An experimental investigation of springback of AA6061 aluminum alloy strip via V- bending process

A B Abdullah and Z Samad
School of Mechanical Engineering, Universiti Sains Malaysia Engineering Campus, Universiti Sains Malaysia, 14300, Nibong Tebal, Penang, Malaysia
E-mail: *mebaha@eng.usm.my

Abstract. Springback is one of the common geometrical defects found in the sheet metal forming process. Aluminium alloy with high content of magnesium such as AA6061 is preferred for their high formability limit, but commonly springback becomes a drawback. In this study, springback behaviour of the AA6061 will be observed. The effect of length, thickness and bend angle to the springback pattern was investigated and the result depicted that springback is more significant to thickness and bend angle, while the length gives less effect.

1. Introduction
Springback is one of considerable geometrical defect in sheet forming processes [1]. Springback can only be controlled and minimized but quite difficult to be eliminated. For that reason, understanding the mechanism and behavior of the springback is beneficial. In most literatures, the springback can be refereed as a condition that occurs when sheet metal or alloy formed, and the material has a tendency to return to its initial shape because of the elastic recovery of the material upon unloading [2]. It is not only influenced by the tensile and yield strengths, but also by thickness, bend radius and bend angle [3]. In most recent research, finite element is the main tool used to understand, predict and improved the component defect through springback [4-6]. In addition, there are few other tools that employed in predicting and measuring the springback such ANN [7], optical method [1] and optimization using the statistical method such as ANOVA and Taguchi method [8-10]. Recently the topic on springback measurement and compensation has devoted attention from researchers. The studies can be discussed into physical and numerical approaches. The physical parameters can be further explored into material properties and process characteristics as well as their sensitiveness. Typically within the former parameter, the issue of isotropic and kinematic hardening [11], Bauschinger effect [12], evolution of elastic properties [13] and elastic and plastic anisotropy [14] were raised. While the later, mostly the problem of sheet thickness, friction coefficient, blank holder force, tool geometry, contact pressure, temperature and unloading procedure discussed [15-17]. Springback measured on various types of sheet forming processes. For example, recently Zhan et al. [18] reviewed a creep age forming (CAF), and they found that to predict the amount of springback is the greatest challenge. Wang et al. [19] presented a practical incremental bending methodology to control punch displacement to achieve more accurate final bend angles. In this method, information collected from loading–unloading cycles were utilized.

The paper will present the experimental study on springback behavior of AA6061. The study focuses on the effect of length, thickness and bend angle to the springback. The paper starts with...
introduction and then follows by the experiment setup. The results are then discussed and, the paper ends with the conclusion.

2. Motivation
Twist springback is one the major geometrical defect in the manufacturing of the propeller blade. Conceptual the blade has complex design, which has hydrodynamic profile and twisted at varies twist angle as shown in figure 1 and summarized in table 1. The chord length also varies from the head to the tip. Preliminary works on the measurement of the twist springback on cold forged propeller blade have been conducted by Abdullah et al. [20]. In order to further understanding the problem of twist springback in the propeller blade, which is complex, pattern of springback in simple shape, need to be explored first. The output of this study will give the fundamental on how springback is happened and the parameters which may influence the occurrence of the springback.

![Figure 1. Nominal model of the propeller blade.](image)

### Table 1: Geometries of the produced blade.

| Section | Chord Length, mm | Twist Angle, degree | Minimum Thickness, mm | Maximum Thickness, mm |
|---------|------------------|---------------------|-----------------------|-----------------------|
| A       | 17.79            | 48.80               | 0.410                 | 2.768                 |
| B       | 19.87            | 51.76               | 0.182                 | 2.177                 |
| C       | 21.72            | 58.90               | 0.154                 | 1.560                 |
| D       | 21.13            | 65.48               | 0.120                 | 1.005                 |
| E       | 18.96            | 67.35               | 0.010                 | 0.703                 |

3. Experimental setup
For v-bending experiment, the die set is prepared and as shown in figure 2. The die and puncher were made from D2 tool steel material and the experiment was performed using the same machine. The experiment will be performed and the springback pattern will be only observed based on the variation of bend angle, length and thickness of the workpiece. In the measurement of the springback, the Rax Vision Mitutoyo Profile Projector (PC 3000) machine was used. In the measurement, the 2 lines technique was employed to measure the angle as shown in figure 3. In this case, the difference between the angle after loading and after unloading is defined as springback. The die valley radius, punch radius and the die opening are constant at 90°, 2 mm and 32 mm respectively as illustrated in figure 4 (a) and (b). In this case, the die radius and punch radius has the same value.
Figure 2. (a) V-bending bottom die; (b) V-bending setup.

Figure 3. The profile projector used in measuring the springback.

Figure 4. The definition of v-bending process, at (a) initial and (b) end.
4. Result and Discussion

For the v-bending experiment, observations were made at different stroke. The bend radius of 5, 7 and 10mm stroke is 17, 24 and 32 degree respectively. The maximum stress is approximately 90MPa and the pattern seems to be the same for each cases. For the 10 mm stroke, the workpiece tend to fail after strain is achieving 0.3. Failure can be observed from the crack mark on the bottom side of the workpiece as shown in figure 5.

![Figure 5](image1.png)

**Figure 5.** The stress strain behaviour of the material.

Figure 6 - 8 present the effect of the length and bend angle to the springback at different thickness. The result shows that the length of the workpiece has less effect to the springback compare to band angle. This can be seen in the results, even though there is negative and positive springback, but the pattern is about the same for each case. At higher thickness as shown in figure 6, the effect of bend angle can be clearly seen. In contrast, at lower thickness the amount of springback is higher but less effect of the bend angle as shown in figure 7 and 8. In other aspect, the effect of length to the springback is found to be insignificant. These results seem to be in line with the other studies conducted by Garcia-Romeu et al. [21] and Ouakdi et al. [22].

![Figure 6](image2.png)

**Figure 6.** The springback behaviour at thickness of 3.0 mm.
Figure 7. The springback behaviour at thickness of 1.5 mm.

Figure 8. The springback behaviour at thickness of 1.0 mm.

5. Conclusion
For conclusion, the study has presented the experimental investigation on springback behavior of AA6061. The effects of length, thickness and bend angle have been studied and the result depicted that the springback is significant to the thickness and bend angle changes. In contrast, it has a very less effect to length of the workpiece. For future works, the springback behavior of the alloy with non-uniform thickness will be further explored. This data is very useful as the fundamental understanding and benchmark for further investigation of the twist springback in the cold forging of propeller blade made of aluminium alloy. Therefore, only length, bend angle and thickness were highlighted in the present study. These parameters may represent the chord length, twist angle and thickness of the blade and for the blade performance, those parameters are very critical and may affect the performance of the blade as well as the propeller.

Acknowledgements
Authors would like to acknowledge the Universiti Sains Malaysia for their sponsorship in this project through Short Term grant scheme (#60312014). Through this opportunity, authors would thank Mr. Fakruruzi and Mr. Zulhairi for their assistant in the experiment.
References

[1] Abdullah A B, Sapuan S M, Samad Z, Khaleed H M T and Aziz N A 2011 Aust. J. Basic Appl. Sci. 5(9) 1756
[2] Marretta L, Ingarao G and Di Lorenzo R 2010 Int. J. Mech. Sci. 52(7) 914
[3] Wang J F, Wagoner R H, Carden W D, Matlock D K and Barlat F 2004 Int. J. Plasticity. 20 (12) 2209
[4] Schwarze M, Vladimirov I N and Reese S 2011 Comput. Method. Appl. M 200(5-8) 454
[5] Shen H Q, Li SH and Chen GL 2010 Mater. Design 31(2) 870
[6] Yu H Y 2009 Mater. Design 30(3) 846
[7] Bozdemir M and Golcu M 2008 J Appl. Sci. 8 3038
[8] Meinders T, Burchitz I A, Bonte M H A and Lingbeek RA 2008 Int. J. Mech. Tool. Manu. 48(5) 499
[9] Khan M A R, Rahman M M, Kadirgama K, Maleque M A and Ishak M 2011 J Mech Eng Sci. 1 16
[10] Parate P R and Yarasu R B 2013 J Mech Eng Sci. 4 479
[11] Vladimirov I N, Pietryga M P and Reese S 2009 J. Mater. Process. Tech. 209(8) 4062
[12] Gau J T and Kinzel G L 2001 Int. J. Mech. Sci. 43(8) 1813
[13] Sun L and Wagoner R H 2011 Int. J. Plasticity. 27(7) 1126
[14] Li X, Yang Y, Wang Y, Bao J and Li S 2002 J. Mater. Process. Tech. 123 209
[15] Li K P, Carden W P and Wagoner R H 2002 Int. J. Mech. Sci. 44(1) 103
[16] Osman M A, Shazly M, El-Mokaddem A and Wifi A S 2010 J. Achieve Mater. Manuf. Eng. 38(2) 179
[17] Grèze R, Manach P Y, Laurent H, Thuillier S and Menezes L F 2010 Int. J. Mech. Sci. 52(9) 1094
[18] Zhan L, Lin J and Dean T A 2011 Int. J. Mach. Tool. Manu. 51(1) 1
[19] Wang J, Verma S, Alexander R and Gau J T 2008 J. Manuf. Processes. 10(1) 21
[20] Abdullah A B, Sapuan S M, Samad Z, Khaleed, H M T. and Aziz N A 2012 Adv. Mater. Res. 512-15 1840
[21] Garcia-Romeu M L, Ciurana J and Ferrer I 2007 J. Mater. Process. Tech. 191 174
[22] Ouakdi E H, Louahdi R, Khirani D and Taboure L 2012 Mater. Design. 35 106