International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Spring Back Optimization for Al-6063 Made Sheet Using Taguchi Method

Bhoodev ^{a*}***, Pinky Maurya*** ^{b}

[a,b] Department of mechnical Engineering, Jaipur Engineering College, Kukas, Jaipur, Rajasthan (India)

ABSTRACT

V-bending is a metal forming process used to bend sheet metal or plate material into a V-shape. In this technique, the sheet metal is placed between a V-shaped die and a punch. The punch applies a force on the sheet metal, which causes it to bend along the line of the V-die. The V-bending process is commonly used in the manufacturing of automotive parts, HVAC ductwork, kitchen products and other similar applications where tight radius bends are required. The V-bending technique is a versatile method that can be used to produce parts with a wide range of geometric shapes and sizes. It is a cost-effective and efficient method of producing high-precision parts with minimal material waste.

The present study investigates the bendability of high-strength aluminum alloy (Al6063) sheets of varying thicknesses using the V-die air bending method. The study aims to understand the characteristics of the V-die air bending method through a numerical simulation procedure. The results of the experiment showed that there was a comparable amount of bendability along the material direction for a particular punch radius throughout the experiment. The displacement data was projected for each direction based on the punch force. In the numerical simulation, V-die air bending was modeled using a full 3D non-quadratic anisotropic yield criterion. The results of this model were then compared with the results obtained using an isotropic yield function, which estimated that bendability along the rolling direction is greater than that along the transverse direction. The thinner material had a larger degree of anisotropy in terms of its pliability, and the features of V-die air bending were also highlighted, both of which suggested a maximum value as an upper bound for the bendability. To facilitate comparison, a newly created anisotropic analytical formulation was also included in the study. This formulation was paired with a kinematic assumption and the study also addressed the restriction.

Keywords: Forming, V bending test, in-house bending test instrument, Aluminum alloy (Al6063), Numerical simulation, DOE, Taguchi method

Introduction

Sheet metal forming operations play a crucial role in a variety of industries, including automotive, aeronautical, electrical, and household appliances. As newer materials and processes continue to be introduced, it is increasingly important to have a thorough understanding of sheet forming behavior and how it is influenced by material properties, tooling, and process parameters. This understanding is crucial for producing high-quality products and ensuring optimal performance. To gain this understanding, researchers employ a range of methodologies, including experimental work, finite element analysis, analytical modeling, and statistical modeling.

These methodologies allow researchers to study the behavior of various sheet metal forming processes in great detail, providing valuable insights into how different materials and processes interact. For example, experimental work allows researchers to observe how different materials respond to various forming conditions, such as temperature and pressure. Finite element analysis, on the other hand, provides a computational tool for simulating and analyzing the behavior of materials during forming. This allows researchers to identify the key factors that influence the behavior of materials and optimize the process parameters to produce high-quality products.

Analytical modeling and statistical modeling are also important tools in the study of sheet metal forming processes. Analytical modeling provides a theoretical understanding of the behavior of materials during forming, while statistical modeling allows researchers to analyze large amounts of data and identify patterns and trends that can inform the design of new processes and tools. Overall, the study of sheet metal forming processes is essential for improving the quality of products and the efficiency of processes in a wide range of industries. By combining experimental, computational, and analytical techniques, researchers are able to gain a comprehensive understanding of the behavior of materials during forming and optimize the design of processes and tools to produce high-quality products. One of the main advantages of bending is its ability to create complex shapes and forms that would be difficult or impossible to achieve with other manufacturing processes. This makes it an ideal solution for creating parts with intricate designs or unique geometries. Additionally, bending is often used to create strong and durable joints, such as those found in construction, bridges, and other structural applications. Another advantage of bending is its ability to mass-produce parts with consistent dimensions and high precision. This makes it a cost-effective option for producing large quantities of parts. The V-bending process is a specific type of bending that utilizes a V-shaped die to create precise and accurate bends in a material. This process offers several advantages over traditional bending methods, including better control over the bend angle, the ability to bend materials with a harder temper, and the ability to produce more consistent and accurate bends. This makes it a popular choice for applications that require high precision and repeatability.

However, there are also some disadvantages to the bending process. One of the main disadvantages is that it can be a costly process, especially for large or complex parts. Additionally, the V-bending process may have limitations in terms of the materials and thicknesses that can be bent and may require specialized equipment. This can make it less accessible for some manufacturers or increase the cost of production. Furthermore, the V-bending process may also have some limitations on the geometry of the parts that can be bent, which can affect the design of the final product. The most common advantages of the V bending technique was following:

1. The V-bending process allows for precise and accurate bends to be made in a material.

2. This process offers better control over the bend angle, which results in more consistent and accurate bends.

3. The V-bending process is able to bend materials with a harder temper, which is not possible with traditional bending methods.

4. The V-bending process is ideal for applications that require high precision and repeatability.

5. The V-bending process can produce parts with tight tolerances and high dimensional accuracy.

6. It can be used to bend a wide range of materials, including sheet metal, wire, and tubing.

7. The V-bending process is a cost-effective solution for mass production of parts.

8. The V-bending process is a fast and efficient method for creating complex and precise shapes.

9. The V-bending process can be automated, making it a suitable choice for high volume production

10. The process can be used to create a wide range of geometries that would be difficult to achieve with other methods.

Springback is a common defect that can occur during the V-bending process and it is caused by several factors. Here are five of the most common reasons behind springback in V-bending:

Material properties: Materials with higher modulus of elasticity have a lower degree of springback, while materials with lower modulus of elasticity have a higher degree of springback. Therefore, it is important to select the right material properties that can withstand the bending process.

Material thickness: thicker materials have a lower degree of springback compared to thinner materials. Therefore, it is important to ensure that the thickness of the material is appropriate for the intended application.

Bend radius: larger bend radius result in lower degree of springback compared to smaller radius. Therefore, it is important to ensure that the radius of the bend is appropriate for the intended application.

Tooling and equipment setup: Improper tooling and equipment setup can cause springback. Therefore, it is important to ensure that the tooling and equipment are properly set up and maintained to reduce the impact of springback.

Bending force: The amount of force applied during the bending process can also affect springback. Therefore, it is important to ensure that the bending force is appropriate for the intended application and that the force is applied consistently across the material.

By understanding the factors that contribute to springback, manufacturers can take steps to reduce its impact on the final product. This includes selecting the right material properties, thickness, and radius of the bend, as well as properly setting up and maintaining the tooling and equipment. Additionally, techniques such as overbending or per-bending can also be used to minimize springback.

Literature Review

V-bending is a technique used to shape metal sheets and many researchers have explored the various parameters that can affect the springback and bend force during the process. In 2011, Farsi and Arezoo [9] conducted an experiment on perforated sheets and found that parameters such as hole size, die angle, die width, and punch radius have an impact on springback and bend force. Their results showed that an increase in hole size and die width leads to an increase in springback, while reducing the hole size, die angle and die width leads to an increase in the bend force.

Abdullah et al. (2013) [1] examined the effect of length, thickness, and bend angle on springback in aluminum-magnesium alloy AA6061 sheets. They found that springback is more affected by changes in thickness and bend angle, while the length has less impact. Choudary and Ghomi (2014) [6] studied the springback effect on Al1100 and Al6061 by considering various factors such as bending angle, sheet thickness, material type, texture, punch speed, punch holding time, sheet width, punch radius, lubrication, warm working, and repeat bending. They found that the most significant factors influencing springback were punch holding time, material type, and lubrication. Chen (2014) [5] investigated the impact of grain size, punch radius, and punch speed on springback in micro V-bending of pure iron sheets. The results showed that for smaller grain size, high punch speed can reduce springback, while for larger grain size, low punch speed can reduce springforward.

Ling et al. (2016) [20] explored the effect of parameters such as cutting type (wire cutting, milling and shear cutting), rolling direction, and thickness of aluminum alloy AA5052 strip on springback in V-bending using Taguchi method. They found that thickness is the most significant factor followed by rolling direction and cutting type does not have any effect on springback. Erdin and Atmaca (2016) [7] studied the effects of holding force, annealing, and anisotropy on springback behavior of 1050-H14 aluminum alloy sheets. They found that the lowest springback is in the direction 45o to the rolling and annealing and application of holding force decrease springback to a greater extent.

Grizelj et al. (2010) [12] studied the springforward effect in V bending of high strength steel St1403 sheets using the MARC FEA software. The results indicated that smaller punch radius or smaller punch angle resulted in a springforward effect. Kardes Sever (2012) [investigated the relationship between Young's modulus and strain on the accuracy of springback prediction in V die bending of Advanced High Strength Steel DP 780 steel sheets. Leu (2013) [18] examined position deviation in asymmetric bend length during V-die bending of high-strength steel SPFC using elastic-plastic FE simulation. The effects of process parameters such as lubrication, material properties and process parameters on position deviation were numerically and experimentally studied. The results showed that small punch width, large die radius and small punch radius reduce position deviation. Leu in 2015 extended his work on asymmetric bending dies in V bending. The analysis showed that the process parameters interact in a complex and irregular way and cannot be considered individually.

Gautam et al. (2017) [11] studied the effect of grain size on springback in V bending of interstitial free steel sheet. Finite element analysis and experimental studies were carried out to find springback. The results indicated that springback is negligible for coarser grain size and high for finer grain size. Gautam and Kumar in 2018 carried out experimental and finite element simulations to find springback in tailor-welded blanks during V bending. The interstitial steel sheets of three thickness combinations were prepared by Nd-YAG laser welding. The parameters under study were anisotropy of the sheets and properties of weld zone. The results indicated that springback is significantly influenced by the weld zone properties than anisotropy of the sheet. In a study by Kazan et al. (2009) [16], an ANN model was developed to predict springback in wipe bending of HSLA steels. The data for training were obtained from finite element simulations, and the ANN model was tested with inputs of different die radius and sheet thickness combinations. The ANN results were compared with the FE simulator and there was a consistency between them.

Farsi & Arezoo (2009) [9] applied ANN to predict final bend angle of components with oblong holes in L-bending. The neural network was trained with experimental data with input parameters such as material type, hole size, blank holder force, ratio of die clearance to sheet thickness, die and punch radius. The neural network was tested by experimental results and it was observed that the network predictions were closer to the experimental results.

Material and Method

The experiments in this study utilized Aluminum alloy sheets of 1mm and 2mm thickness. These sheets possess a range of beneficial properties including excellent flame retardancy, high mechanical strength, and dimensional stability. Due to these properties, Aluminum alloy sheets are widely used across a variety of applications. They are commonly used as modifiers and sparkers on fire for motorcycles and mobile devices, power LED lighting, sound boxes, power supply modules, and acoustic shielding systems, among others. The versatility and reliability of Aluminum alloy sheets make them an ideal choice for a wide range of industries, and their properties make them well-suited to withstand demanding conditions. The results of the experiments conducted in this study will provide valuable insights into how these sheets perform in different conditions, and how they can be optimized for different applications. The Sheets used for the present study was shown in figure 1 for 1 mm and 2 mm thickness.

Figure 1 Al-6063 sheets required for V-Bending process

The construction of the composite material used in this project required the utilization of a specific type of aluminum alloy: 6063. This alloy was sourced from a local supplier in Jaipur, in the form of cylindrical rods. These rods were then used to create the raw AL6063 sheets that would be used for the making of the AMC (Advanced Material Composite). However, it is not uncommon for raw materials purchased from local suppliers to contain impurities. To ensure that the final product met the necessary standards and specifications, an initial heating process was conducted before proceeding with the V bending process. This heating process was completed in the college laboratory, in order to ensure that the raw materials were of the highest quality before being shaped into the desired form. By conducting this initial heating process, we were able to remove any impurities present in the raw materials and ensure that the final product would be of the highest quality.

Punch and Die Fabrication

The fabrication of the V-dies for this project required a variety of angles and openings to be taken into consideration. Three different die angles were used: 60, 90, and 120. The die openings were also varied, with sizes of 24mm, 32mm, and 40mm being utilized. To ensure that the punches would be compatible with the dies, different die radii were also incorporated into the design. The radii used were 2mm, 4mm, and 6mm. All of the dies and punches were fabricated using EN24 steel and were then hardened to ensure that they were durable and long-lasting. To create the final product, sheets were cut to a specific size using EDM (Electrical Discharge Machining) technology. The size of the sheets used for this project were 80mm in width and 20mm in height. The use of EDM allowed for precise and accurate cutting of the sheets, ensuring that the final product would be of the highest quality. The use of different die angles, die openings, and die radii in the fabrication process allowed for a wide range of possibilities when it comes to the final product. The use of EN8 steel and hardening process also added to the overall strength and durability of the dies and punches, making them suitable for use in a variety of different applications. The use of EDM technology in the cutting process also ensured that the final product would be of the highest quality and would meet all necessary specifications.

Figure 2 Close inset view of the punch and die assembly

Factor and Levels

In accordance with the information presented in the prior chapter, a total of three process parameters will be selected. The final list of variables and their values are displayed in table 4.1. This list was prepared using the findings of the literature review as well as the AMC results for made of AL6063. According to Farsi and Arezoo (2011) and Abdullah and Samad (2013), sheet thickness plays a significant role in influencing springback and bend force in metal forming. Additionally, die angle, as stated by Tekiner (2004), and die opening, as noted by Tan et al. (1992) and Zhang et al. (1997), also affect springback and bend force. The punch radius, as outlined by Bruni et al. (2006) and Farsi and Arezoo (2009), also impacts the size of the bent zone and subsequently, springback and bend force. Yilamu et al. (2010) and Parsa et al. (2015) have found that thickness variation in laminated sheets, particularly in terms of the position of the sheet, can significantly impact springback and bend force. In this study, the parameters being considered include sheet thickness, die angle, die opening, and punch radius, all of which can be controlled independently.

The position of the sheet is also taken into account, specifically in terms of the Al-6063. The choice of experimental design is crucial, and is determined by the specific experiment and the number of input parameters.

TABLE1 FACTOR AND LEVEL SELECTION FOR V BENDING

Factor	1	2	3

A	Thickness	1.0	1.5	2.0
B	Die Angle	60	90	120
C	Die Opening	25	35	45
D	Punch Radius	2.5	4.5	6.5

TABLE 2 L9 ORTHOGONAL ARRAY FOR V BENDING STUDY (REAL)

Run	**Thickness**	**Die Angle**	**Die Opening**	**Punch Radius**
1	1	60	25	2.5
2	1	90	35	4.5
3	1	120	45	6.5
4	1.5	60	35	6.5
5	1.5	90	45	2.5
6	1.5	120	25	4.5
7	2	60	45	4.5
8	2	90	25	6.5
9	2	120	35	2.5

Result and Discussion

In this study, the v-bending process for aluminum alloy Al6063 was analyzed using four input parameters: thickness of sheet, die angle, die opening, and punch radius. Three response parameters were selected: springback, thickness variation, and bending force. The results of the study showed that the thickness of the sheet had a significant impact on all three response parameters, with an increase in thickness leading to a decrease in springback, an increase in thickness variation, and an increase in bending force. The die angle and die opening also had a significant effect on springback, with a decrease in die angle and an increase in die opening resulting in less springback. The punch radius was found to have little effect on the response parameters. Overall, the study provides valuable insights into the v-bending process of aluminum alloy Al6063, and can be used to optimize the process for better performance and efficiency. The study can also be used to guide the design of dies and punches for v-bending of Al6063 alloy, and to improve the performance of the process.

S/N ratio analysis of Spring back

In the present study, Signal-to-Noise (S/N) ratio analysis was used to evaluate the performance of the v-bending process for aluminum alloy Al6063, with a specific focus on the response parameter of springback. The S/N ratio is a statistical method that compares the level of the desired signal (in this case, the desired response of low springback) to the level of the undesired noise (any variations or fluctuations in the response that are not due to the input parameters). The goal of the S/N ratio analysis is to identify the input parameters that have the greatest impact on the response parameter, and to optimize the process to minimize the level of noise and maximize the level of the desired signal.

In this study, the S/N ratio was calculated for springback using the Taguchi method and the "smaller is better" option was adopted. This option was chosen because in the v-bending process, the springback is an undesired phenomenon and a lower springback value is desirable. The results of the S/N ratio analysis showed that the die angle and die opening have a significant impact on springback, with a decrease in die angle and an increase in die opening resulting in less springback.

The thickness of the sheet and the punch radius were found to have less effect on springback. The S/N ratio analysis was found to be a powerful tool for identifying the key input parameters that have the greatest impact on the response parameter of springback, and for optimizing the process to achieve the desired level of performance. The results of the S/N ratio analysis suggested that to achieve low springback values, it is important to use a small die angle and a large die opening. Overall, the study provides valuable insights into the v-bending process of aluminum alloy Al6063 and the use of S/N ratio analysis with the Taguchi method to optimize the process for springback with "smaller is better" option can be useful in similar studies in the future. The result of S/N ratio for the spring back response parameter was present in table 5.3 and table 5.4. The unit system for all factors and response parameters was following: Thickness (mm), Die angle (degree), Die opening (mm), Punch Radius (mm) and Springback (degree)

TABLE 3 SPRINGBACK RESULTS FOR V BENDING STUDY

Run	**Thickness**	**Die Angle**	**Die Opening**	**Punch Radius**	**Springback**	**S/N Ratio**
1	1	60	25	2.5	4.35	-12.77
2	1	90	35	4.5	3.58	-11.08
3	1	120	45	6.5	2.81	-8.97
4	1.5	60	35	6.5	4.57	-13.20
5	1.5	90	45	2.5	3.42	-10.68
6	1.5	120	25	4.5	1.85	-5.34

Run	**Thickness**	**Die Angle**	**Die Opening**	**Punch Radius**	**Springback**	**S/N Ratio**
7	2	60	45	4.5	4.21	-12.49
8	2	90	25	6.5	2.34	-7.38
9	2	120	35	2.5	1.86	-5.39

In the present study, Signal-to-Noise (S/N) ratio analysis was used to evaluate the performance of the v-bending process for aluminum alloy Al6063, with a specific focus on the response parameter of springback. The study used four input factors: sheet thickness, die angle, die opening and punch radius. The goal of the S/N ratio analysis was to identify the input parameters that have the greatest impact on the response parameter, and to optimize the process to minimize the level of noise and maximize the level of the desired signal.

The study used the Taguchi method to calculate the S/N ratio for each input factor and the "smaller is better" option was adopted for springback. The results of the S/N ratio analysis showed that die angle and die opening have the highest impact on springback, followed by sheet thickness and punch radius. The delta value was used to measure the difference in S/N ratio between the factors and the rank of the springback was calculated based on the delta values. The results of the study indicate that to achieve low springback values, it is important to use a small die angle and a large die opening, followed by optimizing the sheet thickness and punch radius. Overall, the study provides valuable insights into the v-bending process of aluminum alloy Al6063 and the use of S/N ratio analysis with the Taguchi method and the "smaller is better" option can be useful in similar studies in the future. The results of the study indicated that die angle and sheet thickness have the most significant impact on springback, which can be used to optimize the process to achieve the desired level of performance. The use of delta value and ranking of springback can provide additional information for further optimization and improvement of v-bending process.

TABLE 4 RANK IDENTIFICATIOBN FOR SPRINGBACK RESPONSE

Factor/Levels	**Thickness**	**Die Angle**	**Die Opening**	**Punch Radius**
1	-10.941	-12.818	-8.499	-9.614
2	-9.741	-9.714	-9.889	-9.636
3	-8.42	-6.569	-10.713	-9.852
Delta	2.52	6.249	2.214	0.239
Rank	2	1	3	4

But Die opening and punch radius show the less importance for the springback outcome of the V bending process. From all input parameters, the punch radius was not showing any relation with springback as seen in figure 3, the possible reason was that in present study the selection of the punch radius was not play crucial role for the springback defects present in the v bending process. But thickness of the see show the crucial impact for the springback defect on the final object. As seen in figure 3 the maximum delta was shown for thickness and minimum delta was shown for punch radius input parameter. The profile analysis of the input parameters was discuss using mean data analysis of the springback

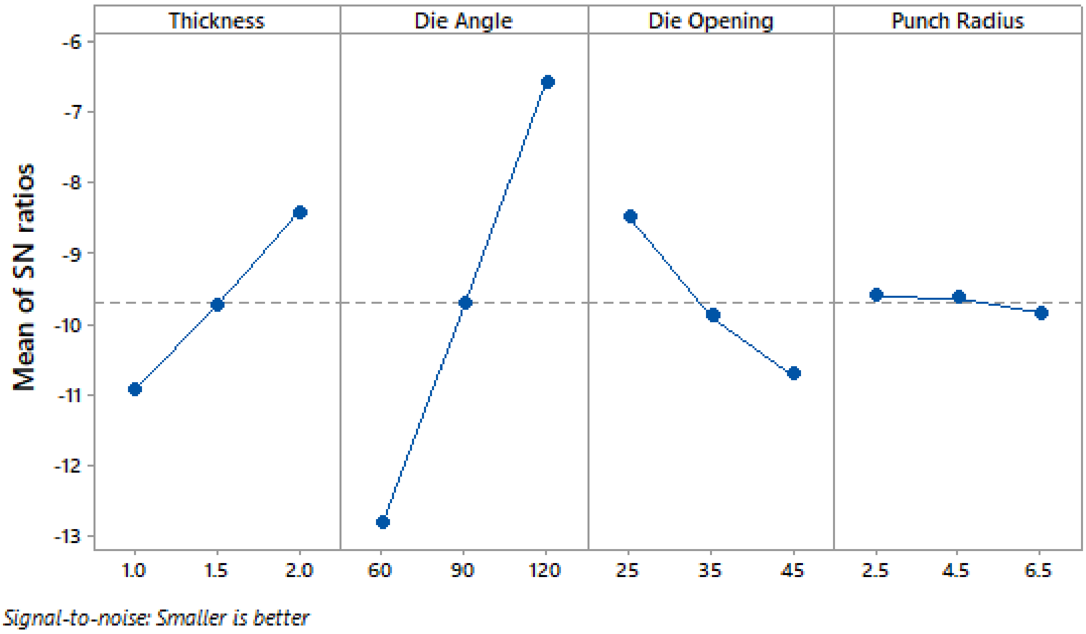

Figure 3 S/N ratio analysis of response spring back

Conclusion

Influence of Thickness: The thickness of the sheet has a significant impact on springback, with a higher delta value (2.52) indicating that as thickness increases, the amount of springback decreases. This is because thicker sheets have more resistance to elastic deformation.

Impact of Die Angle: Die angle is the most influential factor (rank 1) with the highest delta value (6.249). This suggests that the acute die angles (closer to 60 degrees) lead to higher springback due to increased bending stress concentration at the bend region.

Effect of Die Opening and Punch Radius: While these factors affect springback, their influence is less pronounced compared to thickness and die angle. A smaller delta for punch radius (0.239) indicates its relatively minor role in altering springback. This could be due to the fact that punch radius mainly affects the initial contact area and bending mechanics, but not the elastic recovery as much as thickness and die angle.

References

1. Abdullah, A. B., & Samad, Z. (2013). An experimental investigation of springback of AA6061 aluminum alloy strip via V-bending process. IOP Conference Series: Materials Science and Engineering, 50(1), 012069.

2. Ali, R. O. A. B., & Chatti, S. (2019). Modeling springback of thick sandwich panel using RSM. The International Journal of Advanced Manufacturing Technology, 103(9-12), 3375-3387.

3. Angsuseranee, N., Pluphrach, G., Watcharasresomroeng, B., & Songkroh, A. (2018). Springback and sidewall curl prediction in U-bending process of AHSS through finite element method and artificial neural network approach. Songklanakarin Journal of Science & Technology, 40(3), 534-539.

4. Bahloul, R., Ayed, L. B., Potiron, A., & Batoz, J. L. (2010). Comparison between three optimization methods for the minimization of maximum bending load and springback in wiping die bending obtained by an experimental approach. The International Journal of Advanced Manufacturing Technology, 48(9-12), 1185-1203.

5. Chen, C. C. (2014). Experimental study on punch radius and grain size effects in V-bending process. Materials and Manufacturing Processes, 29(4), 461-465.

6. Choudhury, I. A., & Ghomi, V. (2014). Springback reduction of aluminum sheet in V-bending dies. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 228(8), 917-926.

7. Erdin, E., & Atmaca, A. (2016). Effects of holding force on the springback behavior of annealed aluminum plates. Procedia Engineering, 149, 56-61. https://doi.org/10.1016/j.proeng.2016.06.638

8. Erdin, M. E., & Atmaca, A. (2016). Effects of holding force on the springback behavior of annealed aluminum plates. Procedia Engineering, 149, 56-61.

9. Farsi, M. A., & Arezoo, B. (2011). Bending force and spring-back in v-die bending of perforated sheet-metal components. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 33(1), 45-51.

10. Gautam, V., & Kumar, D. R. (2018). Experimental and numerical investigations on springback in V-bending of tailor-welded blanks of interstitial free steel. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 232(12), 2178-2191.

11. Gautam, V., Shukla, R., Singh, J., & Kumar, D. R. (2017). Effect of grain size on springback in v-bending of interstitial free steel. Proceedings of the International Conference on Recent Advances in Mechanical Engineering, 247-251.

12. Grizelj, B., Cumin, J., & Grizelj, D. (2010). Effect of spring-back and springforward in V-die bending of St1403 sheet metal plates. Journal for Theory and Application in Mechanical Engineering, 52(2), 181-186.

13.Hahn, M., Weddeling, C., Khalifa, N. B., & Shabaninejad, A. (2016). Springback behavior of carbon-fiber-reinforced plastic laminates with metal cover layers in V-die bending. In ASME 2016 11th International Manufacturing Science and Engineering Conference American Society of Mechanical Engineers, V001T02A060.

14.Habibi Parsa, M., Mohammadi, S. V., & Mohseni, E. (2017). Thickness change and springback of cold roll bonded aluminum/copper clad sheets in air bending process. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 231(4), 675-689.

15.Jamli, M. R., Ariffin, A. K., & Wahab, D. A. (2015). Incorporating feedforward neural network within finite element analysis for L-bending springback prediction. Expert Systems with Applications, 42(5), 2604-2614.

16.Kazan, R., Fırat, M., & Tiryaki, A. E. (2009). Prediction of springback in wipe bending process of sheet metal using neural network. Materials & Design, 30(2), 418-423.

17.Kumar, T. A., & Ravichandran, M. (2018). Prediction and investigation of springback in U bending process using taguchi and RSM. TAGA Journal, 14, 2957-2967.

18. Leu, D. K. (2013). Position deviation in V-die bending process with asymmetric bend length. The International Journal of Advanced Manufacturing Technology, 64(1-4), 93-103.

19.Leu, D. K. (2015). Position deviation and springback in V-die bending process with asymmetric dies. The International Journal of Advanced Manufacturing Technology, 79(5-8), 1095-1108.

20. Ling, J. S., Abdullah, A. B., & Samad, Z. (2016). Application of Taguchi method for predicting springback in V-bending of aluminum alloy AA5052 strip. Journal of Scientific Research and Development, 3(91), 7.