Optimization of Springback in V- Bending at Elevated Temperatures Using Taguchi Approach

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Abstract

In recent decades the high demands of Dual-Phase (DP) brass find wide applications in electrical, electronic and other appliance industries. Therefore, study of material characterisation and springback behaviour are essential in forming of sheet metal components. In the present work, an isothermal uniaxial tensile test was performed to evaluate the accurate mechanical properties, which are essential pre-requisite for optimization of process parameters to decrease and minimize spring-back for any sheet-metal-forming operations. The V-bending test was conducted at specified test parameters temperature (773 K, 873 K, and 973 K), punch velocity (1 mm/min, 5 mm/min, and 10 mm/min), holding-time (30 s, 60 s, and 90 s) and orientation (0^0, 45^0, and 90^0) concerning rolling direction. Taguchi approach was utilized to optimize the test parameters such as temperature, punch velocity, holding-time, and orientation. The optimal set of parameters obtained were Temperature (973 K), Punch Velocity (1 mm/min), Holding-Time (90 sec) & orientation (90°) and using these optimal set of parameters a confirmation test has been conducted and it was reported that the spring-back was decreased significantly in V-bending process for dual phase (DP) brass sheet. The main objective of the study is to investigate the springback behaviour in V-bending process on brass sheets to understand the formability and to optimise the processes parameter to minimize the springback effect using Taguchi Technique to meet the needs of the sheet metal forming processes.

Keywords
Sheet Metal Forming (SMF) Operations; Dual Phase (DP) Brass Sheet; and tensile test.

1. Introduction

Dual-phase (DP) Brass is made of zinc and copper, in which Zn content plays a crucial role to result in better properties such as tensile strength, workability, corrosion resistance to specified conditions, and wear resistance. Dual Phase (DP) Brass has huge applications in industries such as electrical, automobile, aerospace, nuclear, and home appliances (Alie Wube Dametew et al. 2002). Under bending, the bent section is subjected to bending moment and causes slight plastic deformation around the bent section only. The plastic deformation behavior depends on mechanical properties. Elastic recovery after forming operations is termed spring-back. Spring-back is nothing but geometrical discrepancy (shape and dimension deviation). The amount of spring-back coefficient depends on the geometrical parameters, material parameters, process parameters, and technological parameters which cover sheet thickness, orientation, tooling geometry, state of friction, lubrication condition, forming velocity, and temperature of the die, etc. (Anggono, et al. 2012). The influence of friction coefficient on spring-back value was reported (Aysha Alhammadi et al. 2018). Upon forming spring-back will present always and cannot be eliminated but can be minimized by reducing elastic recovery of sheet metal with the help of suitable die design, and optimal setting of process parameters (Bakhshi-Jooybari et al. 2009). To produce the parts with quality and economy, it is very important to take the spring-back into account and understand the bending mechanics to evaluate the spring-back and bending forces accurately (Gautam et al. 2016). Deviation of shape and size upon forming the components causes rejection and hence it becomes essential to understand the spring-back phenomenon of the sheet metal components (Badrish et al. 2020). For the right understanding of the spring-back behavior of the material in sheet metal forming, experiments are necessary tools though they are expensive and time taking. Different experimental tests were performed to investigate the spring-back of sheet metals including U-bending (Dametew et al. 2002), and V-bending (Badrish et al. 2020). Under the hot forming condition, formability increases, and spring-back decreases (Nikhare et al. 2021). Bending is an easy and majorly used sheet-metal forming process for manufacturing lightweight and high-strength components. An important aspect of straight-line bending is that metal deforms plastically in the bend region and not in the region away from the bend. To produce sound sheet metal components, the evolution of the spring-back phenomenon and minimizing it is most crucial and important (USLU et al. 2016). Taken the test variables like work metal thickness, die-opening, and radius of punch for titanium sheet metal (grade-2) as per the $L_9 3^3$ OA, presented that thickness of work metal was a highly significant factor over the spring-back (Karaağaç et al. 2019). Studied the influence of test variables such as holding-time & punch-radius on spring-back and spring-forward at a particular range of temperature (300 K - 1123 K) of a titanium alloy (Ti–6Al–4 V) under V-bending. Implemented analysis of variance (ANOVA) for V-bending operation of aluminum (A1100) to predict the influence of radius of punch, sheet metal thickness, and bend angle on spring-forward & spring-back. Reported anisotropic effect on spring-back, it displays spring-back increases as an increase in anisotropy of sheet metal upon forming (Ramadass et al. 2019).

2. Literature Review

Badrish, et al. (2020) found the optimisation of springback in V-bending at different temperatures, deformation speeds on Inconel 625 alloy with experimentation and FE analysis method. Taguchi approach was implemented to determine springback by considering four different parameters. By utilising S/N ration and ANOVA optimal set of parameters have been obtained. Validated the experimental data with data obtained from FE analysis. Badrish, et al. (2020) conducted experimental and finite element studies of springback using split-ring test for Inconel 625 at different temperatures and deformation rates. The Sellar's constitutive model along with Barlat'89 yield criteria was implemented in order to obtain best numerical results. Nikhare, et al. (2021) examined the effect of presence of discontinuity on punch as well as die side on the Origami-based sheet metal. It was also noticed that the material discontinuity on die side reports lower springback than the case with material discontinuity on punch side for sample A and B where the width at material discontinuity is higher. Karaağaç, et al. (2019) investigated the effect of local heating temperature and bending parameters on the formability and springback in the V-bending of galvanized DP600 sheet material. The experiment was carried out at different temperatures, die angle and holding time. It was noticed that there were radical changes in springback angles and formability due to the martensite changes in the microstructure of the material. The effect of process parameters such as elevated temperature, punch speed and holding time on Ti-6Al-4V alloy to obtain minimum springback by implementing the FE simulation and experiments. In this work, essential process parameters such as temperature, holding time and punch speed are considered in order to study the effect of spring back in a V bending process on Ti-6Al-4V alloy. FE simulations have been carried out using ABAQUS/CAE software. The input material properties for performing FE simulations have been taken from the conducted uniaxial tensile tests. For validation of FE simulations, V bending experiments have also been conducted at room temperature and 700°C. The results reveal that the temperature has a major influence in reducing the spring back effect. Therefore, high temperature and punch speed would be an excellent combination for reducing spring back in a V bending process on Ti-6Al-4V alloy. Alie Wube Dametew, et al. (2002) stated that in bending, bent portion undergoes plastic deformation under the action of the bending moment and this deformation behaviour depends on the material characteristics such as young's modulus, yield stress, the ratio of yield stress to ultimate tensile stress, and microstructure. It influenced with geometrical parameters, material parameters, process parameters, and technological parameters which include sheet thickness, orientation, tooling geometry, friction condition, lubrication condition, forming speed, die temperature, etc. Ramadass, et al. (2019) selected the sheet thickness, die opening, and punch radius as the process parameters for titanium grade 2 material and, based on Taguchi (L9) orthogonal array, reported the sheet thickness to be the most influential parameter on springback. Zong, et al. (2015) investigated a titanium alloy (Ti–6Al–4 V) in the V-bending process by understanding the effect of holding time and punch radius over spring-go (forward) and springback effects within different temperature ranges (RT to 850 °C). Thipprakamas et al. (2011) computed ANOVA and Taguchi analysis in the V-bending process of aluminum (A1100) for studying the effect of punch radius, material thickness, and bending angle on spring-go and springback. Dharam Singh et al. (2021, 2022) reported that flow stress behavior is very much influenced by warm forming temperature conditions. All the factors were summarised and displayed in an Ishikawa diagram (cause and effect diagram) reported in Figure 1.

After extensive literature analysis, it was observed that a lot of research was carried out on study of spring-back phenomenon for conventional sheet materials like titanium, steel, and aluminum. Anyhow, no substantial efforts have been made to know the characterization of material properties and spring-back phenomenon of dual phase (DP) brass under hot forming condition. In the present work, experimental investigation of Springback in V-bending and optimization of test variables at Elevated Temperature Conditions have been carried out by the Taguchi approach ($L_{27}3^4$ OA). Four factors (temperature, punch velocity, holding time, orientation) and three levels are selected. To find the significance level of individual parameters over spring-back, an ANOVA analysis was carried out.

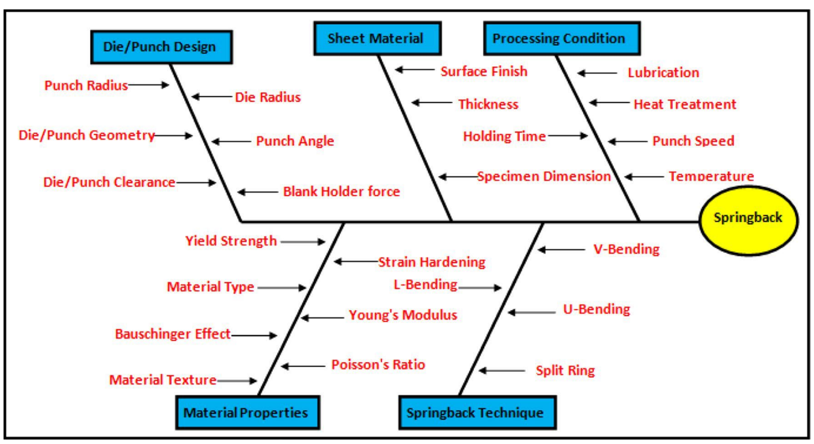


Figure 1. Ishikawa diagram (Cause-and-effect diagram) for spring-back behavior

3. Materials and Methods

3.1 Material Composition

A list of chemical elements which are present in the dual phase (DP) brass was reported in Table 1 as below.

Table 1. Chemical composition of Brass sheet metal

Element	Zn	Pb	Fe	Cu	IMP
% in wt	Bal	0.292	0.1	64.305	0.6

3.2 Microstructure

The microstructure of the parent dual phase (DP) brass sheet was evaluated according to standards of ASTM E3-95. The figure 2 shown below, reveals that microstructure consists of alpha and beta matrices.

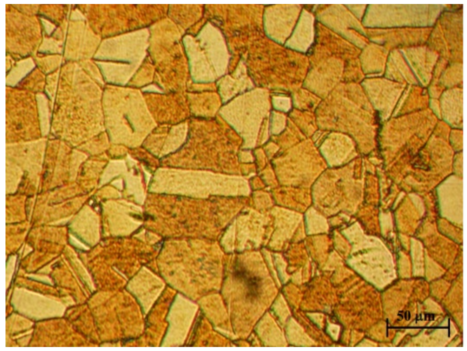


Figure 2. Initial Microstructure of parent Brass sheet meta

4. Experimental Details

4.1. Tensile Test

The dual-phase (DP) brass was cold-rolled to 1 mm thickness and uniaxial tensile test specimens were prepared according to the sub-sized ASTM E08/E8M-11, by using wire cut EDM (30 mm gauge length, 21 mm width, and 1 mm thickness) as depicted in Figure 3(a). figure 3(b) represents the orientation with respect to rolling direction. Uniaxial isothermal tensile tests have been conducted at a temperature of (773 K, 873 K, and 973 K) under a constant quasi-static strain rate of (0.1, 0.01, and $0.001 s^{-1}$) with different sheet orientations (0^0, 45^0, and 90^0) concerning rolling direction. To carry out the tension test, 50 KN capacity BISS Electra Servo Electric, computer-controlled UTM was utilized under very low straining conditions. The furnace split into two zones, the heating capacity of 1000 ºC with an accuracy of ± 3 °C, set of three thermocouples was regulated the temperature of the sample. Mechanical properties were evaluated experimentally. The experimental set up was presented in figure 4. The mechanical properties determined from experiment was reported in Table 2.

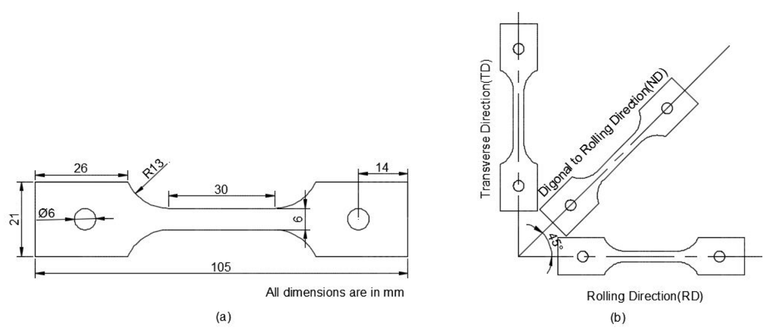


Figure 3. (a) standard test specimen according to sub-sized ASTM E08/E8M-11 and (b) various sheet orientations w.r.t. rolling direction

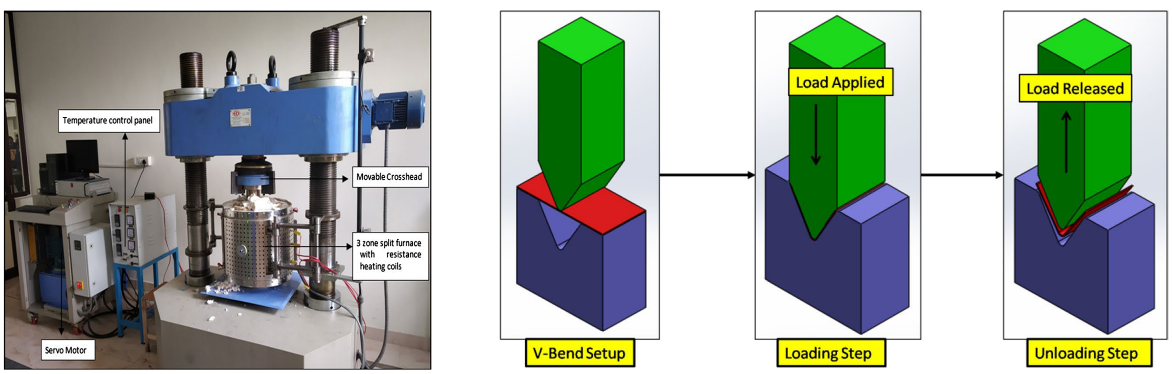
Figure 4. Uniaxial Tensile Test Machine

Table.2 Mean mechanical properties of dual phase (DP) Brass sheet

Temperature	Orientation	YS (MPa)	UTS (MPa)	% Elongation
773K	0º	125	134	43
	45º	118	124	39
	90º	115	121	36
873K	0º	65	74	47
	45º	61	65	43
	90º	58	64	30
973 K	0º	34	39	52
	45º	31	36	48
	90º	29	34	38

4.2. V-Bending Test

The experimental estimation of spring-back of dual phase (DP) brass sheet metal in V-bending operation has been conducted on a 100 KN compression testing rig. The experimental setup consists of a suitable punch and dies arrangement with a 3 mm punch radius and 60° angle of the nose. The test was performed at a constant temperature condition. The specimens of rectangular strips of 80 × 40 mm of 1 mm thickness were taken for V-bending. The formulated orthogonal array L_{27} (3^4) having three levels and four test variables was selected to run the experiment as shown in Table 3. The test was carried out on three specimens for each set of test factors and the mean spring-back value was presented for the study. The experimental setup of the V-bending process was depicted in Figure 5 (a). The applied load was through punch, over a specified amount of holding-time and then unloaded, upon releasing the punch load, the sheet tries to regain its original shape. These steps in the V-bending operation were presented in figure 5(b).



(a) (b)

Figure. 5 (a). Compression testing rig utilized for V-bending. (b). Schematic diagram of the V-bending process

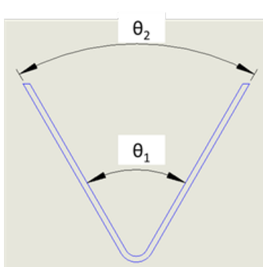


Figure 6. Springback angle calculation

$$\theta' = \frac{(\theta 1 + \theta 2)}{2} \quad (1)$$

The phenomenon of spring-back plays a very important role in SMF operations. The selected test variables (temperature, punch velocity, holding-time, and orientation) for analysis of spring-back value. The mean angle of the V-bend in every sample was estimated by Figure. 6 and Equation 1, where θ_1 and θ_2 represented the angles of the inner and outer face of the V-bended sheet. The mean angle was calculated from three different samples taken for each set of process parameters is depicted in Table 4.

5. Results and Discussion

5.1 Analysis of Taguchi Technique (Selection of Factors and Levels)

Table 3. Levels and Control factors

Level / **Parameter**	Level 1	Level 2	Level 3
Temperature	773 K	873 K	973 K
Punch Velocity	1 mm/min	5 mm/min	10 mm/min
Holding-time	30 sec	60 sec	90 sec
Orientation	0^o	45^o	90^o

5.2 Design of Orthogonal Array for the outcome (spring-back and S/N ration)

Table 4. Formulation of L_{27} (3^4) orthogonal array for Springback angle and S/N ratio

Experiment Number	Temperature (K)	Punch Velocity (mm/min)	Holding-Time (sec)	Orientation (^{0})	Springback	S/N Ratio
1	773	1	30	0^0	65.43	-36.45
2	773	1	60	45^0	64.54	-36.15
3	773	1	90	90^0	63.85	-36.82
4	773	5	30	45^0	65.10	-36.75
5	773	5	60	90^0	63.58	-36.63
6	773	5	90	0^0	63.42	-36.23
7	773	10	30	90^0	64.82	-36.94
8	773	10	60	0^0	64.24	-36.44
9	773	10	90	45^0	63.01	-36.04
10	873	1	30	0^0	62.13	-36.61
11	873	1	60	45^0	62.08	-36.91
12	873	1	90	90^0	61.26	-36.00
13	873	5	30	45^0	63.21	-36.62
14	873	5	60	90^0	62.47	-36.50
15	873	5	90	0^0	61.98	-36.50
16	873	10	30	90^0	62.47	-36.21
17	873	10	60	0^0	62.67	-36.80
18	873	10	90	45^0	63.54	-36.21
19	973	1	30	0^0	61.99	-35.19

20	973	1	60	45^0	61.47	-35.19
21	973	1	90	90^0	61.34	-35.77
22	973	5	30	45^0	61.21	-35.49
23	973	5	60	90^0	61.99	-35.18
24	973	5	90	0^0	61.80	-35.08
25	973	10	30	90^0	61.50	-35.58
26	973	10	60	0^0	61.61	-35.48
27	973	10	90	45^0	61.52	-35.18

5.3 Finding Optimization and Contribution of Process Parameters

Table 5. Analysis of Variance for TPM (Average Spring-back)

Source	Seq.SS	P-Value	Contribution %
Temperature	86.056	0.028	75.01
Punch Velocity	02.040	0.652	1.93
Holding-Time	16.024	0.007	12.04
Orientation	12.962	0.008	10.02
Total	117.082	-	100

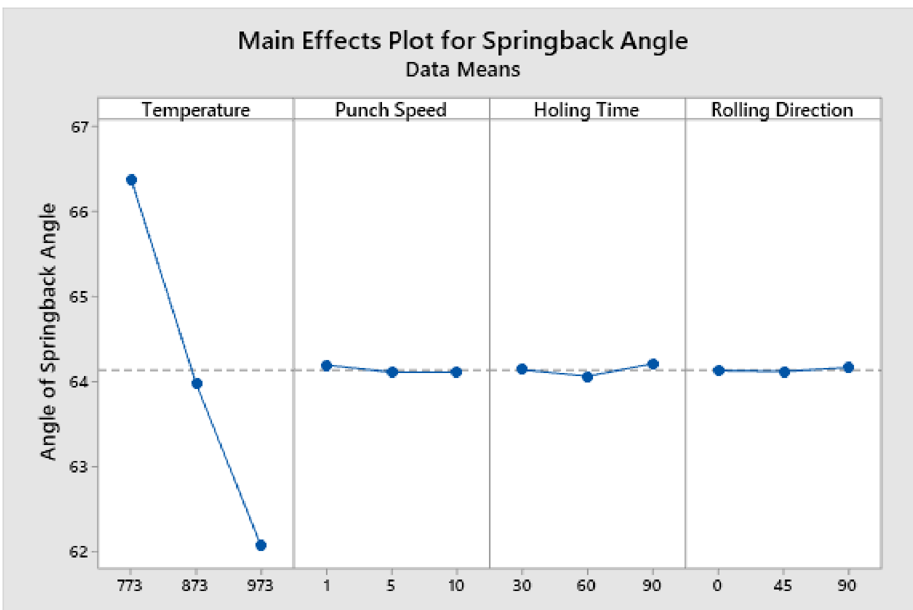


Figure 7. Main effect plot for the average angle of spring-back

Analysis of the Taguchi approach was performed using two metrics, specifically Target Performance Measure (TPM) and Noise Performance Measure (NPM). NPM provides the basis for choosing the right set of test variables that minimizes variability in most expected outcomes. Analysis of the S/N ratio accounts for the NPM. Average results are frequently accounted for in to study of the TPM. Average outputs were the average of all the metrics that have been taken into account (now it is taken as three) for a set of parameters. The governing factors of NPM indicate the variation of test factors and governing factors of TPM indicate target test factors. The mean spring-back values were presented in Table 5.

ANOVA is a statistical approach, mainly considered to distinguish the performance and significance of chosen individual test parameters over the desired output (in the present case it is spring-back in the v-bending process of dual phase (DP) brass sheet). It implies a quantitative index for differentiation (percentage of contribution) for individual test factors to find the most significant factor over the spring-back phenomenon. Table. 6 presents the ANOVA by TPM analysis. TPM analysis reported that the hot temperature has the largest contribution to the reduction of spring-back to minimum value followed by holding-time, orientation, and punch speed for dual phase (DP) brass. Dual-phase (DP) brass becomes ductile as forming temperature increases, resulting the good formability which simply retains the given form without any difficulty. From Figure. 7, it was noticed that spring-back decreases with the rise of temperature and holding-time. Sheet orientation also has a significant contribution over the spring-back effect, and varies with orientation w.r.t rolling-direction. The highest spring-back value was obtained when punch and grain-orientation is at 45° followed by 0° and 90°. The present study reveals that punch speed has a minimum and negligible effect on spring-back.

Table.7 represents the ranking of test factors based on the level of contribution, which minimizes the effect of spring-back. From the response Table 8, it was clear that a greatly significant factor was the temperature in minimizing spring-back followed by holding-time, sheet-orientation and punch-speed. The confidence level taken for analysis of *p*-value is 0.05 (5%).

Table 6. Analysis of TPM

	Temperature	Punch Velocity	Holding-Time	Orientation
Level 1	7.38	5.20	5.68	5.10
Level 2	4.98	5.12	5.14	5.57
Level 3	3.07	5.12	4.62	4.77
Delta	4.31	0.08	1.06	0.80
Rank	1	4	2	3

Table 7. NPM by ANOVA

Source	Seq.SS	P-Value	Contribution %
Temperature	193.217	0.012	49.98
Punch velocity	12.971	0.977	1.63
Holding-Time	109.131	0.011	25.36
Orientation	99.089	0.076	23.02
Total	414.651	-	100

NPM analysis from ANOVA gives that the temperature, holding-time, and orientation display more effect on the maximization of the S/N ratio when compared with punch-speed. On the basis of delta ranking was done to test factors that aid in the rise of the S/N ratio, depicted in Table 8. Therefore, temperature displays the highest effect followed by holding-time, orientation, and punch velocity from NPM analysis.

Table 8. Response of NPM

	Temperature	Punch Velocity	Holding-Time	Orientation
Level 1	-36.94	-36.51	-36.12	-36.31
Level 2	-36.21	-36.31	-36.41	-36.02
Level 3	-35.68	-36.31	-36.70	-36.90
Delta	1.26	0.20	0.62	0.61
Rank	1	4	2	3

Analysis of S/N ratios was carried out based on the 'smaller is better' with MINITAB software as the target is to minimize the spring-back [21]. The S/N ratios are estimated by Equations 2 and 3. After finding the S/N ratio for every run, it was noticed that run 21 (temperature = 973 K, punch velocity = 1 mm/min, holding-time = 90 s, and orientation = 90°) have the greater S/N ratio as presented in Table 4. Hence Now it was selected optimum set of process parameters that minimizes spring-back in the v-bending process. Confirmation tests have been conducted for validation. From the Table 9 it was observed that punch velocity has been pooled out without loss of accuracty of prediction.

$$\frac{S}{N} = -10 \text{ X } \log_{10} (y^{-2}) \tag{2}$$

$$\bar{y} = \sum_{i=1}^{n} \frac{y_i}{n} \tag{3}$$

Table 9. The optimum level of each test factors

Process Parameter	TPM		NPM		Factor effect (TPM or NPM)
	% Contribution	Pooled	% Contribution	Pooled	
Temperature	80.12	No	50.12	No	Both
Punch velocity	1.63	Yes	1.61	Yes	Neither
Holding-Time	10.01	No	25.13	No	Both
Orientation	8.24	No	23.14	No	Both

Table.10 Optimum settings for each test factor

Process Parameter	TPM		NPM		Selected Level	Actual Value
	Level	% Contribution	Level	% Contribution		
Temperature	3	80.12	3	50.12	3	973 K
Punch velocity	1	1.63	3	1.61	1	1 mm/min
Holding-Time	3	10.01	3	25.13	3	90 sec
Orientation	3	8.24	3	23.14	3	90^0

Deferent test factors have been taken to conduct a confirmation test that displays a reduction in the spring-back phenomenon. From the analysis of either NPM or TPM, if a test variable doesn't pool then those factors taken to have a dominant influence in minimizing spring-back (such as temperature, holding-time, and orientation) as presented in Table.10. The optimal setting of test factors reported as temperature = 973 K, punch velocity = 1 mm/min, holding-time = 90 s & orientation = 90°. Validation tests have been conducted to verify the test results(spring-back) which was displayed in Table. 11. The optimal set factors resulting in the spring-back phenomenon were decreased to around 72.68%.

Table. 11 Confirmation test results for V-bending

Run	Die angle, θi	Springback angle θf	$\Delta\theta = \theta f—\theta i$	Mean $\Delta\theta$
Iteration 1	60°	61.05°	1.05°	1.06°
Iteration 2		61.11°	1.11°	
Iteration 3		61.03°	1.02°	

6. Conclusion

The main conclusions reported from the present study are:

- The mechanical properties of the dual phase (DP) brass sheet are considerably affected by the test temperature, strain-rate, and rolling direction. It is observed that the yield strength and ultimate strength of dual phase (DP) brass sheet decreases with an increase in test temperature.

- Analysis of the Taguchi approach (L_{27} 3^4) was considered for optimization of test factors to minimize the spring-back phenomenon of dual phase (DP) brass thin sheet material upon v-bending. From the study of ANOVA, *S/N* ratio, & confirmation test over the spring-back, it was concluded that temperature was a highly significant factor followed by holding-time, orientation, and punch velocity. Optimal setting of test factors were temperature = 973 K, punch velocity = 1 mm/min, holding-time = 90 sec, & orientation = 90°. With these optimal set parameters, the spring-back effect was decreased to around 72.68%.

- It was reported that Springback is inversely proportional to test temperature and holding-time but directly proportional to the punch velocity. The relationship associated with orientation and spring-back angle was not distinct but is observed that spring-back is highest at 45° and then followed by 0° & 90°.

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