [4]. Plastic forming of sheet metals is affected by a combination of various process and material parameters such as punch velocity, force, mold and material geometry, anisotropy, chemical composition of the material, heat treatment, etc. [5]. Mechanical properties such as strain hardening exponent, strain rate sensitivity exponent and texture also have significant effect on formability [6]. Springback is an important phenomenon in sheet forming operations, which occurs after removing the applied loads from the deformed sheet due to the elastic recovery in the workpart [7]. It is possible to reduce springback in bending operations by compressing the material between the punch and the die [8]. It is difficult to predict springback of the bent workpart analytically in a bending operation. Determination of springback by trial and error technique is costly and time consuming method [4]. Precise prediction of springback is very important for the design of forming tools and quality of the product [7, 9, 10]. At this point, experimental investigation have been mostly used to determine the springback behavior of bent specimens [2].

Number of researchers have investigated the springback behavior in bending operations over the past several decades. Bakhshi-Jooybari et *al.* [11] investigated the effects of sheet thickness, punch tip radius and sheet anisotropy on the springback of CK67 steel sheet in V-bending and U-bending processes by experiments and computer simulations. Bahloul et *al.* [8] examined the effects of geometry parameters in bending operations by finite element (FE) analysis to predict the punch load and stress distribution. Panthi and Ramakrishnan [12] proposed an analytical model based on strain and deformation energy to predict springback of metal sheets such as copper, aluminum and steel in arc bending. Sharad and Nandedkar [13] predicted springback steel sheets by using FE analysis, for various die radii, sheet thicknesses, R/t ratios and strength coefficients. Nasrollahi and

* Corresponding author. Tel.: +90-533-711-1384; fax: +90-364-227-4535.
E-mail address: eminerdin@hitit.edu.tr

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Arezoo [5] studied the springback in sheet metal components with holes on the bending area using experimental measurements, FE method and neural networks to understand the influence of process variables such as hole type, number of holes, the ratio of hole width to sheet width, die radius and pad force on springback behavior. Panthi et *al.* [14] used FE method to determine the effects of geometry and material properties, and friction on the springback in bending operations. Chan et *al.* [15] specified the significant effects of mold tip and lip radius, and bending angle on springback behavior according to the results of the performed FE analyses. As clear from literature review, most of the former studies were conducted via FE analyses. Furthermore, effect of holding force applied at the end of the process has not remarked detailedly. In the present study, typical V-bending tests were performed on a universal testing machine to investigate the effects of holding force on springback behavior of 1050-H14 aluminum alloy plates annealed at 120 ^{o}C for 20 minutes by comparing with standard (not annealed) counterparts. Various holding forces were applied at the end of the bending operations to determine the effect of hardening on springback values.

Nomenclature

C, K	strength coefficients
E	elasticity (Young's) modulus
HB	Brinell hardness
L	length
m	strain rate sensitivity exponent
n	strain hardening exponent
R	mould tip radius
r	mould lip radius
r_n	normal anisotropy/mean plastic strain ratio
T	temperature
T_m	melting temperature
t	thickness
w	width
β	bending angle
ε	strain
$\acute{\varepsilon}$	strain rate
υ	Poisson's ratio
ρ	density
σ_y	yield strength
σ_y	ultimate tensile strength

2. Theoretical Background

As all metal forming processes, V-bending is an elastoplastic deformation operation as schematized in Fig. 1. Before the yielding of the workpart, deformation is elastic. Thus, elastic part of the deformation returns after the bending load is removed due to elastic recovery which leads to springback.

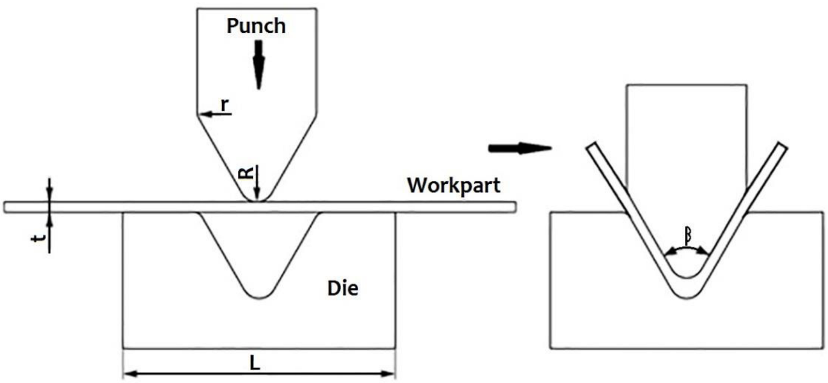


Fig. 1. Schematic drawing of V-bending process.

Prediction of the springback value in a bending operation analytically is a hard work because of the nonlinear behavior of plastic deformation. Strength of the workpart changes during plastic deformation as a function of various material and operation parameters which can be expressed as follows;

$$\sigma = f(C, K, \varepsilon, \acute{\varepsilon}, n, m, r_n, T) \tag{1}$$

In the foregoing equation, *C* and *K* are strength coefficients used in the calculation of plastic stress via strain (ε) and strain rate ($\acute{\varepsilon}$), respectively. Calculation of the stress in terms of strain depends on strain hardening exponent (n). n denotes the increase of material strength during plastic deformation. r_n denotes the normal anisotropy (mean plastic strain ratio) of the material which significantly effects the behavior during plastic deformation. Normal anisotropy is the measure of the variation of material properties with direction due to the forming history of the material

In the recent study, effect of strain hardening due to holding force applied at the end of the bending operation and effect of material anisotropy caused by the rolling direction of the workpart on springback was investigated. Moreover, annealing is applied to specimens to see the change of material behavior in the bending operation.

3. Experimental Study

Aluminum alloys are widely used in industry due to their low density and high specific strength. One of the most common manufacturing methods for aluminum sheets/plates is bending. In this study, aluminum alloy 1050-H14 plates were bent to 60^o using V-bending molds (Fig. 2). Chemical composition and properties of the testing material are given in Table 1 and Table 2, respectively.

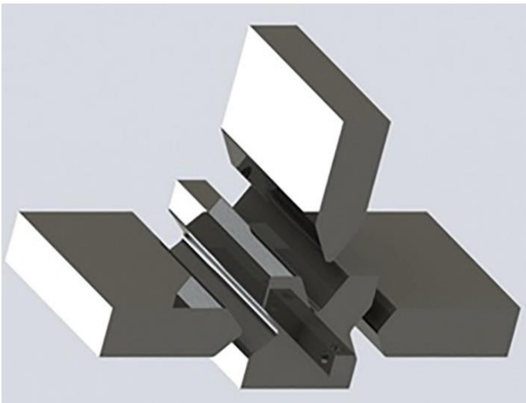


Fig. 2. V-bending mold model.

Prismatic testing specimens having length (*L*), width (*w*) and thickness (*t*) of 150 mm, 50 mm and 3 mm, respectively were bent to investigate the springback behavior. Various holding forces (2.25 kN, 5 kN, 10 kN and 15 kN) were applied at the end of the bending process. Holding force was applied to compress the specimen from bending region after the completion of the bending process to harden the material due to plastic deformation. This process was performed to decrease springback value by hardening the material in the bending region. Holding force was removed as soon as it reached the determined value.

Table 1. Mechanical and physical properties of the testing material.

HB10	σ_y [MPa]	σ_{uts} [MPa]	ρ [kg/m^3]	E [GPa]	ν	T_m [^{o}C]
30	103	110	2705	69	0.33	646

Table 2. Chemical composition of the testing material.

Si	Fe	Cu	Mn	Mg	Zn	Ti	V	Al	Other, each
0.25	0.40	0.05	0.05	0.05	0.05	0.03	0.05	99.50	0.03

The annealed test specimens and standard counterparts with 0^o, 45^o and 90^o anisotropy directions were investigated in the bending tests (Fig. 3) to observe the effects of anisotropy direction on the mechanical properties of the material. The annealing condition was selected to remove the residual stresses stemming from rolling operation by avoiding recrystallization in the microstructure.

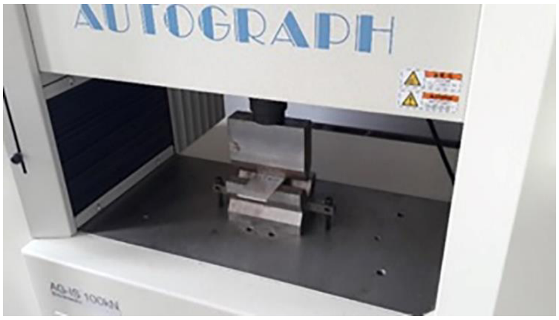


Fig. 3. V-bending operation.

Anisotropy directions of the specimens were given in Fig. 4. As seen from the figure, 0^o represents the specimens in which longitudinal and rolling directions coincide while 90^o represents the specimens in which width and rolling directions coincide. 45^o symbolize specimens in which rolling direction is transverse to longitudinal direction.

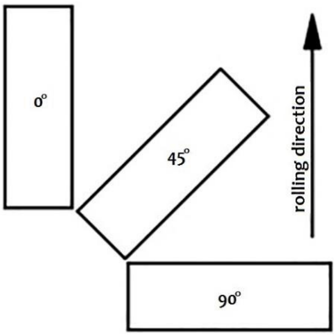


Fig. 4. Anisotropy directions of the specimens.

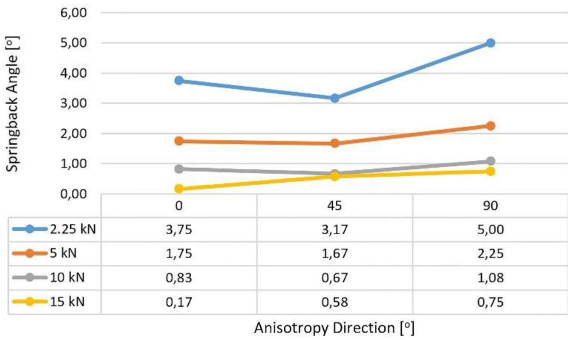
Each bending test parameters and testing procedure were summarized in Table 3. Total number of 24 bending tests allowed the investigation of anisotropy, holding force and annealing on springback behavior.

Table 3. Bending test parameters and procedure.

Holding Force	Annealing	Anisotropy		
		0^o	45^o	90^o
2.25 kN	not annealed	a, b	a, b	a, b
	annealed	b, c	b, c	b, c
5 kN	not annealed	a	a	a
	annealed	c	c	c
10 kN	not annealed	a	a	a
	annealed	c	c	c
15 kN	not annealed	a	a	a
	annealed	c	c	c

a: effects of anisotropy and holding force on springback behavior
b: effects of anisotropy and annealing on springback behavior
c: effects of anisotropy, annealing and holding force on springback behavior

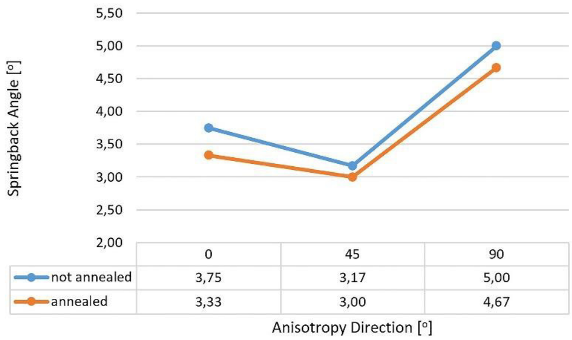
Fig. 5 shows the effect of anisotropy direction and holding force on the springback value of the testing specimens. As seen from the figure, anisotropy direction of the bent specimen has significant effect on springback value. The biggest springback (5^o) in the specimen making 90^o with the rolling direction of the plate with 2.25 kN holding force is 33 % higher than the ones springback making 0^o with the rolling direction. It is also clear that holding force considerably decreases springback. For example, the springback of the specimen making 90^o with the rolling direction of the plate decreases from 5^o to 0.75^o with increasing holding force from 2.25 kN to 15 kN.



	0	45	90
2.25 kN	3,75	3,17	5,00
5 kN	1,75	1,67	2,25
10 kN	0,83	0,67	1,08
15 kN	0,17	0,58	0,75

Fig. 5. Effects of anisotropy and holding force on springback behavior.

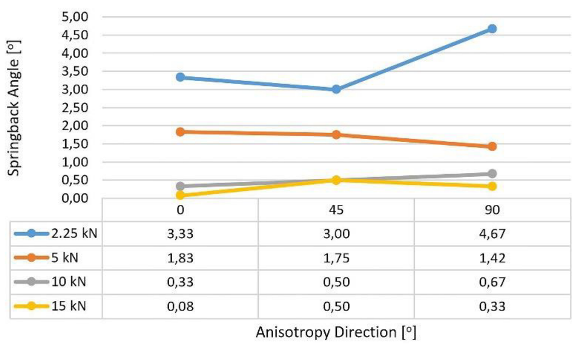
Fig. 6 shows the effect of anisotropy direction and annealing condition on the springback value of the testing specimens having 2.25 kN holding force. As mentioned above, anisotropy direction significantly effects springback value. The highest springback values were observed in the specimens making 90^o with the rolling direction of the plate and the lowest ones were observed in the specimens making 45^o with the rolling direction. Furthermore, annealing decreases springback in all anisotropy directions. For example, springback value was decreased 11.2 % in the specimen making 0^o with the rolling direction of the plate by annealing.



	0	45	90
not annealed	3,75	3,17	5,00
annealed	3,33	3,00	4,67

Fig. 6. Effects of anisotropy and annealing on springback behavior.

Fig. 7 shows the effect of anisotropy direction and holding force on the springback value of the annealed testing specimens. The results are compatible with the former ones. Effects of holding force and annealing together decreased springback dramatically. As seen from the figure, springback values are very small in the annealed specimens subjected to 15 kN holding force, especially in the specimen making 0^o with the rolling direction of the plate.



	0	45	90
2.25 kN	3,33	3,00	4,67
5 kN	1,83	1,75	1,42
10 kN	0,33	0,50	0,67
15 kN	0,08	0,50	0,33

Fig. 7. Effects of anisotropy and holding force on springback behavior of stress relieved specimens.

4. Results and Discussion

In this study, springback behavior of 1050-H14 aluminum alloy plates were investigated. Effects of holding force, annealing and anisotropy on springback value were examined. Typical V-bending tests were performed on a universal testing machine. Various holding forces were applied at the end of the bending operations to determine the effect of hardening on springback values. Obtained results were specified as follows;

- Anisotropy has a significant effect on springback behavior. The highest value of springback is in the perpendicular direction with the rolling direction and the lowest one is in the direction making 45^o with the rolling direction.
- Application of holding force decreases springback values dramatically due to strain hardening in the bending region,
- Annealing also decreases springback values due to the removal of residual stresses,
- Application of holding force on annealed specimens has a significant affirmative effect on springback values. Allowable springback values obtained in annealed specimens with 15 kN holding force.

Effect of heat treatment should be analyzed more detailed with various annealing temperatures and cooling conditions by considering the change in the mechanical properties and microstructure of the material. Effect of holding force on the mechanical properties in the bending region should be investigated in the further studies.

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