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EXPERIMENTAL RESEARCH CONCERNING THE BENDING OF AZ31 MAGNESIUM ALLOY SHEETS

Andrei Dragos BORS[1], Gheorghe BRABIE[2,*], Bogdan CHIRITA[3]

1) PhD Student, Departament of Industrial Engineering, Vasile Alecsandri University of Bacau, Romania
2) Prof., PhD, Departament of Industrial Engineering, Vasile Alecsandri University of Bacau, Romania
3) Prof., PhD, Departament of Industrial Engineering, Vasile Alecsandri University of Bacau, Romania

Abstract: *The tests were done using different values of blankholder forces. The values of the blankholder forces (BHF) were taken between 0kN and 10 kN. Two forming speeds and two to five specimens were used during the tests. The obtained results were an arithmetic average of each test done on the same conditions. The following parameters of the springback effect were determined during the tests: θ_1 – angle between the bottom of the piece and the side wall;* θ_2 *– angle between the flange and the side wall; ρ – the radius of curvature of the piece wall.*

Key words: *springback angle, bending angle, springback radius, forming speed, blankholder force.*

1. INTRODUCTION

The most important problem of the magnesium alloy sheets are thouse regarding cold forming – the malleability. The processing of these alloys differs greatly from the steel and aluminum alloys that are most used in the industry. The main advantage of magnesium alloys is that of lower density than the most commonly used alloys – aluminum and steel [4].

The U-bending test consists in a continuous and non-shock forming of a rectilinear specimen, around a piece up to an angle formed between the face of a portion of the bent specimen and the extension of the face of the other part, or until a crack occour (Fig. 1) [3].

After removing the forces results a change in the shape of the piece, phenomenon that is called springback or arcing. The springback is characterized by two geometrical parameters of the bent piece: the springback angle and radius. The springback radius is considered to be negligible in the case of a large bending radius and also in the case of bending with small bending radius. The springback is influenced by the following parameters: mechanical properties of the material; shape and dimensions of the piece; bending angle; the structure of the mold used; the adopted working procedure.

This paper presents the manner in wich the following parameters have influienced the springback effect after the bending of the magnesium alloy sheets: influence of the blankholder force; influence of the rolling direction; influence of the forming speed; influence of the width of specimen. The main objective of the experimental analysis is to establish an optimal range of variation of the working parameters.

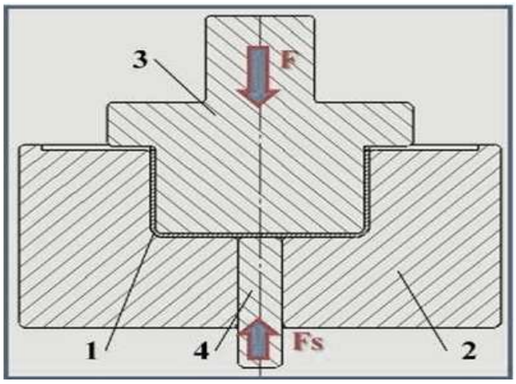

Fig. 1. U-bending mold [1, 2].

2. EXPERIMENTAL

The tests were done using a mold for deepdrawing of rectangular pieces. The construction of the mold allows different blankholder forces. The dimensions of the specimens were length 300 mm and width 30 mm, 50 mm and 80 mm. An average of four attempts were made for each variation of the working parameters. The variation of the blankholder force was achieved by means of a hand-operated hydraulic device, the pressure reading of the fluid being carried out by means of a pressure gauge of 250 BAR. The forming force was obtained by means of a mechanically driven tensile-compressive machine equipped with a variable speed regulator. Another parameter that varied during the tests was the rolling direction. The profile of the tested specimen and the springback parameters were determined with a MicroVu Spectra device. In Fig. 2 the machines and instalations used are presented.

* Corresponding author: Calea Marasesti 157, Bacau, 600115, Romania,
Tel.: (+40) 0723 612 502;
E-mail addresses: *andreidragosb@yahoo.com* (A. Bors); *g-brabie@ub.ro* (G. Brabie)

Fig. 2. Equipment used for tests: *a* – mold used for tests; *b* – MicroVu Spectra device [5].

Table 1

The dimensions of the mold elements

Mold Elements	**Dimensions [mm]**
Punch dimensions	78×120
Pitch connection range	10
Opening of the mold	80
Mold connection range	5
The length of the punch stroke	50

Table 2

Dimensional parameters of the samples

Number of samples [pcs]	**Lenght [mm]**	**Width [mm]**	**Rolling direction [°]**
6	300	30	0
3	300	30	90
5	300	50	0
2	300	50	90
5	300	80	0
2	300	80	90

The dimensions of the mold elements are shown in Table 1.

The shape of the samples used is shown in Fig. 3.

The samples were cut from the sheet metal at the angles of 0^o and 90^o relative to the rolling direction.

The dimensional parameters of the samples are shown in Table 2.

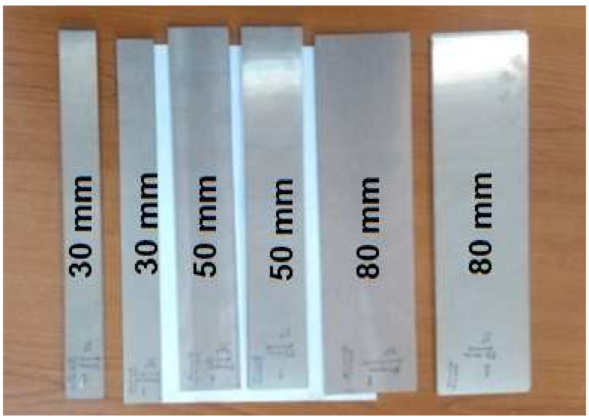

Fig. 3 Specimens used during the tests.

3. RESULTS AND DISCUSSIONS

The experimental study on the influence of the blankholder force on the springback parameters was performed under dry friction conditions between material and tools. The parameters that were varied during the tests were: the blankholder force, the forming speed and the rolling direction. The tests were carried out on specimens with three distinct width: 30 mm, 50 mm, and 80 mm.

Experimental results for 30mm widths samples are shown in Tables 3, 4 and 5.

The profiles of the U-bent pieces are shown in Fig. 4.

Table 3

Springback parameters – θ_1 angle

Specimen	**Rolling direction [°]**	**Blank-holder force [kN]**	**θ_1 angle [°]**	
			L	***R***
P01	0	0	119.09	119.19
P02	0	5	119.25	119.56
P03	0	5	120.28	123.19
P04	0	5	118.35	119.39
P01	90	0	126.19	127.07
P02	90	5	118.48	122.44
P03	90	5	121.24	118.49

Table 4

Springback parameters – θ_2 angle

Specimen	**Rolling direction [°]**	**Blank-holder force [kN]**	**θ_1 angle [°]**	
			L	***R***
P01	0	0	49.07	46
P02	0	5	43.55	44.28
P03	0	5	51.11	49.02
P04	0	5	53.07	49.47
P01	90	0	49.05	45.49
P02	90	5	41.4	40.08
P03	90	5	51.34	52.49

Table 5

Springback parameters – curvature radius of piece wall ρ

Specimen	**Rolling direction [°]**	**Blank-holder force [kN]**	**Curvature radius of piece wall ρ [mm]**	
			L	***R***
P01	0	0	111.69	117.42
P02	0	5	113.65	115.28
P03	0	5	113.95	125.43
P04	0	5	106.99	115.06
P01	90	0	122.06	150.1
P02	90	5	121.05	131.6
P03	90	5	102.98	107.4

Fig. 4. The influence of the blankholder force on the springback.

It was observed that if the blankholder forces are growing the intensity of springback angle θ$_1$ is increasing and the intensity of springback angle θ$_2$ is decreasing; springback angles, θ$_1$ between the bottom of the piece and the side wall and θ$_2$ between the wall of the piece and flange recorded a tiny variation for low values of blankholder forces; curvature radius of piece wall ρ shows small variations for high values of blankholder forces. Comparing the test results of the cuted pieces at 0 and 90 degrees to the rolling direction, it is noted that the variation of the springback angle is much more conclusive in the case of the sample cuted perpendicular to the rolling direction. The experimental results for the 50mm width pieces are shown in Tables 6, 7 and 8.

Table 6

Springback parameters – θ$_1$ angle

Specimen	Rolling direction [°]	Blank-holder force [kN]	θ$_1$ angle [°]	
			L	***R***
P01	0	0	127.8	126.42
P02	0	5	120.22	122.28
P03	0	5	126.21	123.24
P04	0	7.5	120.18	121.02
P05	0	10	113.25	113.43
P01	90	0	130.23	133.14
P02	90	5	130.5	125.58

Table 7

Springback parameters – θ$_2$ angle

Specimen	Rolling direction [grd]	Blank-holder force [kN]	θ$_2$ angle [°]	
			L	**R**
P01	0	0	52.48	52.58
P02	0	5	50.09	51.18
P03	0	5	55.5	56.43
P04	0	7.5	43.16	45.19
P05	0	10	35.28	40.03
P01	90	0	58.18	62.52
P02	90	5	51.2	54.47

Table 8

Springback parameters – curvature radius of piece wall ρ

Specimen	Rolling direction [°]	Blank-holder force [kN]	Curvature radius of piece wall ρ [mm]	
			L	***R***
P01	0	0	112.54	115
P02	0	5	112.06	117.38
P03	0	5	125.22	103.51
P04	0	7.5	143.41	119.88
P05	0	10	171.46	146.96
P01	90	0	110.7	124.3
P02	90	5	112.86	116.58

Fig. 5. The influence of the blankholder force on the springback.

The profiles of the U-bent pieces are shown in Fig. 5

It was observed that if the blankholder forces are growing the intensity of the springback is decresing; springback angles, θ$_1$ between the bottom of the piece and the side wall and θ$_2$ between the piece wall and flange, record a strong variation for low blankholder forces. Springback angle θ$_1$ shows a stronger variation than springback angle θ$_2$; curvature radius of wall piece ρ shows higher variations for higer values of blankholder forces. By comparing the test results of the cut pieces at 0^o and 90^o in the rolling direction it was observed that the variation of the springback angle is much more conclusive in the case of the perpendicular cut to the rolling direction.

The experimental results for the 80mm width pieces are shown in Tables 9, 10 and 11.

Table 9

Springback parameters – θ$_1$ angle

Specimen	Rolling direction [°]	Blank-holder force [kN]	θ$_1$ angle [°]	
			L	***R***
P01	0	0	128.16	133.1
P02	0	5	125.11	128.04
P03	0	5	123.32	125.31
P04	0	7.5	121.14	124.31
P05	0	10	119.01	120.36
P01	90	0	131.13	132.17
P02	90	5	126.18	130.25

Table 10

Springback parameters – θ_2 angle

Speci-men	Rolling direction [°]	Blank-holder force [kN]	θ_2 angle [°]	
			L	***R***
P01	0	0	62.44	66.36
P02	0	5	66.32	66.04
P03	0	5	53.44	51.53
P04	0	7.5	55.46	56.02
P05	0	10	50.02	49.07
P01	90	0	68.11	63.43
P02	90	5	56.49	59.45

Table 11

Springback parameters – curvature radius of piece wall ρ

Speci-men	Rolling direction [°]	Blank-holder force [kN]	Curvature radius of piece wall ρ [mm]	
			L	***R***
P01	0	0	97.44	98.23
P02	0	5	109.6	115.24
P03	0	5	158.66	124.6
P04	0	7.5	149.22	140.94
P05	0	10	168.66	153.78
P01	90	0	108.49	108.74
P02	90	5	116.28	115.85

Fig. 6. Influience of the blankholder force on springback.

The profiles of the U-bent pieces is shown in Fig. 6.

It was observed that if the blankholder forces grow the intensity of the springback decreases. Springback angles, θ_1 between the bottom of the piece and side wall and springback angle θ_2 between piece wall and flange, record a stronger variation for lower values of the blankholder forces. The decreasing of the intensity of springback is more obvious for springback angle θ_1; curvature radius of piece wall ρ shows a higher variation for higher values of blankholder forces. By comparing the test results of the cut pieces at 0^o and 90^o in the rolling direction it is noted that the variation of the springback angle is much more conclusive in the case of the sample cut perpendicular to the rolling direction.

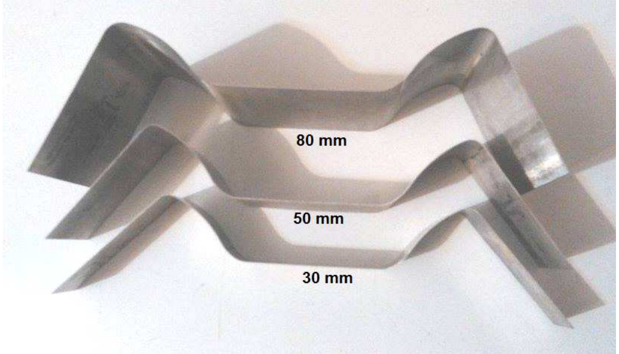

Fig. 7. Influence of forming speed on springback.

Concerning the influence of the forming speed on springback, the results obtained for the samples with 30 mm, 50 mm and 80 mm widths at 0^o as the rolling direction (Fig. 7) were compared. In order to minimize the influence of the blankholder force, its value has been kept constant to F = 5 kN.

The values of the springback parameters for the two forming speeds used are shown in Tables 12, 13 and 14.

It was observed that if the values of forming speed grows the intensity of the springback increases; Springback angles, θ_1 between the bottom of the piece and side wall and springback angle θ_2 between piece wall and flange, record a stronger variation for lower values of forming speeds; curvature radius of piece wall ρ shows higher variations for lower values of forming speed.

The profiles of the U-bent pieces are shown in Fig. 7.

Table 12

Springback parameters – θ_1 angle

Specimen	Specimen width [mm]	Forming speed [mm/s]	θ_1 angle [°]	
			L	***R***
P01	30	0.23	119.25	119.56
P02	50	0.23	120.22	122.28
P03	80	0.23	125.11	128.04
P01	30	0.12	118.35	119.39
P02	50	0.12	126.21	123.24
P03	80	0.12	123.32	125.31

Table 13

Springback parameters – θ_2 angle

Specimen	Specimen width [mm]	Forming speed [mm/s]	θ_2 angle [°]	
			L	***R***
P01	30	0.23	43.55	44.28
P02	50	0.23	50.09	51.18
P03	80	0.23	66.32	66.04
P01	30	0.12	53.07	49.47
P02	50	0.12	55.5	56.43
P03	80	0.12	53.44	51.53

Table 14

Springback parameters – curvature radius of piece wall ρ

Specimen	Specimen width [mm]	Forming speed [mm/s]	Curvature radius of piece wall ρ [mm]	
			L	***R***
P01	30	0.23	113.65	115.28
P02	50	0.23	112.06	117.38
P03	80	0.23	109.6	115.24
P01	30	0.12	106.99	115.06
P02	50	0.12	125.22	103.51
P03	80	0.12	158.66	124.6

Concerning the influence of the rolling direction on the springback parameters, the results were obtained for the 30 mm, 50 mm, and 80 mm width samples at different values of the blankholder force (Fig. 8) being compared for different rolling direction.

In order to minimize the influence of the forming speed, its value was kept constant at v = 0.23 mm/s. The values of the springback parameters relative to the rolling direction used are shown in Tables 15, 16 and 17.

It was observed that at the change of the rolling direction there is an increase of the intensity of springback effect upon all parameters analised. Springback angles, θ_1 between the bottom of the piece and side wall and springback angle θ_2 between piece wall and flange, record a higher variation for 90^o rolling direction comparative with 0^o. However, it can be seen that the springback angle θ_1 shows a more consistent variation comparative with springback angle θ_2 for all the three width variations of the specimens; the curvature radius of the piece wall ρ shows less higher variations when changing the rolling direction.

Table 15

Springback parameters – θ_1 angle

Specimen	Rolling direction [°]	BHF [kN]	θ_1 angle [°]	
			L	***R***
P01 30mm	0	0	119.09	119.19
P01 50mm	0	0	127.8	126.42
P01 80mm	0	0	128.16	133.1
P01 30mm	90	0	126.19	127.07
P01 50mm	90	0	130.23	133.14
P01 80mm	90	0	131.13	132.17

Table 16

Springback parameters – θ_2 angle

Specimen	Rolling direction [°]	BHF [kN]	θ_2 angle [°]	
			L	***R***
P01 30mm	0	0	49.07	46
P01 50mm	0	0	52.48	52.58
P01 80mm	0	0	62.44	66.36
P01 30mm	90	0	49.05	45.49
P01 50mm	90	0	58.18	62.52
P01 80mm	90	0	68.11	63.43

Table 17

Springback parameters – curvature radius of piece wall ρ

Specimen	Rolling direction [°]	BHF [kN]	Curvature radius of piece wall ρ [mm]	
			L	***R***
P01 30 mm	0	0	111.69	117.42
P01 50 mm	0	0	112.54	115
P01 80 mm	0	0	97.44	98.23
P01 30 mm	90	0	122.06	150.1
P01 50 mm	90	0	110.7	124.3
P01 80 mm	90	0	108.49	108.74

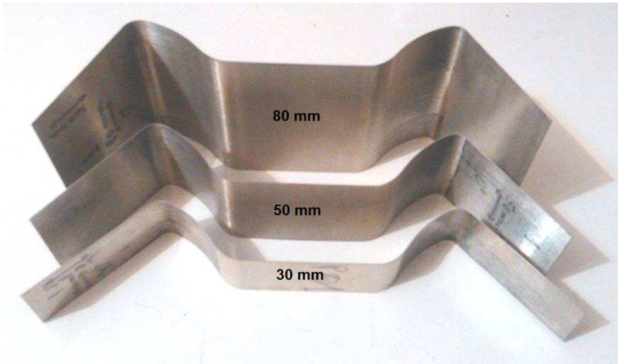

Fig. 8. Infliuence of rolling direction on springback.

The profiles of the U-bent pieces are shown in Fig. 8.

Concerning the influence of the width of the specimens on the springback parameters, the results were obtained for the 30 mm, 50 mm, and 80 mm width specimens and compared to constant values of the blankholder force (Fig. 9) and rolling directions.

In order to highlight the influence of the width of the specimen, the forming speed was kept constant at v = 0.23 mm/s. The values of the springback parameters in relation to the used widths of the specimens are shown in Table 18.

Table 18

The values of the springback parameters in relation to the used widths of the specimens

Speci men	θ_1 angle [°]		θ_2 angle [°]		Curvature radius of piece wall ρ [mm]	
	L	***R***	***L***	***R***	***L***	***R***
P01 30	119.09	119.19	49.07	46	111.69	117.42
P01 50	127.8	126.42	52.48	52.58	112.54	115
P01 80	128.16	133.1	62.44	66.36	97.44	98.23

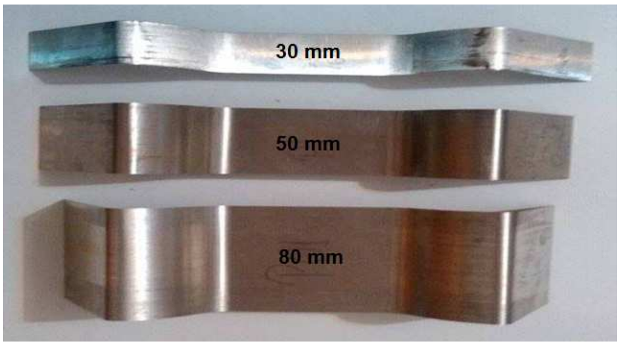

Fig. 9. Influience of width piece on springback.

It was observed that as the width of the specimen is higher there is a slightly increase of the intensity of springback effect; Springback angles, θ_1 between the bottom of the piece and side wall and springback angle θ_2 between piece wall and flange, record small variations as the width of the specimen is higher; the curvature radius of the piece wall ρ shows negative variations as the width of the specimen is higher. This happens because as the width of the piece is higher the value of the blankholder force is lower.

The profile of the U-bent pieces is shown in Fig. 9.

4. CONCLUSIONS

The behavior of AZ31 magnesium alloy sheets when conducting the U-bending test was studied. The tests tracked the behavior of the material having different specimen dimensions. The influence of the blankholder force, the rolling direction, the forming speed and the width of the specimens were monitored.

After the performed tests it was found that the measured values of the two springback angles recorded significant values in the sense that the springback effect is very high in the case of magnesium sheets. It has been found that the higher the blankholder force, the springback effect tends to be lower. The disadvantage of the magnesium sheets under the present conditions is that the material does not withstand to higher blankholder forces in order to obtain a low value of springback angles. The ideal value of the springback angle is 0, meaning that after the bending operation is finished there is no springback effect.

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