International Journal of Engineering & Technology, 7 (4.18) (2018) 166-170

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Effect of Tensile and Material Properties on Springback Behavior of DP590 Advanced High Strength Steel During Bending Process

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Abstract

Bending process has been used widely in many industries such as automotive. It is considered as an important process in sheet metal forming. The use of advanced high strength steels in automotive industry has remarkably increased in recent years. Amongst these advanced steels, dual phase steels (DP) have good formability but at the same time springback behavior of this high strength steels also usually increases, which is unfavorable especially after bending and during the assembly processes. Material properties and process parameters are some of contributing factors of the springback behavior. This paper presents an investigation of the uniaxial tensile deformation in transverse (90^o), diagonal (45^o), and rolling (0^o) directions and the effect of material properties of DP590 on springback behavior in bending process. Air V-bending was used for the springback measurements on DP590 specimens with different rolling direction, which is 90°, 45° and 0 and various process parameter values which are die radius and gap, punch radius, thickness, and punch travel. A deformation speed of 25 mm/min was used in this experiment. Tensile test was performed to obtain the value of tensile properties such as young modulus, yield strength, strain hardening coefficient and strength coefficient by analysis stress-strain curve. By adaptive Design of Experiments (DOE) using full factorial, analysis of variance (ANOVA) techniques and Taguchi Method (TM) was chosen as intelligent sampling method to investigate the significant factors contributing to springback behavior. The experimental data shows that the rolling direction, die gap, thickness, punch travel, die radius and punch radius are significant parameters contributing to the springback behavior in the V-die bending of DP590 at the significance level of 0.05. The result form this experiment could be used in improvement of predict the springback behavior and also to understanding the material properties of AHSS in order to eliminate springback and achieve good final product.

Keywords: *Springback; Advanced High Strength Steel; Air V-bending; Design of Experiment; Material Properties*

1. Introduction

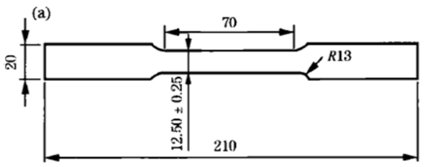
Nowadays, popularity of lightweight material such as Advanced High Strength Steel (AHSS) increases because of their characteristic and mechanical properties. In the automotive industry, demand of lightweight material, especially AHSS increase in order to produce a transport with higher fuel efficiency. Usually, AHSS used to make products such as the car components, body panels of a car, and the part of suspension. Dual phase steel (DP) is one of typical advanced high strength, low carbon steel with hard martensite and soft ferrite. The austenite of DP steel is transformed into martensite and ferrite on cooling when the steels are annealed by holding the strip in the $\alpha+\gamma$ temperature region for a set period of time and then quenched [1].
Dual Phase Steel (DP) is one common lightweight material that's being used in automotive fabrication due to their best feature in physical and material properties compare to High Strength Low Alloy (HSLA). Researches on DP steels have been carried out by many researchers [2,3] due to its high strength as well as high formability. Although AHSS are better in strength, the formability and ductility are lower. Because of that the applications of AHSS become limited in automotive industry due to the problem of springback. Springback is one of major defect that occur when the material has undergoes bending process, where the force bending has been release, the material try to return to original shape due to elastic recovery [4,5]. The parameters affecting springback must be identified to avoid undesired shapes.
Bending is an essential process in sheet metal forming and has been used widely in many industries such automotive. The bending process can be performed in numerous ways. One of frequently used technique is the V-shaped dies since they are simpler and more cost effective to manufacture [6]. Several researchers have reported their findings on the fundamental understanding on springback behavior of sheet metal processed via V-bending. However, trial-and-error methods were still being used to address and establish proper and suitable solution for these elastic distortion problems.
In recent years, springback prediction have been conducted using intelligent sampling method such as finite element analysis (FEA), computer aided design (CAD), Design of Experiment (DOE) and metamodelling techniques are often used in order to improve efficiency. DOE is the important factor to establish accuracy and efficiency of full factor, analysis of variants and Taguchi method. [7]. This paper presents the effect of punch travel, thickness, rolling direction on springback behavior and tensile properties of

DP590 steel sheets by adaptive Design of Experiments (DOE) using intelligent sampling method.

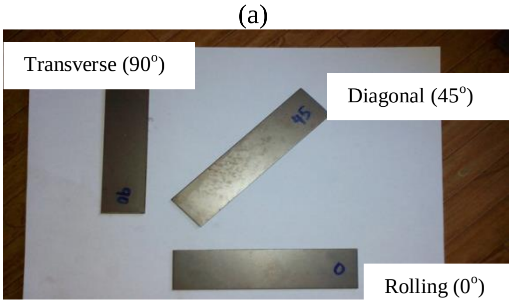
2. Materials and Methods

In this study, the material used is Dual-Phase Steel (DP590), one of steel that categories on Advance High Strength Steel sheets, provided by OSI Sdn. Bhd. To observe the cross section DP590, the microstructure observation has been carried out. The microstructure of DP590 was observed by Scanner Electron Microscope (SEM).

The size of specimens for tensile test is 200mm×25mm× thickness based on three rolling direction 0, 45° and 90°. The total is 5 specimens each rolling direction and it will be 15 specimens for each thickness 1 mm and 2 mm. The total specimen is 30 specimens. The dogbone was created based on ASTM 370 (Designation E 8M-04) in metric scale using CNC Milling Machine [9]. The specimens will undergo tensile test using Universal Testing System model INSTRON with a maximum capacity of 100 kN at 1.25 mm/min speed. Specimens for tensile and bending were prepared from the sheets. Fig. 1 shows the geometries of the tensile test and bending test samples.



(a)



(b)

Fig. 1: (a) Specimen geometry for ASTM E8 tensile test, and (b) bending test

For bending test, two thicknesses were used; 1 mm and 2 mm. DP590 steel was cut based on rolling direction 0, 45° and 90°. The specimen size of P590 for bending test was 130mm×30mm×1mm and 2 mm thickness as per requirement. Hydraulic shear cutting machine was used to cut the material and the edges were cleaned to remove the burrs.

Two-level experimental design matrix and full factorial design (2^k) were chosen and applied for five predetermined process parameters. The two-level values, 2^6 full factorial design or 64 runs of the specimen were initiated for all parameters' combinations. The springback value is the process response for this experimental design matrix. ANOVA method was also implemented to demonstrate the degree of significance of each process parameter affecting springback in the air V-bending process. Five process parameters were predetermined in this experiment; the die radius, *Rd*; punch radius, *Rp;* die gap, *Wd*; punch velocity, *Vp*; and punch travel, *Tp* within the low and high levels as displayed in Table 1. Rolling direction, *R* is not considered as a factor in DOE.

The statistical p value was used to determine significance level of each parameters. The p value used in this experiment is at the 0.05 significance level or 95% confidence level. The p value smaller than 0.05 indicates that the power level has a statistically significant effect on the responses [8].

Table 1: Parameter of V-Bending Process and their respective level DOE

Process parameter	Level	
	Low (-)	High (+)
Die radius (mm)	5	8
Punch Radius (mm)	8	12.5
Die Gap (mm)	50	70
Punch Velocity (mm/min)	27	45
Punch Travel (mm)	12	18
Thickness (mm)	1	2

3. Results and Discussion

Microstructure of DP590 observed under scanning electron microscope in shown in Fig. 2. The figure shows that DP590 steel consists of a ferrite (bright grey) and a hard martensite (dark) at the second phase in the form of islands. The composition ferrite is high that the composition of martensite. The existence of martensite at the second phase in DP590 steel will give the high strength of material while the soft ferrite will give DP590 steel excellent ductility. The function of ferrites also gives material to deform while martensite functions as reinforcement structure to DP590 structure.

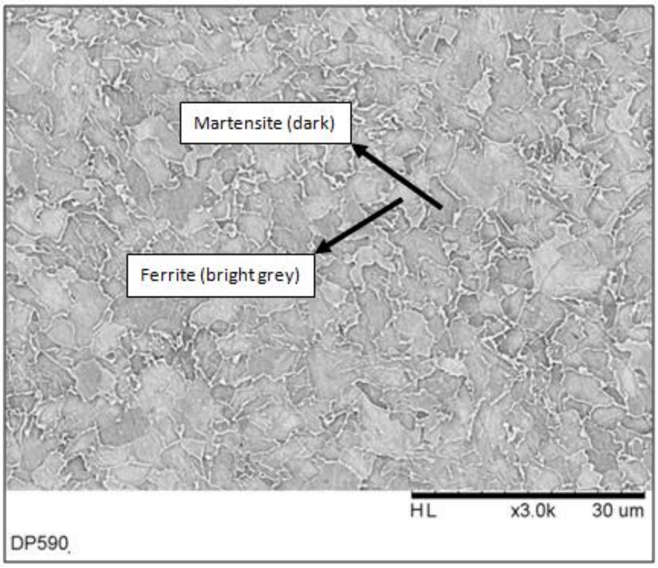


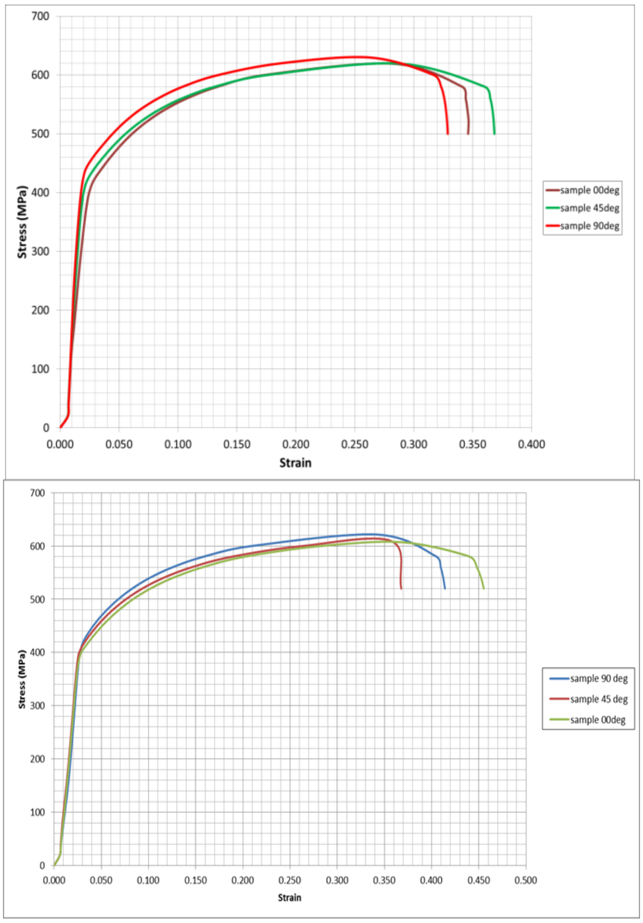
Fig. 2: Microstructure DP590 using Scanning Electron Microscope.

Tensile test was performed on DP590 steel sheet to determine the materials properties and the graph is plotted as stress *vs* strain as shown in Fig. 3 (a) for 1 mm and (b) for 2 mm thickness. The materials uniaxial tensile elongation increases with increasing of thickness of the materials for all direction. The behaviors in rolling direction and transverse directions were also different quantitatively from in the diagonal direction. The value of strains in diagonal direction at various thicknesses is 0.370. But at the true stress stage the values of stress in all direction was not different.

Fig. 4 shows the effect of thickness to springback behaviour. The result indicates that the greater the thickness of material the angle of springback will decrease. The highest value at springback angle was observed to be in transverse, diagonal, and rolling directions, respectively.

The material yield strength was also determined at various thicknesses and is shown in Fig. 5. Yield strength for 1 mm thickness is 422.45 MPa and for 2 mm thickness the value of yield strength are 415.32 MPa. From the graph springback vs. yield strength we can conclude that, when the value of yield strength greater the angle springback will increased due to increase the point where plastic stage begin. When yield strength greater, that mean the point where plastic flow begin became increased. So when the plastic behaviour greater, the springback behaviour also became greater.

(a) 1 mm



(b) 2 mm

Fig. 3: Stress vs strain curve of DP590 at various thicknesses; (a) 1 mm and (b) 2 mm in different direction

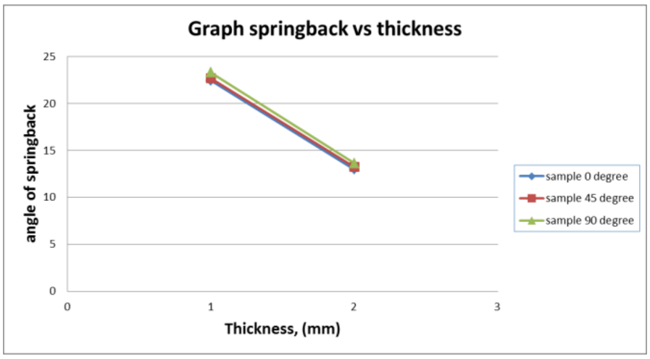


Fig. 4: Springback angle *vs* thickness

Fig. 6 shows the effect of strain hardening coefficient, n to springback phenomenon. Based on literature, the range of strain hardening coefficient, n between 0 to 1, and the value of 0 is for the perfectly plastic solid material while value of 1 is for completely elastic materials. The result shows the springback angle value is reduce with increasing number of n. When the material has more elastic behaviour the springback is lowered but when the material has more plastic behaviour the springback became greater. Table 2 summarizes mechanical properties data for different thickness. The data shows that material direction has strong correlation with the material behavior.

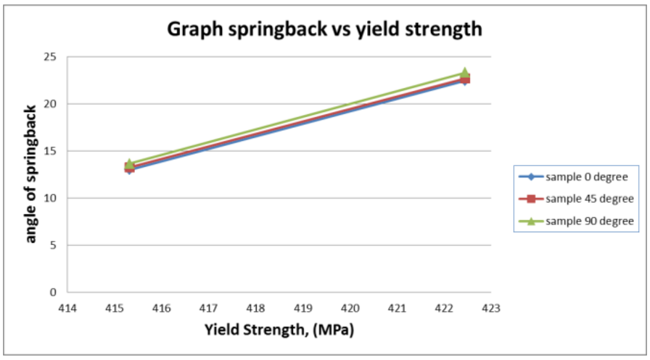


Fig. 5: Springback angle *vs* yield strength

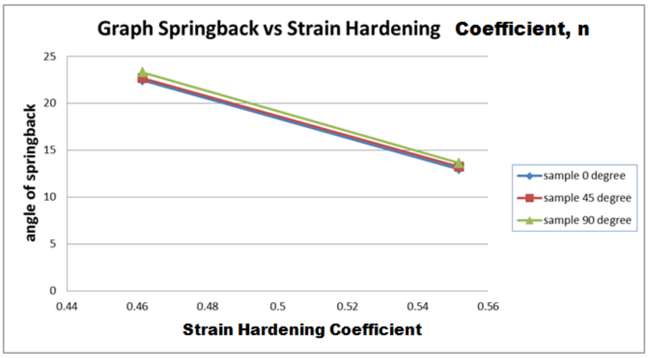


Fig. 6: Springback angle *vs* strain hardening coefficient, (n)

Table 2: Summary of material properties for DP590

Tensile Properties	Thickness value (1 mm)	Thickness value (2 mm)
Yield Strength, $\boldsymbol{\sigma_y}$	422.45 MPa	415.32 MPa
Ultimate Strength, $\boldsymbol{\sigma_{uts}}$	621.92 MPa	611.59 MPa
Strain Hardening Coefficient, n	0.4615	0.5517
Strength Coefficient, K	1347.15 MPa	1691.95 MPa
Young Modulus, E	156.64 GPa	202.97 GPa

Based on the intelligent sampling method via DOE, the prediction of springback can be carried out with a short time to improve accuracy in end product. The springback is calculated as the difference between the bent angle after the removal load and during loading. The amount of springback could be calculated based on springback angle, $\Delta\theta$, using the following equation:

$$\Delta\theta = \theta_i - \theta_f \tag{1}$$

where θ_i is the angle during loading while θ_f is the angle after unloading.

Full Factorial Method: Factorial design was used in this study to find the most significant parameter that give effect the springback. MINITAB 16 software was used to analyse the data and systematically examine the process parameters that influence springback. Table 3 shows part of results from experimental design matrix data. The coefficients and *p* values of springback analysis from the design of experiment with full factorial are displayed in Table 4. Punch radius, die radius, die gap, punch travel and thickness are identified as parameters that strongly affect springback with respective *p* values of 0.000, 0.021, 0.000, 0.000 and 0.003. Another parameter, punch velocity with *p* value of 0.466 is identified as insignificant.

Table 3. Part of experimental results and design matrix of the responses. a=punch radius, mm, b=die radius, mm, c=die gap, mm, d=punch travel, mm, e=punch velocity, mm/min, f=thickness, mm and g=springback angle, $\Delta\theta$.

No.	a	b	c	d	e	f	g
1	8	5	50	12	27	2	4.26
2	12.5	5	50	12	27	2	5.16
3	8	8	50	12	27	2	5.06
4	12.5	8	50	12	27	2	5.18

5	8	5	70	12	27	2	4.32
6	12.5	5	70	12	27	2	5.22
7	8	8	70	12	27	2	5.31
8	12.5	8	70	12	27	2	5.75
9	8	5	50	18	45	1	5.17
10	12.5	5	50	18	45	1	6.50
11	8	8	50	18	45	1	6.54
12	12.5	8	50	18	45	1	6.85
13	8	5	70	18	45	1	5.54
14	12.5	5	70	18	45	1	5.60
15	8	8	70	18	45	1	5.13
16	12.5	8	70	18	45	1	5.49

Table 4. Estimated springback effects and coefficients.

Term	Effect	Coefficient	Term	*p value*
Constant		5.5554	72.99	0.000
Punch Radius	0.7592	0.3796	4.99	0.000
Die Radius	0.3746	0.1873	2.46	0.021
Die Gap	-0.6458	-0.3229	-4.24	0.000
Punch Travel	0.9374	0.4687	6.16	0.000
Punch Velocity	-0.1191	-0.0595	-0.75	0.466
Thickness	-0.4974	-0.2487	-3.27	0.003

Fig. 7 shows the significant effect for each parameter evaluated by percentage of plot standardized plot effect to springback. It shows that radius, die radius, die gap, punch travel and thickness are significant parameters affecting springback. However, another parameter, punch velocity is identified as not significant.

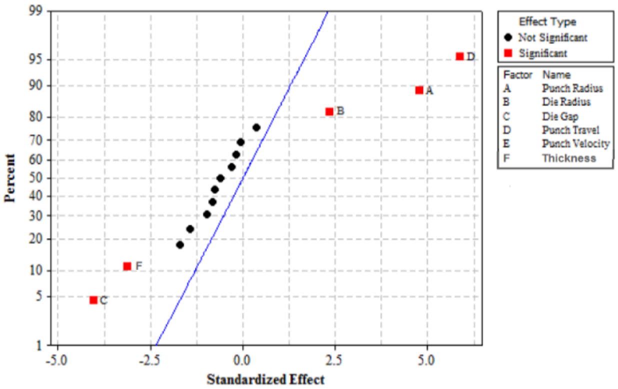


Fig. 7: Parameters that affecting springback for experiment

Taguchi Method: Taguchi design is used to find the ranking of the parameters that affect the springback. Plot for S/N ratio, smaller-is-better main effect of each parameter to springback is shown in Fig. 8. Positive effect indicates that springback increases as the factor changes from low to high levels while negative effect indicates that a reduction in springback occurs from high to low level for the same parameters [10]. Punch travel was identified as parameter which has the big effect on springback angle as compared to others. Fig. 8 shows that the total mean of S/N ratio of -9 dB was calculated and shows as a straight line at the middle on the graphs. The main effects signify deviations of the average between the high and low levels for each factor. The effects of punch travel, punch and die radius factors are positive, which indicates an increase of springback is observed when the factor changes from low to high.

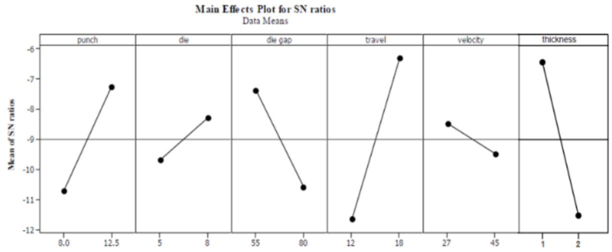


Fig. 8: Main effects plot for the influenced parameters to springback.

Table 5. ANOVA and response result for S/N ratio.

Factors	Deg. Of Freedom	Sum of Seq	Mean of Seq	*F*	*P*	Contribution %	Mean S/N ratio (dB)		
Punch radius *(Rp)*	1	47.84	47.84	6.11	0.033	16.35	Level 1 -	Level 2 +	Rank
Die radius *(Rd)*	1	7.84	7.84	1	0.041	2.68	-10.72*	-7.26	3
Die gap *(Wd)*	1	41.30	41.30	5.27	0.045	14.12	-9.69*	-8.29	5
Travel *(Tp)*	1	113.23	113.23	14.46	0.003	38.71	-7.38	-10.60*	4
Velocity *(Vp)*	1	4.00	4.00	0.51	0.491	1.37	-11.65*	-6.33	1
Thickness (T)	1	78.30	78.30	3.73	0.004		-8.49 24.27	-9.49*	6
Residual Error	10	7.31	7.31			2.5	-11.21	-6.79*	2
Total	16	292.50				100			

*Optimum level

Without considering for rolling direction, ANOVA result as well as response for S/N ratio smaller-is-better is shown in Table 5. The model presents the contribution of thickness of the material, punch radius and radius, die width, as well as punch velocity and travel to springback is 97.5 % of the total variation from 2.5 % residual error. It shows that punch travel factor is statistically significant as factors affecting springback with *p*-value is less than 0.05 (0.003), followed by thickness, punch radius, die gap and die radius factors (respective *p*-value of 0.004, 0.033, 0.045 and 0.041). Punch velocity is proven to be not significant factor with *p*-value of 0.491. Furthermore, the punch travel is shown to give higher contribution percentage of 38.71 % which specifies the parameter is highly significant in affecting springback. A small variation will have a great influence on the performance of factor with high contribution percentage. The order of strong parameters affecting springback is as follows: punch travel, *Tp* (38.71%), thickness, T (24.27%), punch radius, *Rp* (16.35%), die gap, *Wd* (14.12%), die radius, *Rd* (2.68%) and lastly punch velocity, *Vp* (1.37%). These results clarify that the DOE intelligent system and experiment design method for V-bending in cool forming can create an optimum springback prediction for the parameters. The result from experimental support the effectiveness of Design of Experiments (DOE) based on full factorial, analysis of variance (ANOVA) techniques and Taguchi Method (TM) as intelligent sampling method to investigate the factors are significant on springback effect for DP590 steel sheets.

4. Conclusion

In this research, the effect of air V bending in cool forming process on mechanical properties and microstructure of DP590 steels was investigated. The "right the first time" design is critical to ensure short leading time and product quality. The results showed that DP590 steels obtained mostly after annealed and quenched process so that the austenite is transformed into microstructure martensite and the ferrite on cooling. It was also concluded that:

1. The material showed complex behaviors for different directions and thickness. The higher the thickness of material will cause the springback reduce.
2. The higher the yield strength the springback will increase due to increase the point where plastic stage begins. When yield strength greater that mean the point where plastic flow begin became increased. So, when the plastic behaviour greater the springback behaviour also became greater.
3. The strain hardening coefficient increased, the springback will reduce due increased the elastic behaviour.
4. Regarding the practical V bending scenarios with various specifications and tensile properties, the validity and the efficiency of the Design of Experiments (DOE) system as intelligent sampling method is verified. Also, the extendibility analyses prove that the system have good maintainable and adaptive advantages with a high degree of flexibility and efficiency

Acknowledgement

The authors would like to thank Universiti Teknologi MARA (UiTM) for financial support [project grant no: 600-irmi/perdana 5/3 mitra (003/2018))-2]. A special thank is addressed to Oriental Summit Industries Sdn. Bhd. Shah Alam, Selangor for the permission and cooperation in this study, and to Mr Azlan and Mr Zukri for their assistance.

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