Experimental, Statistical, and Analytical Evaluation of The Springback Behavior of Martensitic 1400 Sheet in V-Bending

Nuri ŞEN (nurisen@duzce.edu.tr)
Duzce Universty https://orcid.org/0000-0002-6501-5858
Ömer SEÇGİN
Sakarya Uygulamali Bilimler Universitesi

Original Article

Keywords: Bending, Springback, ANOVA, Martensitic 1400

Posted Date: November 17th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-106435/v1

Abstract

Ultra-high-strength Martensitic 1400 steel is preferred in the automotive industry because of its high strength as well as its light weight. In this study, Martensitic 1400 steel was subjected to the V-bending process. As a result of 48 different tests, the amount of springback resulting from the V-bending process was determined. A finite element (FE) model was then created based on these experimental data. After it was determined that the experimental results concurred with the FE model, without performing new experiments, further analyses were carried out at different temperatures. Using the results of a total of 96 FE analyses, variance analysis was performed and the effects of the operation parameters on springback were determined. As a result of the study, it was concluded that the most effective parameter on springback in the V-bending process was the die angle and that holding time had no significant effect. It was observed that the springback increased in parallel with the punch radius and die angle and that increases in temperature reduced the springback.

1. Introduction

In the automotive industry sheet metal is generally used after plastic deformation and forming. The chassis and most of the parts used in the vehicles are made of metal. This indicates that metal parts make up the majority of the weight of the vehicles. The current fuel-saving strategy emphasizes the use of light but durable materials. Consequently, the use of martensitic sheets in the automotive industry is becoming widespread. The most important features of these sheets are high strength and light weight. These materials increase the safety of the vehicles and can save lives in the event of an accident. They also lower fuel consumption and carbon emission [1].

Studies have been carried out on the forming of martensitic sheets, but when the literature is examined, these studies are seen to be limited. Among the researchers working on this subject, Xie et al. applied the V-bending process to AZ31B magnesium alloy sheet and investigated the influence of direct-current pulses on springback. They determined that when grain size and the number of twinning crystals decreased, springback decreased as well [2]. Park et al. combined martensitic steel sheet with polymer material as a laminate and produced a new material with high strength (500 MPa). They subjected it to the V-bending test and examined the delamination mechanism formed during the bending process [3].

Springback is caused by the elastic behavior of the material. In the metal forming process, springback error is defined as the deformation that occurs in the geometry when the force on the part is removed [1, 4]. Reducing this defect is of great industrial importance. For this reason, many studies have been aimed at understanding and reducing springback. Springback can occur in all bending methods: tube bending [5, 6], L-bending [7–9], U-bending [10, 11], press bending [12, 13], V-bending [14, 15], air bending [16, 17].

In this study, experimental, statistical, and analytical investigations were performed on the springback behavior in the V-bending process. A total of 48 different experiments were conducted and the amount of springback of the samples was determined via a 3D coordinate-measuring machine (CMM). A finite element (FE) model of the bending process was then created using Simufact Forming V16 software. Using the experimental sets and the same parameters, 48 different analyses were performed. The analysis results were found to concur with the experimental results. Without the need for new experiments, 48 more FE analyses

were then conducted using different temperature values. Consequently, a variance analysis (ANOVA) was performed using the 96 analysis results obtained, and the effects of the experimental parameters on springback were determined.

2. Material And Methods

2.1. Material

In in the experiments of this study, Martensitic 1400 sheet with a thickness of 1.5 mm was formed by bending in a V shape. Samples were prepared in 40 × 40 mm dimensions using guillotine shears. The chemical composition and stress-strain curves of the material are given in Fig. 1. Its strength perpendicular to the rolling mill was 1441.8 MPa. Information on its strength in the other directions can be seen in the figure. Tensile tests were carried out using a 100 kN UTEST flexure testing machine. Spectral analysis was performed using the GNR Metal Lab Plus spectrometer.

2.2. Method

Experimental studies were carried out at two different temperatures: room temperature (22 °C) and 300 °C. Samples were heated by adjusting the proportional-integral-derivative (PID) temperature control panel (± 1 °C temperature sensitivity) on the experimental setup. Temperature control was provided using the thermocouple on the resistor rod. The sheets were heated on the die by this heating system (Fig. 2). Only local heating was applied [18]. The warm forming process is often used to reduce springback in metal forming [19, 20]. The sheet was formed immediately after it was heated without removing the die.

In the literature, holding time has also been examined as a parameter in V-bending [21–23]. Holding time is when the punch waits for a certain period of time on the die before withdrawing after pressing the sheet metal. At the end of the forming process, two different periods were determined for holding time: 0 s and 10 s.

Four die angles (30 °, 60 °, 90 °, and 120 °) were used to determine the effects of different die angles. For each angle, 2, 4, and 6-mm tip radii were used. The experimental setup and dies used in the study are shown in Fig. 3, with R referring to the punch tip radius. The bending angle is given in Eq. (1), where α is the die angle.

$$Bending\ angle = \frac{180-\alpha}{2} \quad (1)$$

A total of 48 bending tests were conducted within the scope of the study. The experimental parameters used in these experiments are given in Table 1. The first 24 experiments were conducted at room temperature. The next 24 experiments were carried out at 300 °C, with the first 24 test sequences and the following 24 test sequences being identical except for the temperature parameter, i.e., Experiment No. 2 and Experiment No. 26 were the same except for the temperature. This was also the case for the other experiments.

At the end of the experiments, the springback values of each sample were measured using a Hexagon CMM (Fig. 4). Figure 4a and 4b show images of the measurement process. The samples were attached to the CMM base with a special paste. Then, as shown in Fig. 4c, via contact points on the two different planes created by

the surfaces of the samples, the angle read by the CMM device and recorded. The difference between the measured angle of the sample and the intended angle indicated the amount of springback.

2.3. Finite element analysis

Finite element (FE) analyses were made using the experimental sets given in Table 1. Finite element analysis was performed via the Simufact Forming V16 program. In the analysis, the die and punch were defined as rigid and the sheet as elastoplastic. The values obtained from the previous tensile test were established as the material model. A 0.621-mm hexahedral mesh was generated for the sheet using a total of 12,288 elements. The thickness of the sheet was divided into three parts to increase the accuracy of the calculation. Views of the FE analysis during bending simulation and the measuring of springback are given in Fig. 5.

As described in the next section, 48 FE analyses were performed with 48 experimental sets using the same parameters (room temperature and 300 °C). Later, it was seen that the experimental results and the analysis results concurred. Finite element analyses for higher temperatures were then carried out without further experiments. In the experimental set given in Table 1, a total of 48 more analyses were performed using 400 °C instead of 22 °C and 500 °C instead of 300 °C, using the other parameters as given in the aforementioned table. Thus, a total of 96 different analyses were carried out.

3. Results And Discussion

3.1. Experimental and FE analyses

From a total of 24 experiments at room temperature, the amount of springback in the samples was measured using a CMM device. The springback values obtained from the results of the experimental measurements and FE analysis are given in Fig. 6. The graph clearly shows that in the experiments at room temperature, springback increased in parallel with the die angle. The results of the springback measurement are given in the last column of Table 1. According to the table, the least springback occurred in Experiment No. 38. In this experiment, 300 °C temperature, 90 ° die angle, 2-mm punch radius, and 10-s holding time were used.

Table 1
Experimental sets

Experiment No	Temperature (°C)	Die angle (°)	Punch Radius (mm)	Holding Time (s)	Springback (°)
1	22	30	2	0	5.234
2	22	30	2	10	4.139
3	22	30	4	0	5.694
4	22	30	4	10	6.052
5	22	30	6	0	6.626
6	22	30	6	10	5.616
7	22	60	2	0	3.859
8	22	60	2	10	3.175
9	22	60	4	0	7.095
10	22	60	4	10	6.708
11	22	60	6	0	8.978
12	22	60	6	10	8.885
13	22	90	2	0	6.915
14	22	90	2	10	6.557
15	22	90	4	0	8.906
16	22	90	4	10	9.259
17	22	90	6	0	11.420
18	22	90	6	10	10.845
19	22	120	2	0	8.959
20	22	120	2	10	7.397
21	22	120	4	0	10.652
22	22	120	4	10	11.034
23	22	120	6	0	14.533
24	22	120	6	10	13.583
25	300	30	2	0	4.898
26	300	30	2	10	5.431
27	300	30	4	0	5.637

Experiment No	Temperature (°C)	Die angle (°)	Punch Radius (mm)	Holding Time (s)	Springback (°)
28	300	30	4	10	6.180
29	300	30	6	0	7.038
30	300	30	6	10	7.212
31	300	60	2	0	3.412
32	300	60	2	10	3.747
33	300	60	4	0	7.126
34	300	60	4	10	7.744
35	300	60	6	0	8.551
36	300	60	6	10	9.521
37	300	90	2	0	2.019
38	300	90	2	10	1.678
39	300	90	4	0	9.161
40	300	90	4	10	9.370
41	300	90	6	0	11.159
42	300	90	6	10	11.248
43	300	120	2	0	2.113
44	300	120	2	10	2.373
45	300	120	4	0	10.732
46	300	120	4	10	11.305
47	300	120	6	0	14.390
48	300	120	6	10	14.441

Experiments were carried out at room temperature (22 °C) and 300 °C. A total of 48 different FE analyses were then conducted according to both room temperature and 300 °C. After the analysis results were found to be compatible with the experimental results, FE analyses were performed using the same FE models and changing only the temperatures to 400 °C and 500 °C. The correspondence of analysis results with experimental studies without the need for retesting is very important in terms of cost reduction and saving time. Therefore, for 400 °C and 500 °C, only FE analysis was performed, without further experiments. Results of the FE analysis are given in Fig. 7.

The figure shows that the amount of springback increased in parallel with the die angle. Here, the importance of the die angle is revealed. During the bending process, compressive stress occurs on the surface of the part

in contact with the forming tool, while tensile stress occurs on the surface of the part in contact with the die. This unbalanced stress distribution on the part is the main factor that creates springback [24]. Increasing the die angle increases the bending moment. Therefore, it was concluded that the springback increased as a result of the expanding angle of the die.

When the experimental groups were considered separately, less springback was observed at 500 °C. The reason for this might have been that the increase in temperature had homogenized the stress distribution mentioned above [25].

Negative springback occurred in the experiments using 30 ° and 60 ° die angles at 500 °C temperature. This was attributed to the use of a small radius. Especially in Experiments No. 13 and 14, less springback was observed in the same group compared to the experiments having the same parameters except for the die radius. There was a similar situation with Experiments No. 19 and 20. The small radius of the die reduced the bending moment and this had a positive effect on springback.

3.2. Variance analysis (ANOVA)

In this study, a total of 96 different FE analyses were made. Using the results of these analyses, an analysis of variance (ANOVA) was performed to determine the effects of the experimental parameters on springback. The ANOVA results are given in Table 2. According to the ANOVA, the die angle (29.73%) was the most effective parameter for springback in V-bending, followed by the temperature (25.23%), and the punch radius (19.14%). When compared with these three parameters, the holding time did not have a significant effect on springback.

Table 2
Variance analysis of finite element analysis results

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	13	843.201	84.36%	843.201	64.862	34.01	0.000000
Linear	4	747.060	74.74%	737.577	184.394	96.69	0.000000
Temperature	1	252.239	25.23%	250.770	250.770	131.50	0.000000
Die Angle	1	297.218	29.73%	292.679	292.679	153.48	0.000000
Punch Radius	1	191.303	19.14%	190.752	190.752	100.03	0.000000
Holding Time	1	6.299	0.63%	3.377	3.377	1.77	0.186989
Square	3	23.750	2.38%	23.750	7.917	4.15	0.008627
Temperature*Temperature	1	1.621	0.16%	1.621	1.621	0.85	0.359286
Die Angle*Die angle	1	2.577	0.26%	2.577	2.577	1.35	0.248378
Punch Radius*Punch Radius	1	19.552	1.96%	19.552	19.552	10.25	0.001943
2-Way Interaction	6	72.391	7.24%	72.391	12.065	6.33	0.000017
Temperature*Die Angle	1	2.475	0.25%	2.475	2.475	1.30	0.257965
Temperature*Punch Radius	1	2.616	0.26%	2.616	2.616	1.37	0.244870
Temperature*Holding Time	1	6.087	0.61%	6.087	6.087	3.19	0.077691
Die Angle*Punch Radius	1	59.159	5.92%	59.159	59.159	31.02	0.000000
Die Angle*Holding Time	1	1.209	0.12%	1.209	1.209	0.63	0.428195
Punch Radius*Holding Time	1	0.844	0.08%	0.844	0.844	0.44	0.507721
Error	82	156.374	15.64%	156.374	1.907		
Total	95	999.575	100.00%				

Contour plots of springback are given in Fig. 8. According to the die angle * temperature interaction graph, springback decreased with rising temperature, while it increased with the increase of the die angle. According to the punch radius * temperature interaction graph, springback decreased with the rise of temperature, while it increased with the increase of the punch radius. According to the punch radius * die angle interaction graph, the decreasing of both parameter values together reduced springback. When the interaction graphs of holding time were examined with the other parameters, holding time exhibited no significant effect on springback.

Conclusions

In this study, Martensitic 1400 sheet metal was processed via V-bending. Experiments were carried out at room temperature (22 °C) and 300 °C. The effects of these parameters on the amount of springback were investigated using different die angles, tip radii, and holding times. An FE model was then created using Simufact Forming V16 software and 48 different analyses were carried out using these experimental parameters. The accuracy of the model was established by determining that the experimental results and the analysis results agreed. Later, without the need for re-testing, 48 different FE analyses were performed for 400 °C and 500 °C temperatures. An ANOVA was carried out using the results of all FE analyses (96 in total), and the effects of the parameters on the V-bending process were determined. The following results were obtained in the study:

- In the V-bending process, the most effective parameter on springback was the die angle (pure contribution 29.3%).
- The springback increased in parallel with the punch radius.
- The springback increased in parallel with the die angle.
- Holding time had no significant effect on springback (pure contribution 0.63%).
- Increases in temperature decreased springback.

Declarations

Authors' Contributions

NŞ has conducted the experiments and the analysis of the work. He has worked on the preparation of the die and manufacturing of it. ÖS has written the manuscript and conducted the analysis of the work together with NŞ.

Authors' Information

Dr. Nuri ŞEN was born in 1981. He received his BSc from the Firat University, Faculty of Tech. Education, Elazig, Turkey in 2004 and his MSc in 2007. In 2015, he completed his Ph.D. at the Karabük University. Since 2015, he has been working as Assist. Prof. Dr. in Duzce university at engineering faculty in the department of mechanical engineering.

Dr. Ömer SEÇGİN was born in 1980. He received his BSc from the Firat University, Faculty of Tech. Education, Elazig, Turkey in 2002 and his MSc in 2005. In 2016. He completed his Ph.D. at the Sakarya University. He works Assist. Prof. Dr. in Sakarya University of Applied Science. His research areas include metal forming, manufacturing, finite element analysis an optimization.

Competing Interests

The authors declare that they have no competing interests.

Funding

We gratefully thank Mert AYGEN and Ali Baran METE, who works in a NETFORM engineering firm, for their help in licensing the software of Simufact Forming V16.

Author Details

[1]Duzce University/Faculty of Engineering/Department of mechanical engineering/Department of construction and production, Düzce / Turkey. [2]Sakarya University of Applied Science/ Technology Faculty /Department of mechanical engineering, Sakarya / Turkey.

References

1. Ul Hassan H, Traphöner H, Güner A, Tekkaya AE (2016) Accurate springback prediction in deep drawing using pre-strain based multiple cyclic stress-strain curves in finite element simulation. International Journal of Mechanical Sciences 110:229–241. doi: 10.1016/j.ijmecsci.2016.03.014
2. Xie H, Wang Q, Liu K, et al. (2015) Investigation of influence of direct-current pulses on springback during V-bending of AZ31B magnesium alloy sheet. Journal of Materials Processing Technology 219:321–327. doi: 10.1016/j.jmatprotec.2014.12.011
3. Park H, Kim SJ, Lee J, et al. (2020) Delamination behavior analysis of steel/polymer/steel high-strength laminated sheets in a V-die bending test. International Journal of Mechanical Sciences. doi: 10.1016/j.ijmecsci.2020.105430
4. Choi J, Lee J, Bong HJ, et al. (2018) Advanced constitutive modeling of advanced high strength steel sheets for springback prediction after double stage U-draw bending. International Journal of Solids and Structures 151:152–164. doi: 10.1016/j.ijsolstr.2017.09.030
5. Zhan M, Wang Y, Yang H, Long H (2016) An analytic model for tube bending springback considering different parameter variations of Ti-alloy tubes. Journal of Materials Processing Technology 236:123–137. doi: 10.1016/j.jmatprotec.2016.05.008
6. Zhan M, Xing L, Gao PF, Ma F (2019) An analytical springback model for bending of welded tube considering the weld characteristics. International Journal of Mechanical Sciences 150:594–609. doi: 10.1016/j.ijmecsci.2018.10.060
7. Jamli MR, Ariffin AK, Wahab DA (2015) Incorporating feedforward neural network within finite element analysis for L-bending springback prediction. Expert Systems with Applications 42:2604–2614. doi: 10.1016/j.eswa.2014.11.005
8. Valinezhad M, Etemadi E, Hashemi R, Valinezhad M (2019) Experimental and FE analysis on spring-back of copper/aluminum layers sheet for a L-die bending process. Materials Research Express. doi: 10.1088/2053-1591/ab51c8
9. Lee EH, Yoon JW, Yang DY (2018) Study on springback from thermal-mechanical boundary condition imposed to V-bending and L-bending processes coupled with infrared rays local heating. International Journal of Material Forming 11:417–433. doi: 10.1007/s12289-017-1375-2

10. Quadfasel A, Lohmar J, Hirt G (2017) Investigations on Springback in High Manganese TWIP-Steels using U-Profile Draw Bending. Procedia Engineering 207:1582–1587. doi: 10.1016/j.proeng.2017.10.1052
11. Komgrit L, Hamasaki H, Hino R, Yoshida F (2016) Elimination of springback of high-strength steel sheet by using additional bending with counter punch. Journal of Materials Processing Technology 229:199–206. doi: 10.1016/j.jmatprotec.2015.08.029
12. Yu Y, Min W, Haibo W, Lin H (2010) Design and Optimization of Press Bend Forming Path for Producing Aircraft Integral Panels with Compound Curvatures. Chinese Journal of Aeronautics 23:274–282. doi: 10.1016/S1000-9361(09)60216-8
13. Yan Y, Wang HB, Wan M (2012) FEM modelling for press bend forming of doubly curved integrally stiffened aircraft panel. Transactions of Nonferrous Metals Society of China (English Edition) 22:s39–s47. doi: 10.1016/S1003-6326(12)61681-1
14. Sun Y, Qu F, Xiong Z, Ding S (2018) Numerical study on springback prediction of aged steel based on quasi-static strain-hardening material model. Procedia Manufacturing 15:730–736. doi: 10.1016/j.promfg.2018.07.311
15. Singh J, Kim MS, Choi SH (2017) The effect of strain heterogeneity on the deformation and failure behaviors of E-form Mg alloy sheets during a mini-V-bending test. Journal of Alloys and Compounds 708:694–705. doi: 10.1016/j.jallcom.2017.02.176
16. Vorkov V, Aerens R, Vandepitte D, Duflou JR (2019) Two regression approaches for prediction of large radius air bending. International Journal of Material Forming 12:379–390. doi: 10.1007/s12289-018-1422-7
17. Şenol Ö, Esat V, Darendeliler H (2014) Springback analysis in air bending process through experiment based artificial neural networks. Procedia Engineering 81:999–1004. doi: 10.1016/j.proeng.2014.10.131
18. Sen N (2020) Experimental investigation of the formability of ultrahigh-strength sheet material using local heat treatment. Ironmaking and Steelmaking 47:93–99. doi: 10.1080/03019233.2019.1680176
19. Sen N, Kurgan N (2016) Improving deep drawability of HC300LA sheet metal by warm forming. International Journal of Advanced Manufacturing Technology 82:985–995. doi: 10.1007/s00170-015-7400-z
20. Ozek C, Tasdemir V (2016) Experimental study on effects of die geometry and temperature on limit drawing ratio. In: ICENS 2016. Sarajevo, Bosnia-Herzegovina, pp 2842–2849
21. Karaağaç İ, Uluer O (2017) Experimental investigation of effect of process parameters on springback in v bending process. Pamukkale University Journal of Engineering Sciences 23:990–993. doi: 10.5505/pajes.2017.78466
22. Wang JL, Fu MW, Shi SQ, Korsunsky AM (2018) Influence of size effect and plastic strain gradient on the springback behaviour of metallic materials in microbending process. International Journal of Mechanical Sciences 146–147:105–115. doi: 10.1016/j.ijmecsci.2018.07.027
23. Löbbe C, Tekkaya AE (2018) Mechanisms for controlling springback and strength in heat-assisted sheet forming. CIRP Annals 67:273–276. doi: 10.1016/j.cirp.2018.04.013
24. Karaağaç İ (2017) The Evaluation of Process Parameters on Springback in V-bending Using the Flexforming Process. Materials Research 20:1291–1299.

25. Karaağaç İ, Önel T, Uluer O (2019) The effects of local heating on springback behaviour in v bending of galvanized DP600 sheet. Ironmaking and Steelmaking 9233:1–7. doi: 10.1080/03019233.2019.1615308

Figures

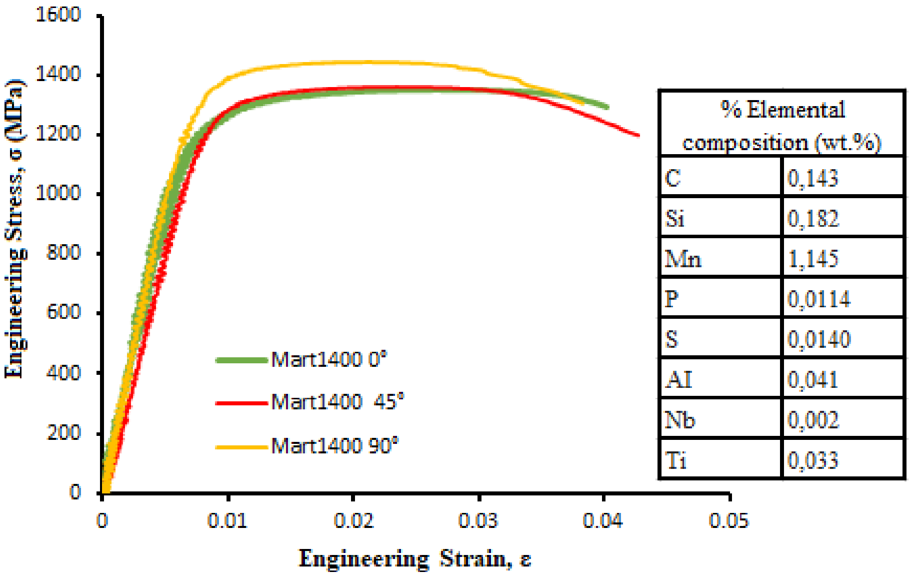

Figure 1

Chemical composition and stress-strain curves of Martensitic 1400 sheet.

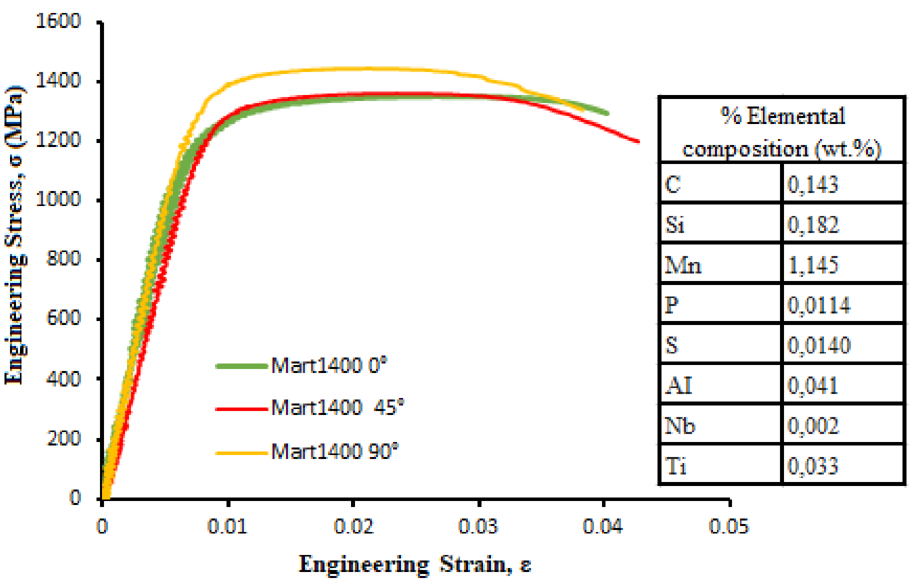

Figure 1

Chemical composition and stress-strain curves of Martensitic 1400 sheet.

Figure 2

Sheet heating process

Figure 2

Sheet heating process

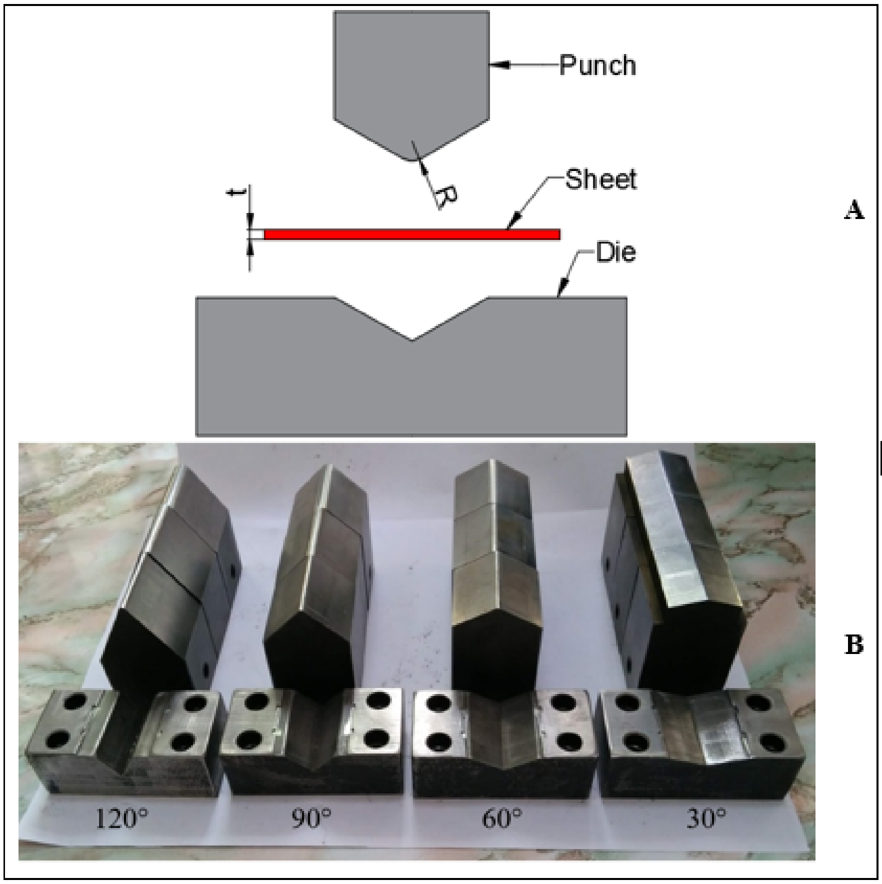

Figure 3

Experimental setup: (A) Experimental setup, (B) Dies used in the experiments.

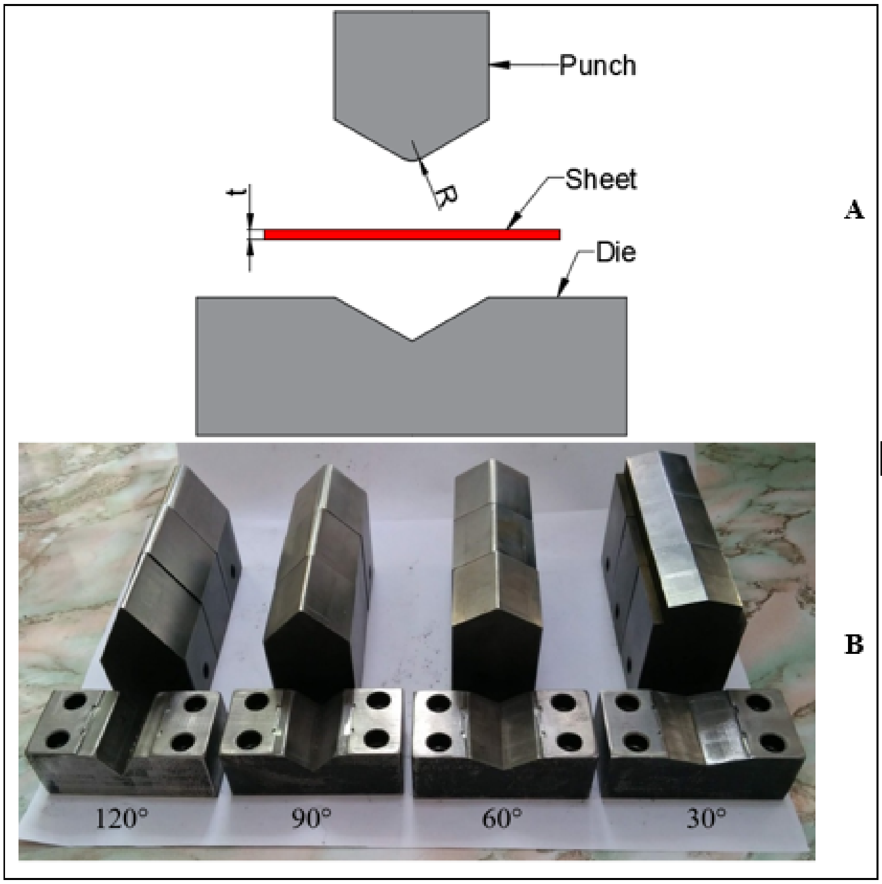

Figure 3

Experimental setup: (A) Experimental setup, (B) Dies used in the experiments.

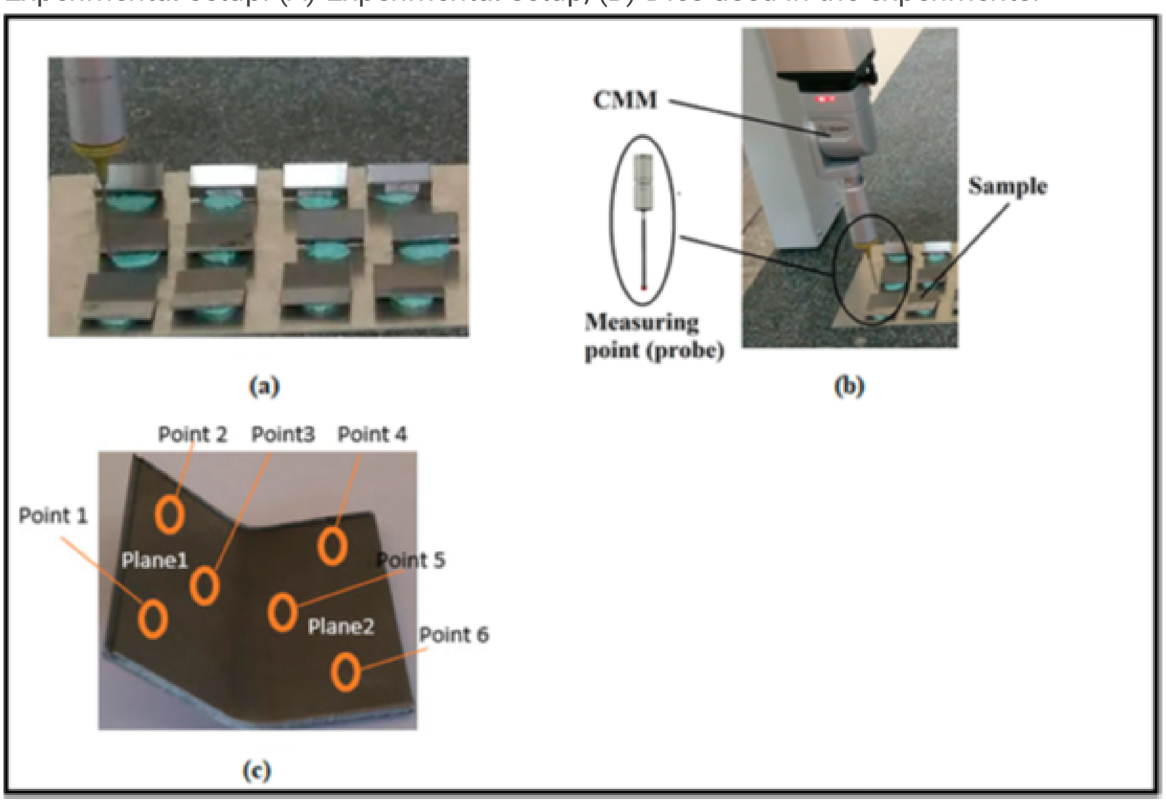

Figure 4

Springback measurement using CMM [18].

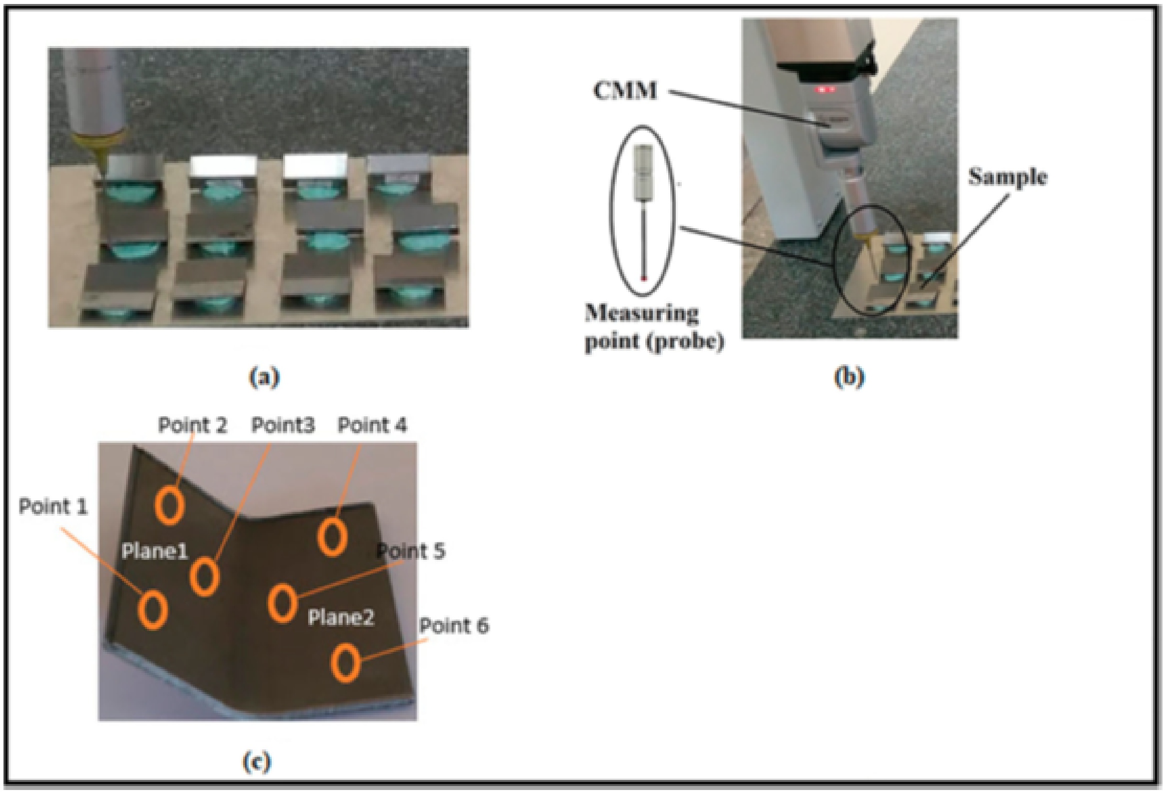

Figure 4

Springback measurement using CMM [18].

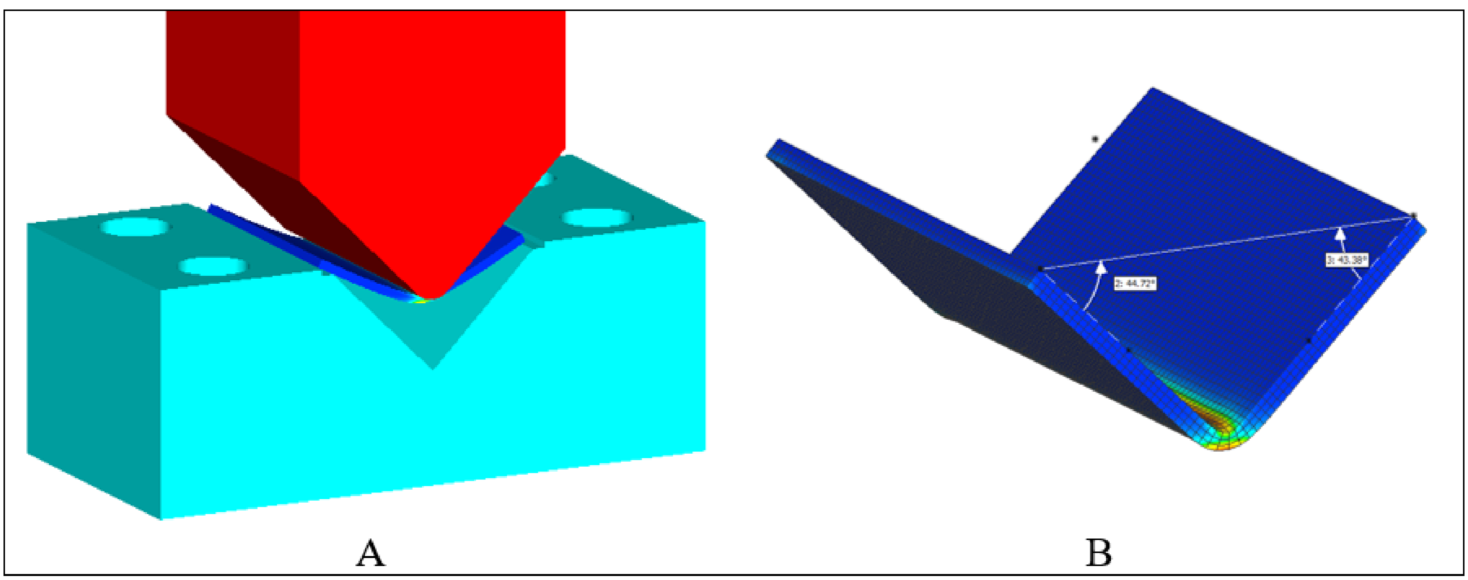

Figure 5

Finite element analysis: (A) Bending simulation process, (B) Measuring springback.

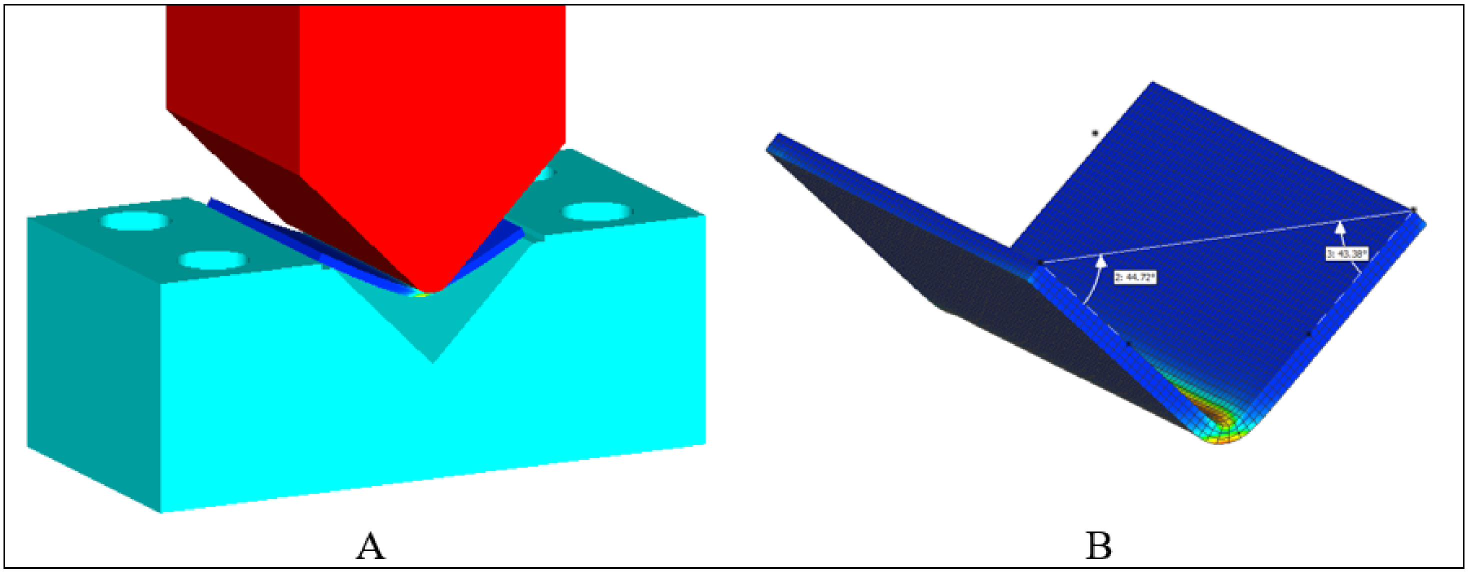

Figure 5

Finite element analysis: (A) Bending simulation process, (B) Measuring springback.

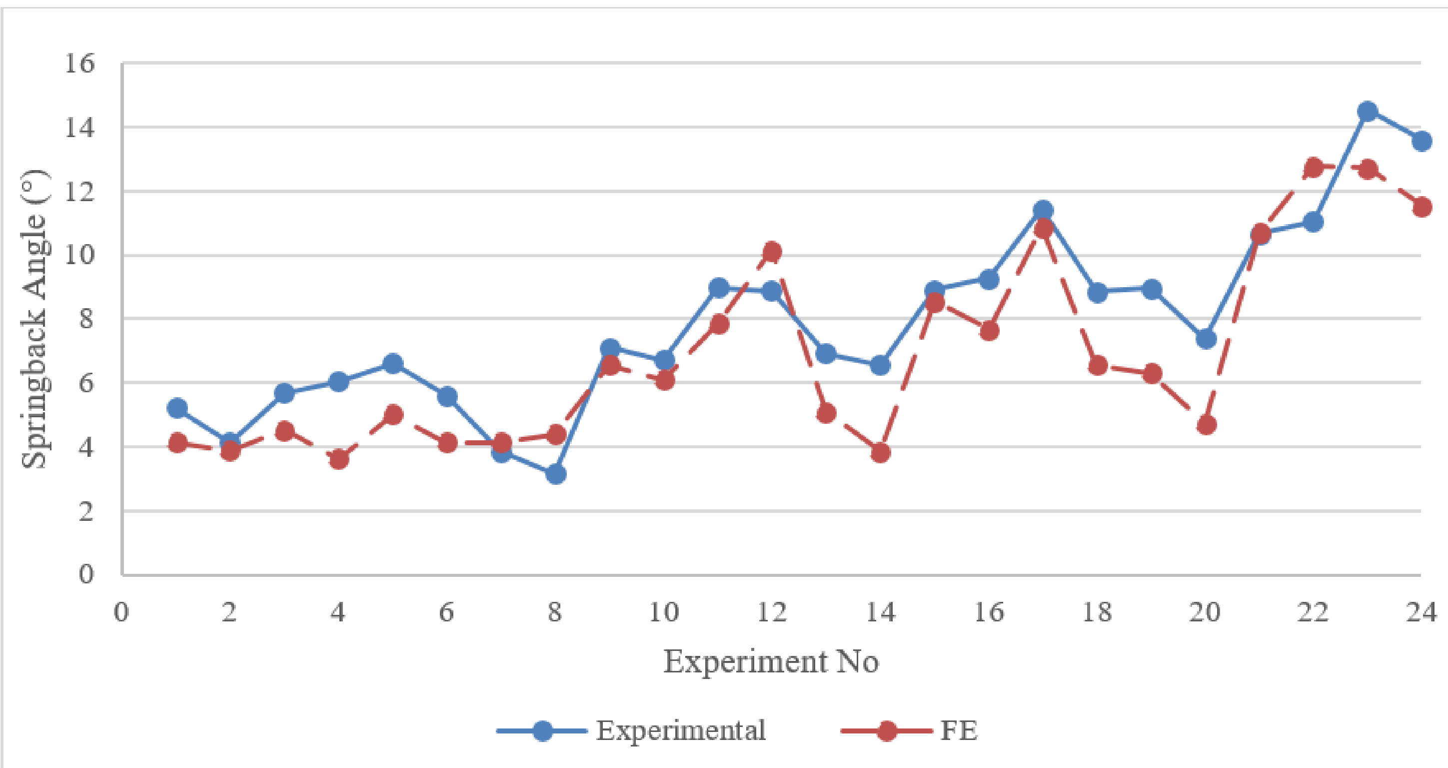

Figure 6

Comparison of the results of experiments conducted at room temperature with FE analysis.

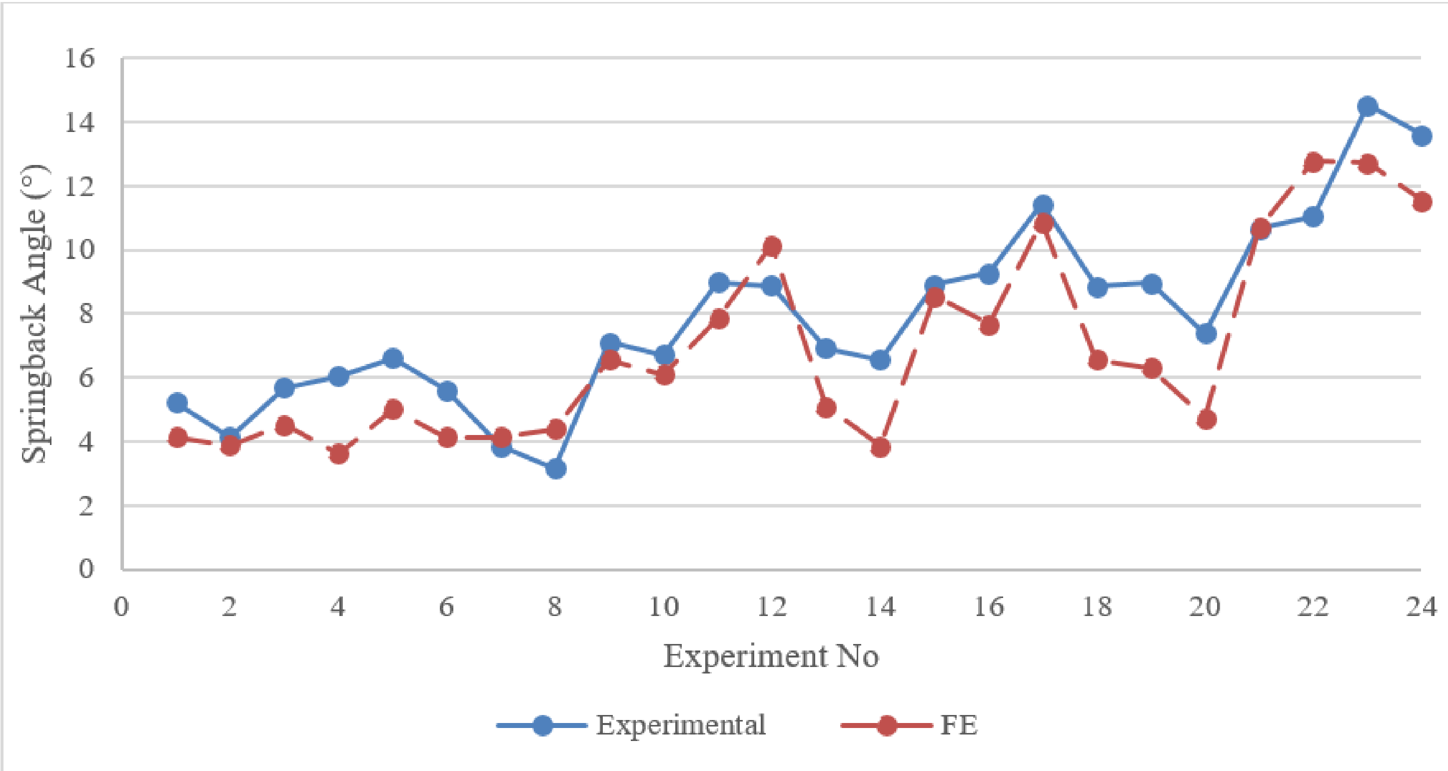

Figure 6

Comparison of the results of experiments conducted at room temperature with FE analysis.

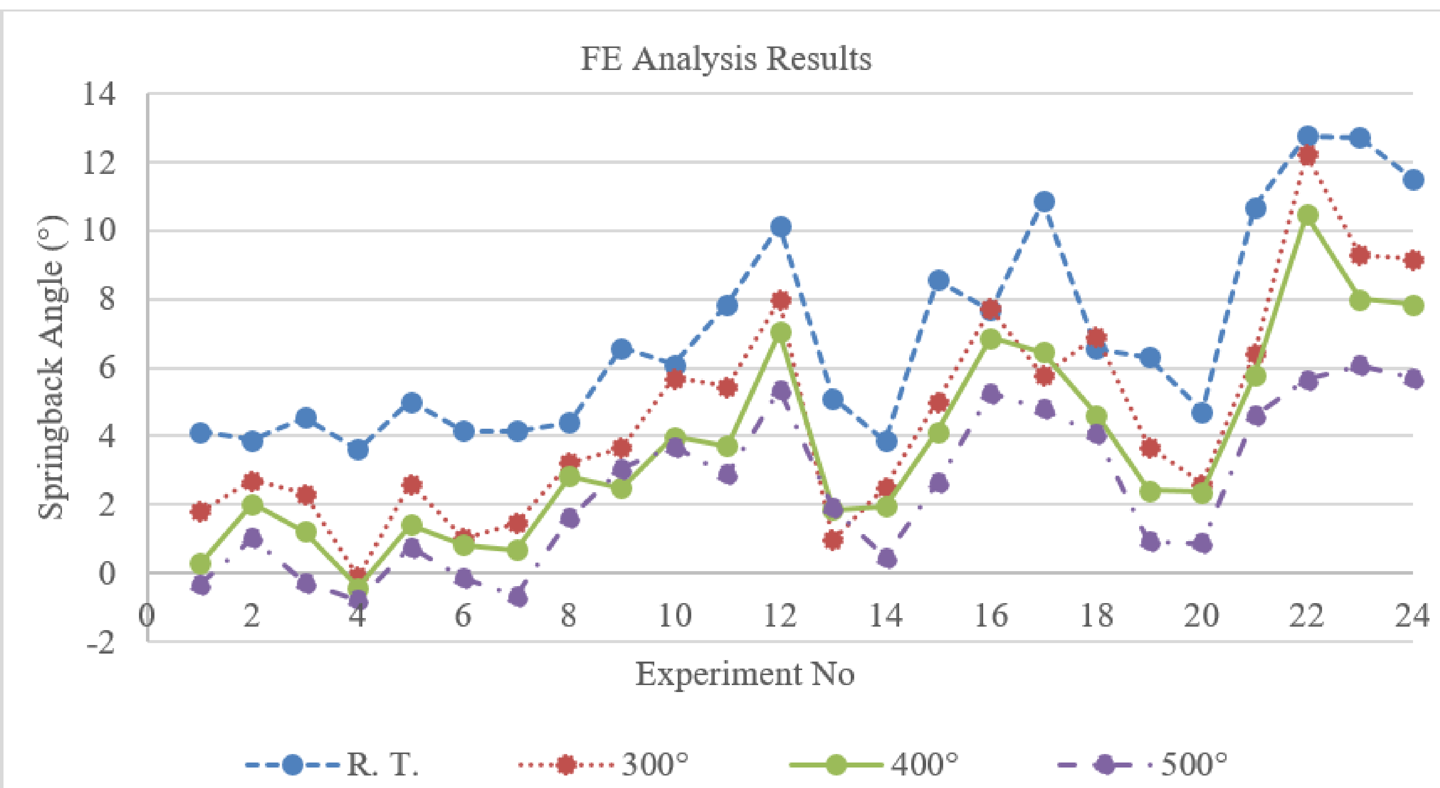

Figure 7

FE analysis results

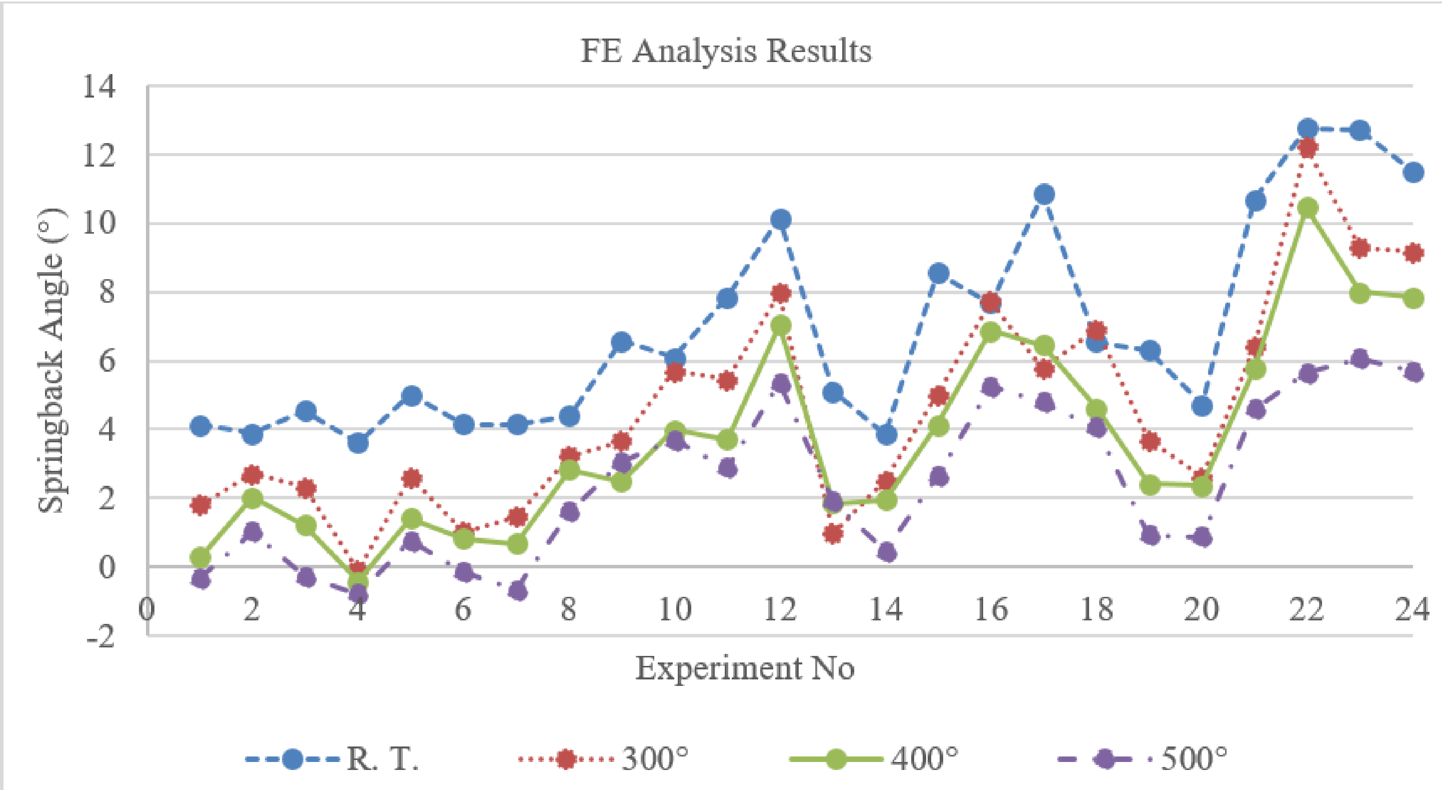

Figure 7

FE analysis results

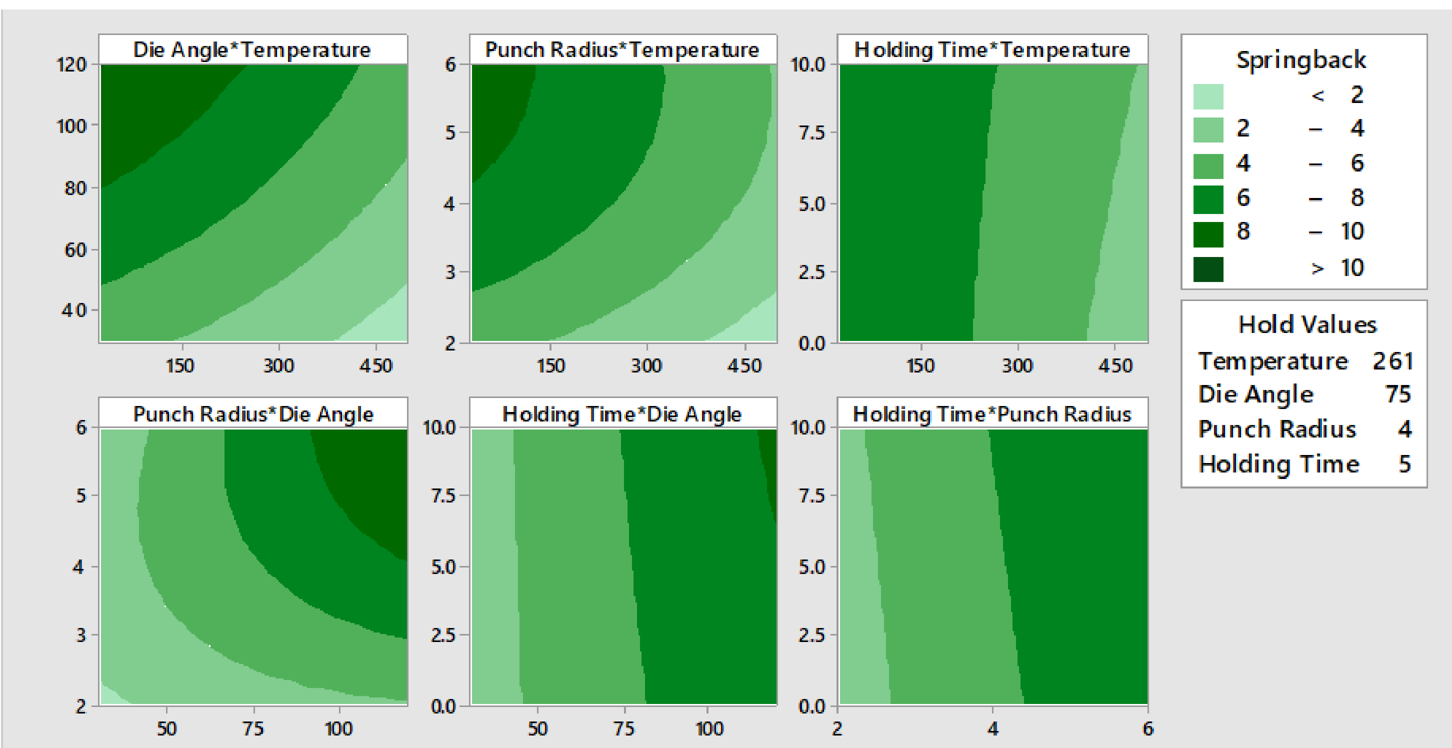

Figure 8

Springback contour plots

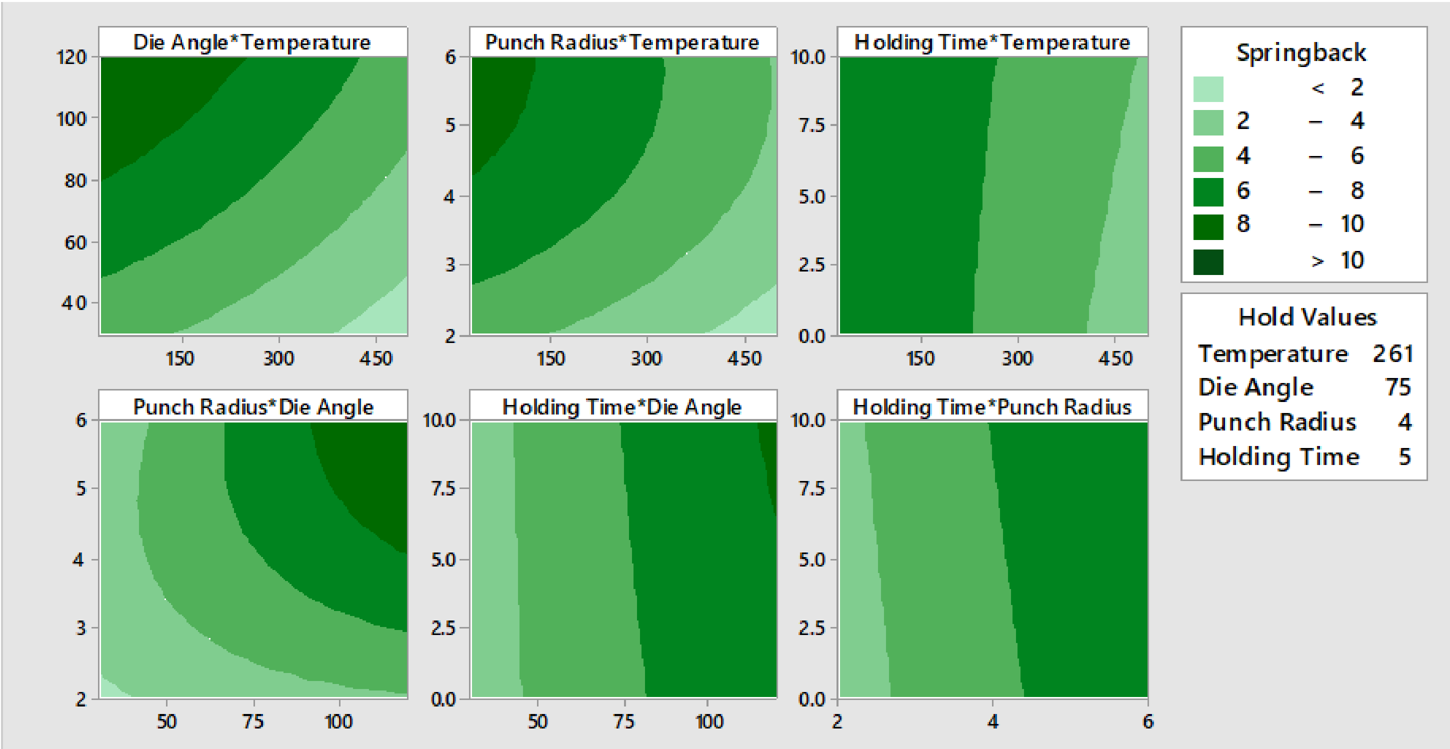

Figure 8

Springback contour plots