Nano World Journal

https://doi.org/10.17756/nwj.2023-s4-040

Research Article

Open Access

Optimization of Process Parameters in V-bending of Sheet Metals Using Taguchi Method

Virajitha Ganipisetty[1], Srivalli Kanthi Kommaraju[1], Pranavi Uppu[1], Thejasree Pasupuleti[2], Manikandan Natarajan[2], Venkateshwar Reddy Pathapalli[1*] and Anand Gujarati[3]

[1]*Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad, Telangana, India*

[2]*Department of Mechanical Engineering, School of Engineering, Mohan Babu University, Tirupati, Andhra Pradesh, India*

[3]*Department of Mechanical Engineering, RK University, Rajkot, Gujarat, India*

[*]Correspondence to:
Venkateshwar Reddy Pathapalli
Department of Mechanical Engineering,
Vardhaman College of Engineering,
Hyderabad, Telangana, India.
E-mail: mr.pvreddy@gmail.com

Received: September 15, 2023
Accepted: November 23, 2023
Published: November 28, 2023

Citation: Ganipisetty V, Kommaraju SK, Uppu P, Pasupuleti T, Natarajan M, et al. 2023. Optimization of Process Parameters in V-bending of Sheet Metals Using Taguchi Method. *NanoWorld J* 9(S4): S234-S239.

Copyright: © 2023 Ganipisetty et al. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY) (http://creativecommons.org/licenses/by/4.0/) which permits commercial use, including reproduction, adaptation, and distribution of the article provided the original author and source are credited.

Published by United Scientific Group

Abstract

The purpose of this experimental study is to examine the springback effect in sheet metal forming processes. The study focuses on the impact of changing process factors on the springback phenomena, including material thickness and tooling geometry. A universal testing machine (UTM) and different sheet metal samples of various thicknesses are used in the trials. Bevel protractor is used to measure the final form and the degree of springback. Present work focuses on the application of Taguchi-method for the optimization of responses in V-bending process. Three different materials and forming parameters have been considered as process parameters. The objective is to optimize the responses: punch force, and springback angle. From analysis of variance (ANOVA), the statistical significance of parameters as well as determining the most influencing parameter among the three considered parameters for sound formability is found out. The findings demonstrate that a variety of parameters, particularly sheet thickness and material, have an impact on the springback effect. Moreover, the research shows that altering the forming conditions and tooling geometry can significantly lessen the springback impact. The results of this study can aid in the creation of more precise and effective sheet metal forming procedures with less springback and forming conditions.

Keywords

Springback, Forming, Sheet metal, V-bending, Optimization

Introduction

The technique of creating thin metal sheets into a variety of intricate shapes and forms is known as sheet metal forming. Manufacturing of automobile parts, electrical enclosures, home appliances, and aerospace components all often employ sheet metal forming [1]. In sheet metal forming, a flat metal sheet is used to create the finished shape. With plastic formation, the desired shape is obtained without the need of machining techniques [2, 3]. As a sheet of metal is formed, a phenomenon known as "springback" takes place as the material attempts to regain its previous shape after undergoing plastic deformation [4]. A substantial issue for precise manufacturing might arise if the finished dimensions of the product alter as a result of this. As a metal sheet is bent, it contracts on the inner side of the curve while stretching on the outside side. As a substance is crushed, it thickens while a material is stretched, they both get thinner. The material strives to regain its initial shape when the external force is released, which might cause the component to spring back and produce a final shape that is not the desired shape [5, 6].

The kind of material being produced, the bending angle, the thickness of the material, and the applied force are some of the variables that might affect the spring back effect [7, 8].

For a precise prediction of springback, researchers found that the Bauschinger effect, which is characterized by yearly re-yielding during reverse deformation, should be taken into account [9]. Large-strain cyclic plasticity has been experimentally examined by a number of researchers [10], while additional research on reverse deformation following plastic deformation has been published [11, 12]. To anticipate spring back analytically, Yi et al. [13] developed a model based on differential strains computed for six possible deformation patterns after release from the maximum bending stress. The effects of punch profile radius and localized compression on springback in V-bending of high strength steel were examined by Gautham et al. [14] using the Taguchi technique. The investigation's goal was to carry out an experimental test to determine how punch corner radii affected springback during free V-bending operations. Localized compressive stresses on bend curvature were employed to account for springback by adding localized compressive pressures between the punch and the die. For the purpose of bending high-strength sheet metal with thicknesses of 0.85, 1.15, and 1.55 mm, "V"-shaped dies and punches of six numbers with the requisite tolerances were manufactured with a 90° included angle.

Wang et al. [15] used a force-displacement, split-control, multi-point forming approach to research the more common springback of the sail surface. The thickness, forming force, and curvature of the plate were studied numerically using the ANSYS software. Depending on the degree of springback in two distinct curvature directions, different sail surface and radius parameters have variable impacts. After the development of the sail surface, the two springback sail surfaces of the two sail forms interact. As a result, the quantity of springback with a small radius of curvature is significantly influenced by the springback in the direction with a huge radius. As plate thickness rose, the large-radius curve's orientation saw an increase in forming force. Zhang [16] applied theoretical analysis, computational modeling, and verification by experiment to investigate the springback compensation of elaborately curved surfaces in multi-point forming and to propose a springback compensation technique. A complex curved surface with the right form was produced by computing the springback compensation surface. This method showed strong predictive outcomes and was used to correctly manufacture curved objects. Additionally, there is a tonne of practical use for this method.

The springback problem is typically resolved using one of two methods [12]. One of the methods is removing the die after forming. The other method is by replacing it with the reaction force at contact, then performing repetitive calculations until the contact force is zero, or by allowing the die to move in the opposite direction after forming until the punch is fully released. The second method is more efficient and has a wider variety of uses since, unlike the first, it can also compute the trimming springback. Both methods yield results that are nearly equivalent. Yang et al. [17] use of adaptive control of springback in free bending blends process test techniques and general theoretical prediction. Real-time measurement of the curve produced by the force due to bending and displacement of punch at the part's final bend was a crucial component of their technology. This strategy almost eliminates the dispersion of material attributes by adding process testing into the production process. By doing this, the error prediction by the springback was brought on by material dispersion attributes is substantially eliminated. It has recently been successful to analyze sheet metal springback issues and multi-point forming processes using artificial neural network techniques. By researching springback control of components, Jamli and Farid [18] application of neural network theory to sheet metal forming reduced the susceptibility process of the material variables and friction status. The Springback is impacted by a number of factors during the sheet metal forming process. A neural network might be able to handle the complexity of the finite element analysis. Plate anisotropy was taken into account in Liu et al. [19] research was on prediction of multi-point shaping springback method for a double-curved workpiece. Elghawail et al. [20] explained a special method for figuring out and managing the springback in influence on the workpieces, when doing multi-point shaping.

Only a relatively small number of earlier works have optimisation of forming parameters in sheet metal V-bending as their main emphasis. Therefore, the current work's goal is to optimise the forming parameters while also taking different sheet metals into account. The present work focuses on the application of Taguchi-method for the optimization of responses in V-bending process. Three different material and forming parameters have been considered as the process parameters. The objective is to optimize the responses: punch force, and springback angle.

Experimentation

Materials

The current investigation employed strips with a 1 mm thickness constructed of AA 6061, brass, and mild steel. The chemical makeup and mechanical characteristics of AA6061, brass, and mild steel are shown in table 1 and table 2, respectively. Tools constructed of EN31 include punches and dies with various configurations, and their 3D models are seen in figure 1 and figure 2, respectively. The bending process took place at the UTM. The constructed experimental setup, which had been knurled was secured into the top jaw of the UTM and the die was placed on the lower jaw, is attached to the UTM as shown in figure 3. To prevent any clearance issues or unequal bending, the die and punch were positioned precisely so that they fit together. The sheet metal strip is then measured and positioned precisely in the horizontal center of the die. When the punch is loaded, the sheet metal begins to bend at different angles into the die with the appropriate punches.

The authors considered three different bending angles in order to conduct the experiment i.e., 45°, 50° and 60°. The experiment's design also takes into account the strips'

Table 1: Chemical composition of the sheet materials [21-23].

Element	Amount (wt.%)		
	AA6061	Brass	Mild steel
Aluminum	96.85	0.03	-
Magnesium	0.9	-	-
Silicon	0.7	-	0.007
Iron	0.6	0.1	99.68
Copper	0.3	56.7	-
Chromium	0.25	-	0.043
Sulphur	-	-	0.014
Phosphorus	-	0.02	0.009
Zinc	0.2	39.85	-
Lead	-	3	-
Titanium	0.1	-	-
Tin	-	0.02	-
Manganese	0.05	-	0.196
Nickel	-	0.08	0.013
Molybdenum	-	-	0.015
Carbon	-	-	0.017
Others	0.05	-	-

Table 2: Mechanical properties of sheet materials [24, 25].

Sheet material	Yield stress (MPa)	Youngs modulus (GPa)	Density (kg/m^3)	Poisson's ratio
AA6061	235	69	2700	0.33
Brass	280	127	8670	0.32
Mild steel	140	193	7840	0.27

thickness and breadth of the sheet metal. To conduct the bending operation, three distinct widths 35 mm, 50 mm, and 60 mm along with 1 mm thickness areused in the present. Later, the angle of the sheet metalis measured using a bevel protractor within few seconds to obtain the value of springback. Load applied on the sheet metal to bend is noted from the UTM.

Design of experiments using Taguchi

Taguchi experimental designs are widely used in manufacturing industry to study the effect of process parameters with minimum number of experiments. Orthogonal arrays are employed for design of experiments. In the present work, material, die angle and sheet width are considered as process parameters. Each of the parameters is considered with three levels. The design should be balanced and orthogonal in order to estimate the most significant parameter impacts. For various parameter-level combinations, Taguchi has set up a few orthogonal arrays that meet the aforementioned criteria [26, 27]. The suitable orthogonal arrays, which satisfies the required degree of freedom, is L_9 (3^3). Thus, the experiments are conducted as per L_9 orthogonal array as shown in table 3, with uncoded levels of parameters. Experimentation is conducted setting the row conditions of table 3, and values of the response variables are computed and noted down.

Results and Discussion

By improving the process parameters, the primary goal

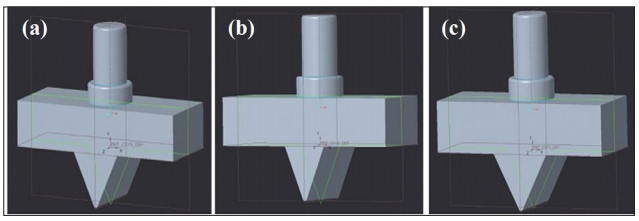


Figure 1: 3D modeled punches of **(a)** 45 degrees, **(b)** 50 degrees, and **(c)** 60 degrees.

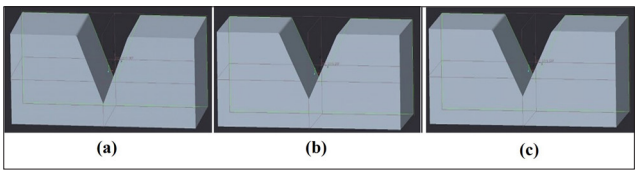


Figure 2: 3D modeled dies of **(a)** 45 degrees, **(b)** 50 degrees, and **(c)** 60 degrees.

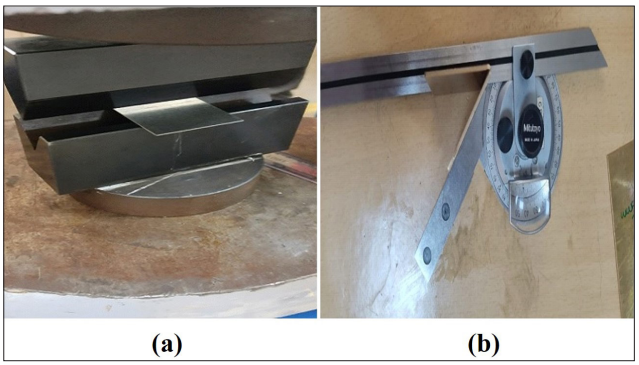


Figure 3: Experimental process and the angle measurement.

of this study is to decrease the punching force and elastic force in the V-bending process. Following the measurement of the elastic angle, figure 4 depicts the plate's deformation image.

Effect of forming parameters on springback

Figure 5 illustrates how process factors affect springback. With a percentage of 67.8%, sheet material is seen to have a significant impact on spring back, followed by sheet width with a percentage of 33.3% and die angle with a percentage of 1.68%. The springback is seen to be greatest for AA6061, next brass, and then mild steel. With a reduction in sheet width, the springback rises. The springback is observed to

Table 3: Considered parameters and their responses.

Test No.	M	DA	SW	Spring back angle	Bending force
1	AA6061 (1)	45	35	5.0	74
2	AA6061 (1)	50	50	4.5	68
3	AA6061 (1)	60	60	4.5	62
4	Brass (2)	45	50	4.0	78
5	Brass (2)	50	60	3.5	72
6	Brass (2)	60	35	4.5	80
7	Mild steel (3)	45	60	3.0	82
8	Mild steel (3)	50	35	3.9	88
9	Mild steel (3)	60	50	3.5	79

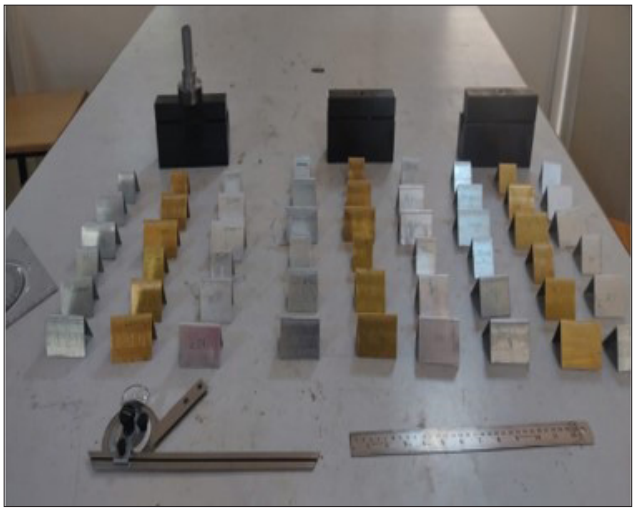


Figure 4: Deformed samples after forming the sheet metal.

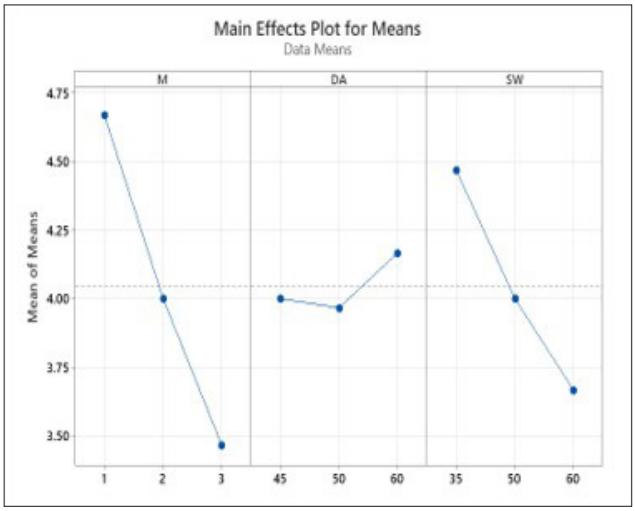


Figure 5: Spring back parametric affect plot.

be less for die angle 50°, when compared to 45° and 60°. The amount of springback that occurs when a sheet metal part is formed depends on the material properties, sheet thickness, tooling geometry, and bending process. In general, materials with a higher yield strength will exhibit more springback, while materials with a lower yield strength will exhibit less springback.

Table 4 presents ANOVA of springback. Table 5 shows the reaction for the mean of means on springback, and it can be seen that the sheet material and sheet width have the most effects on springback, with die angle having a much less impact.

ANOVA of springback

Springeback angle = $6.148 - 0.6000M + 0.01238DA - 0.03193SW$ (1)

Effect of forming parameters on punch force

Figure 6 illustrates how process factors affect punch force. With a percentage of 70.1%, sheet material is seen to have a significant impact on punch force, followed by sheet

Table 4: ANOVA of spring back.

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	3	3.18219	1.06073	88.34	0.000
M	1	2.16000	2.16000	179.90	0.000
DA	1	0.05365	0.05365	4.47	0.088
SW	1	0.96854	0.96854	80.67	0.000
Error	5	0.06003	0.01201		
Total	8	3.24222			
Model Summary					
S	**R^2**	**R^2 (adj)**	**R^2 (pred)**		
0.109575	98.15%	97.04%	93.64%		

Table 5: Response table for means of spring back.

Level	M	DA	SW
1	4.667	4.000	4.467
2	4.000	3.967	4.000
3	3.467	4.167	3.667
Delta	1.200	0.200	0.800
Rank	1	3	2

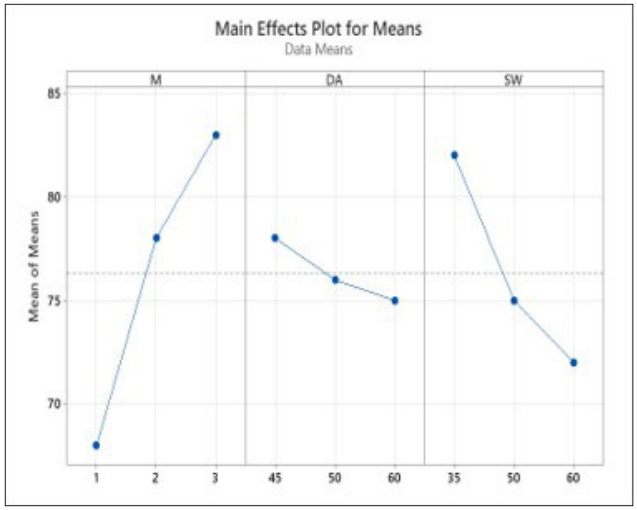


Figure 6: Punch force parametric affect plot.

width (24%), and die angle (5.74%). Punch power is seen to be greatest for mild steel, next brass, and then AA6061. The punch force is increasing with increasing sheet width. The punch force is observed to be less for die angle 60°, when compared to 45° and 50°. The amount of punch force required for the sheet metal part to form depends on the material properties, sheet thickness, tooling geometry, and bending process. In general, materials with a higher strength will require more punch force, while materials with a lower yield strength will require less punch force. Table 6 presents ANOVA of punch force.

ANOVA for punch force

Punch force = 92.28 + 7.500M – 0.2810DA – 0.3491SW (2)

The response for the mean of means on punch force is shown in table 7, and it is evident that sheet material and sheet width have the biggest impact, with die angle having a considerably smaller impact.

Table 6: ANOVA of punch force.

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	3	480.919	160.306	100.57	0.000
M	1	337.500	337.500	211.74	0.000
DA	1	27.627	27.627	17.33	0.009
SW	1	115.792	115.792	72.65	0.000
Error	5	7.970	1.594		
Total	8	488.889			
Model Summary					
S	**R^2**	**R^2 (adj)**	**R^2 (pred)**		
1.26250	98.37%	97.39%	93.59%		

Table 7: Response table for means for punch force.

Level	M	DA	SW
1	68.00	78.00	82.00
2	78.00	76.00	75.00
3	83.00	75.00	72.00
Delta	15.00	3.00	10.00
Rank	1	3	2

Table 8: Comparison of predicted and experimental values of both the responses.

Response	Sheet material	Die angle	Sheet width	Experimental	Predicted	Error %
Spring back	3	50	60	3.5	3.0	3
Punch force	1	60	60	63	61.9	1.6

Confirmation tests

Trials experiments were conducted at the optimal combination of process parameters and the results were noted down. The results that were found were compared to what the regression equation predicted would happen. The results of both the predicted and the obtained is shown in table 8. The error of both results is within the limits.

Conclusions

By adjusting the sheet material, die angle, and sheet width, sheet metal V-bending was performed on a UTM, and the forming parameters were evaluated in terms of punch force and springback. The Taguchi method was used to define its ideal circumstances. To identify the important parameters, an ANOVA was employed. The research's current findings are as follows. According to the statistical study, sheet material has the most impact on punch force and springback.

- The experiment confirms Taguchi's findings that AA6061 sheet material, a 60° die angle, and a 60 mm sheet width are the ideal forming conditions for punch force. The punch force is found to be in ideal circumstances.
- Taguchi identified mild steel sheet material, a 50° die angle, and a 60 mm sheet width as the best forming parameters for springback, and the experiment supports his findings. In the best-case scenario, we can observe what the punch force isless than 5% for both springback and punch force.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Altan T, Tekkaya AE. 2012. Sheet Metal Forming: Fundamentals. ASM International.
2. Wagoner RH, Lim H, Lee MG. 2013. Advanced issues in springback. *Int J Plast* 45: 3-20. https://doi.org/10.1016/j.ijplas.2012.08.006
3. Trzepieciński T. 2020. Recent developments and trends in sheet metal forming. *Metals* 10(6): 779. https://doi.org/10.3390/met10060779
4. Cleveland RM, Ghosh AK. 2002. Inelastic effects on springback in metals. *Int J Plast* 18(5-6): 769-785. https://doi.org/10.1016/S0749-6419(01)00054-7
5. Firat M, Kaftanoglu B, Eser O. 2008. Sheet metal forming analyses with an emphasis on the springback deformation. *J Mater Process Technol* 196(1-3): 135-148. https://doi.org/10.1016/j.jmatprotec.2007.05.029
6. Chatti S, Hermi N. 2011. The effect of non-linear recovery on springback prediction. *Comput Struct* 89(13-14): 1367-1377. https://doi.org/10.1016/j.compstruc.2011.03.010
7. Tekıner Z. 2004. An experimental study on the examination of springback of sheet metals with several thicknesses and properties in bending dies. *J Mater Process Technol* 145(1): 109-117. https://doi.org/10.1016/j.jmatprotec.2003.07.005
8. Firat M, Kaftanoglu B, Eser O. 2008. Sheet metal forming analyses with an emphasis on the springback deformation. *J Mater Process Technol* 196(1-3): 135-148. https://doi.org/10.1016/j.jmatprotec.2007.05.029
9. Yoshida F, Uemori T. 2002. A model of large-strain cyclic plasticity describing the Bauschinger effect and workhardening stagnation. *Int J Plast* 18(5-6): 661-686. https://doi.org/10.1016/S0749-6419(01)00050-X
10. Wilson DV, Bate PS. 1986. Reversibility in the work hardening of spheroidised steels. *Acta Metall* 34(6): 1107-1120. https://doi.org/10.1016/0001-6160(86)90221-X
11. Hasegawa T, Yakou T, Karashima S. 1975. Deformation behaviour and dislocation structures upon stress reversal in polycrystalline aluminium. *Mater Sci Eng* 20: 267-276. https://doi.org/10.1016/0025-5416(75)90159-7
12. Christodoulou N, Woo OT, MacEwen SR. 1986. Effect of stress reversals on the work hardening behaviour of polycrystalline copper. *Acta Metall* 34(8): 1553-1562. https://doi.org/10.1016/0001-6160(86)90100-8
13. Yi HK, Kim DW, Van Tyne CJ, Moon YH. 2008. Analytical prediction of springback based on residual differential strain during sheet metal bending. *Proc Inst Mech Eng Part C J Mech Eng Sci* 222(2): 117-129. https://doi.org/10.1243/09544062JMES682
14. Gautam V, Kumar P, Deo AS. 2012. Effect of punch profile radius and localised compression on springback in V-bending of high strength steel and its FEA simulation. *Int J Mech Eng Technol* 3(3): 517-530.
15. Wang WW, Chen Z, Yu JB, Zhou M. 2012. numerical simulation on the multi-point forming of sail surfaces under force-displacement separated control. *Appl Mech Mater* 217: 1959-1963. https://doi.org/10.4028/www.scientific.net/AMM.217-219.1959
16. Zhang QF. 2014. Compensation algorithm for springback in multi-point forming and its validation by numerical simulation and experimental methods. Jilin University, Changchun, China. (Doctoral Dissertation)

17. Yang M, Manabe KI, Nishimura H. 1996. Development of real-time process control system for precision and flexible V-bending with an on-line database. *J Mater Process Technol* 60(1-4): 249-254. https://doi.org/10.1016/0924-0136(96)02338-2

18. Jamli MR, Farid NM. 2019. The sustainability of neural network applications within finite element analysis in sheet metal forming: a review. *Measurement* 138: 446-460. https://doi.org/10.1016/j.measurement.2019.02.034

19. Liu C, Li M, Yue T. 2021. Springback prediction method for double-curved workpiece considering plate anisotropy in multi-point forming. *J Mech Sci Technol* 35(6): 2623-2636. https://doi.org/10.1007/s12206-021-0533-0

20. Elghawail A, Essa K, Abosaf M, Tolipov A, Su S, et al. 2017. Prediction of springback in multi-point forming. *Cogent Eng* 4(1): 1400507. https://doi.org/10.1080/23311916.2017.1400507

21. Ekambaram S, Murugan N. 2015. Synthesis and characterization of aluminium alloy AA6061-alumina metal matrix composite. *Int J Curr Eng Technol* 5(5): 3211-3216.

22. Ilayaraja G, Sasieekhumar AR, Dhanakodi P. 2011. Inhibition of mild steel corrosion in acidic medium by aqueous extract of *Tridax procumbens* L. *J Chem* 8: 685-688. https://doi.org/10.1155/2011/979542

23. Jain A, Kumar R, Kumar S. 2018. Modeling and optimization for different quality characteristics on electric discharge drilling by Taguchi methodology. *Natl J Multidiscip Res Dev* 3(3): 56-60.

24. Esmaili P, Hasanzadeh R, Modanloo V. 2016. The study of deep drawing of brass-steel laminated sheet composite using taguchi method. *Int J Eng* 29(1): 103-108.

25. Chandu KVPP, Rao EV, Subramanyam BV. 2014. The strength of friction stir welded aluminium alloy 6061. *Int J Res Mech Eng Technol* 4: 1-6.

26. Reddy PV, Krishnudu DM, Pranavi U, Ramulu PJ. 2019. Optimization of the Forming Parameters in U-bending for Punch Force and Springback Using Taguchi Method. In Narayanan R, Joshi S, Dixit U (eds) Advances in Computational Methods in Manufacturing. Lecture Notes on Multidisciplinary Industrial Engineering. Springer, Singapore, pp 75-84.

27. Kumar GS, Reddy PV, Krishnudu DM. 2020. Multi-response optimisation in CNC turning of Al-6082 T6 using grey Taguchi method coupled with principal component analysis. *Int J Comput Aid Eng Technol* 13(4): 508-520. https://doi.org/10.1504/IJCAET.2020.110487