RESEARCH ARTICLE OPEN ACCESS

Predictive Modeling of Bending force On AISI 304 during V- Bending Process

Dattatray Narayan Choudhari* , Dr.S.K.BIRADAR**, M.D. Irfan***
*(PG Scholar, Mechanical Engineering Department, M.S.S.C.E.T, Jalna, Maharashtra, India.)
(Email: dattatraychoudhari2@gmail.com)
** (Principal, Mechanical Engineering Department, M.S.S.C.E.T, Jalna, Maharashtra, India.)
(Email: shantisagarbiradar@gmail.com)
*** (Mechanical Engineering Department, M.S.S.C.E.T,Jalna, Maharashtra, India)
(Email: irfanmohd777@gmail.com)

Abstract

Metal forming plays a very important role in producing industries. In industrial sector the great value among various manufacturing operations due to its advantages such as cost effectiveness, enhanced mechanical properties, flexible operations, higher productivity, considerable material saving. The objects is that we use in our daily life are man-made, engineered parts, which are acquire from some raw material through some manufacturing process by using various metal forming process. The metal forming process are classified into compressive forming, tensile forming, combine tensile and compressive forming, Bending, Shearing etc. are widely used to produce a large number of simple to complex components in automotive, aircraft, household, defense and nuclear applications. Sheet metal bending is a widely used sheet metal forming process in which a force is applied to a sheet metal blank to form the desired shape. During bending, the metal is deformed plastically along a straight line to change its shape and is employed with the trial-and-error method. The accuracy and success of the bending process depends upon the operating parameters as well as the material properties. Components of different cross sectional profiles like cylindrical, conical, elliptical, oval, etc. are manufactured by sheet metal bending process. There are number of existing techniques available for the bending of plates, such as stamp-bending, stretch-bending, press-bending, and roll-bending. All the above mentioned techniques, except roll bending, requires heavy investments in tooling in order to bend the plates for different radii. So V bending is a more flexible, effective and more efficient than other bending process.

.

INTRODUCTION

Metal forming is a process of making metal parts and objects through mechanical deformation. In this, the material is deformed to the required shape without adding or removing of material and its mass remains unchanged. Metal forming processes are classified into bulk forming processes and sheet metal forming processes. The bulk forming processes are rolling, forging, wire drawing and extrusion. In this forming processes, ratio of volume to surface area and ratio of volume to thickness are high. In bulk deformation processing methods, the nature of force applied may be compressive, compressive and tensile, shear or a combination of these forces. Sheet metal forming process is used for producing a high variety of products. The sheet metal forming processes are stretch forming, bending, and deep drawing. In this process, piece of sheet metal is plastically deformed by tensile load into three dimensional shapes, without any significant changes in thickness of sheet or characteristics of surface. Sheet metals forming involve application of tensile or shear forces predominantly.

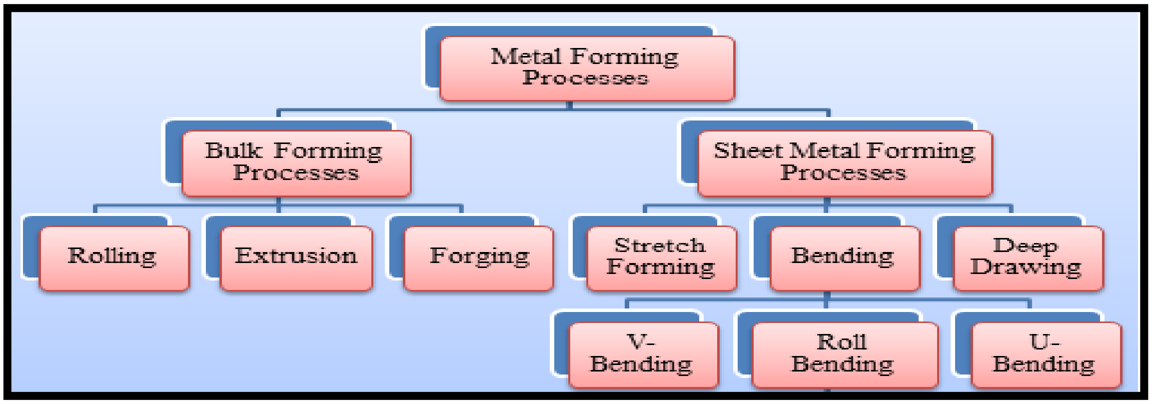

Figure :- Classification of Metal Forming Processes

Sheet Metal Forming

Sheet metal forming is one of the most common metal manufacturing processes that are widely used for producing a large number of simple to complex shape components in a very short time. In this process, sheet metal blanks are plastically deformed into three-dimensional shapes by the application of forces without much change in sheet thickness. It involves the conversion of flat, thin sheet metal blanks into parts of desired shape. The popularity of sheet metal products is attributable to their light weight, improved mechanical properties, good surface finish, low cost and high degree of dimensional accuracy. The sheet metal forming industry is one of the major manufacturing centers for the automobile, aerospace, steel industries, power plants, agriculture sector and electrical industries. In the past several decades, sheet forming engineering has grown with the advent of new materials, processes and control techniques. Concerning materials, research has aimed at an understanding the effect of material composition and behavior on the sheet formability. The sheet forming behavior is influenced by material properties, tool or machine geometry parameters and process parameters in a complex fashion. The appropriate knowledge of material behavior, selection of proper forming process parameters, tool design, process sequence and specific issues related to advances in material and forming technology is essential for successfully controlling and improving a process to produce a better product. Today's highly competitive market mandates the sheet forming industry to make major changes in its traditional product development cycle from conceptual design to production. There is a strong need to reduce the cost, shorten the development cycle and improve product quality. Different approaches such as experimental, numerical, analytical modeling, empirical modeling and finite element analysis are employed to study the various facets of sheet metal forming processes.

Sheet metal forming processes like deep drawing, stretching, bending etc. are widely used to produce a large number of simple to complex components in automotive, aircraft, household, defense and nuclear applications. Some of these components are shown in figure 2.2. These parts are manufactured using one or more of the sheet metal forming processes. Sheet metal bending is a widely used sheet metal forming process in which a force is applied to a sheet metal blank to form the desired shape. During bending, the metal is deformed plastically along a straight line to change its shape and is employed with the trial-and-error method. The accuracy and success of the bending process depends upon the operating parameters as well as the material properties. Components of different cross sectional profiles like cylindrical, conical, elliptical, oval, etc. are manufactured by sheet metal bending process. There are number of existing techniques available for the bending of plates, such as stamp-bending, stretch-bending, press-bending, and roll-bending. All the above mentioned techniques, except roll bending, requires heavy investments in tooling in order to bend the plates for different radii. Additional tooling and/or machines are required to complete the production process. Another shortcoming of these processes is the prolonged set up time required for successive bending of two plates into different bend radii. In addition, a complete shell, formed by any of these bending processes, normally has two or more welded seams. Furthermore, these processes are only suitable for producing small and medium diameter shells. These limitations clearly indicate the deficiencies of the existing processes.

Figure :- Different components produced using sheet metal forming processes

V-Bending Process

In V-bending, v-shaped concave die and the convex punch are used (Fig. 3). In V-bending process, sheet-metals can be bent to both acute and obtuse angles, including bending accurately to 90^0. In V-bending process, load is applied through the punch to a sheet-metals blank, which is plastically deformed to acquire the shape of gap between the die and punch.

V bending is more flexible, effective and more efficient than the closed die bending which is widely used in small-batch-part sheet metal manufacturing satisfying the higher accuracy and short lead time. This allows the V- bending process to be adaptable for different material types, thickness of the sheet and variety of components. During this process, the excessive strain is reduced on the press brake as the forces required are small to form the bend.

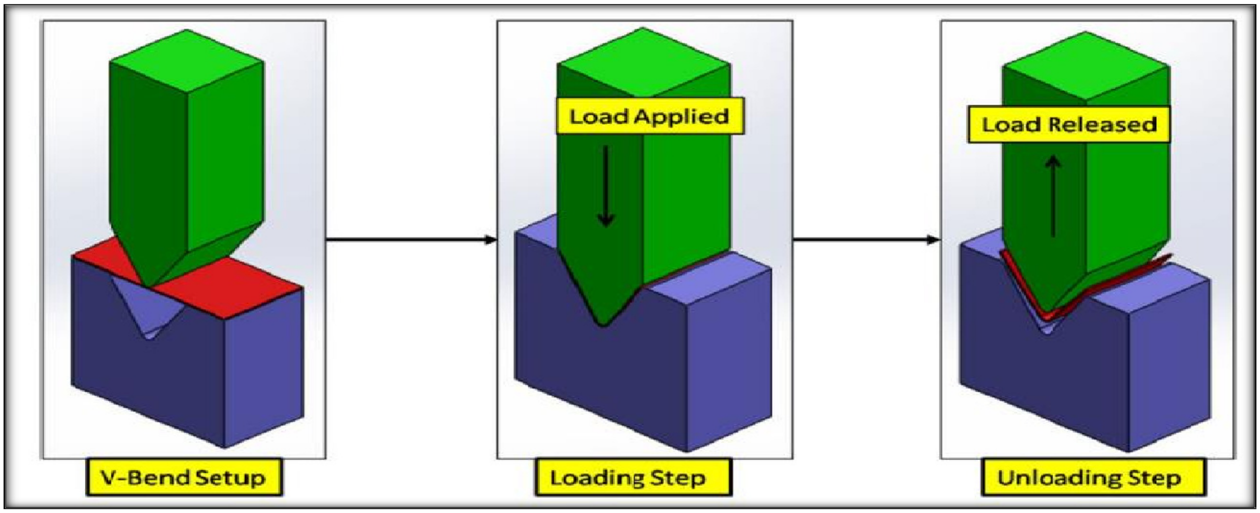

Figure : Air Bending Process [12]

There has been an increase in the number of researches in bending process, particularly pertaining to springback and bend force. Bending force is the important issue in the sheet metal manufacture to design die and punch for a specific product. The bending force is mainly used for the tooling design and selection of the press brake. In general, bending force is the force applied to the sheet metal to deform and transform into the required shape. The bending force depends upon material properties, geometrical properties, process parameters and surface properties.
Modeling of bend force in bending is often essential for designing bending tools and selection of press. Modeling of the bending process for effective utilization of product is a common issue in manufacturing engineering. This prediction can be conducted using analytical methods, semi-empirical formula and approximate numerical analysis.

Critical Literature Review

Springback reduction of aluminum sheet in V-bending dies (2014)

Imtiaz A Choudhury et al [1] investigated the effect of process parameters on springback, which is one of the major defects associated with sheet metal–forming industry. Eleven process parameters of V-bending operation, the bending angle, sheet thickness, material type, material texture, punch speed, punch holding time, sheet width, punch radius, lubrication, warm working, and repeat bending, was considered for the investigation. Taguchi L_{12} orthogonal array design was used for the experimentation. Bending tests were conducted on two types of aluminum sheets (Al 1100 and Al 6061). Main focus of the investigation was to minimize the effect of process variables on the springback. Analysis of variance (ANOVA) was performed to determine the percentage contribution of each factor to springback and optimum levels of entire factors were ascertained. From the investigation, it is concluded that the punch holding time, material type, and lubrication were found to be the most significant factors affecting springback.

The Experimental Investigation of Springback in V-Bending Using the Flex forming Process (2016)

IbrahimKaraagaç [2] in his study experimentally investigated the factors affecting the springback resulting from the bending of copper and brass sheet metal materials in V-bending dies using the flex-forming process. The process parameters in the experimental studies were determined to be: holding time, bending angle and fluid pressure. Sheet metals were formed in V-bending dies by both flex-forming and conventional bending processes to compare the performance of the flex-forming process against the conventional bending process. Springback values in the parts formed using the flex-forming process for copper and brass sheet metals were determined to be 39.06 and 41.42% less, respectively, than those formed by the conventional bending method.

Analysis of spring back and bend power of galvanized iron sheet in V-Die Bending Phase (2020)

Saravanakumar S et al [3] explored the springback effect of Galvanized Iron board. Performance of galvanized Iron sheet metal is determined by sheet thickness, die angle, die opening, and punch radius. The parameters above are performed experimentally, and the S / N curve is plotted using Taguchi analysis to classify most affected parameters. The Regression-based mathematical models for springback prediction in the Galvanized Iron sheet bending process V-Die were developed. Sheet thickness, Die angle, Die opening, and Punch radius were considered input parameters, and springback and Bend force were considered as output parameters for model development. For Galvanized Iron sheets, various regression models were built based on experimental findings, including linear, linear-square, linear-interaction, and quadratic terms for the springback prediction. Quadratic model was found to be best model for predicting springback in a specified environment.

Prediction of Springback in the Air Bending Process Using a Kriging Meta model (2016)

Fayiz Abu Khadra et al [4] reported the use of the kriging approach to predict the springback in the air bending process. The materials and the geometrical parameters, which significantly affect the springback, were considered as inputs, and the springback angle was considered as the response. A verified nonlinear finite element model was used to generate the training data required to create the kriging meta model. The training examples were selected based on computer-generated D-optimal designs. A comparison between the kriging approaches and the response surface methodology was conducted and discussed. The results showed that kriging accurately predicts the finite element springback results. Comparing the accuracy of kriging with a response surface methodology shows that kriging with a 2^{nd} degree polynomial and exponential correlation function predicts the springback more accurately than the response surface methodology.

The Evaluation of Process Parameters on Springback in V-bending Using the Flex forming Process (2017)

Ibrahim Karaagaç [5] discussed the one of the significant problems in bending sheet metals, springback behavior, caused by the elastic stress formed after the bending process. In this study, the effects of forming pressure, die angle and holding time on the springback behavior were experimentally investigated for V-bending using the flexforming process. Furthermore, springback behavior was predicted using a fuzzy logic system. The study was carried out using a thin rubber membrane instead of the thick ones normally used in flex-forming processes. During the flex-forming process, it was observed that springback were 60.57% and 41.92% less than those formed by a conventional die for AL1050-0 and AL5754-0 sheet metal materials, respectively. It was determined that an increase of 15^0 in the die angle increased springback values on average by 0.12^0 and 0.23^0 for AL1050-0 and AL5754-0, respectively. It was also found that an increase of 10 seconds in the holding time decreased springback values on average by 0.14^0 and 0.19^0 for AL1050-0 and AL5754-0, respectively. It was determined that there were no forming defects on the surfaces of the parts bent through the flex-forming process.

Inferences from Literature Review

1. The more research work is already carried out in analyzing the spring back effect of sheet metals in V-bending process.
2. Very few works are identified in analyzing the bending force on sheet metals in V-bending process.
3. The more research work has been carried out in analyzing the effect of process parameters of V-bending on aluminium (Al 1100 and Al 6061), mild steel, copper and brass sheet metal, galvanized Iron sheet metal, HSLA (420&ST12) grade material, high-tensile strength steel (JSC440 and JSC590) grades, CR4 steel, Inconel 625 alloy, etc.
4. No works have been carried out in analyzing the effect of process parameters of V-bending on AISI 304 sheet metal.

Various predictive models are developed for springback using Taguchi method, Response surface methodology, artificial neural network, Finite element method, etc

Problem Statement and Project Objectives

The present project work **"Predictive Modeling of Bending Force on AISI 304 During V-Bending Process"** has been undertaken keeping into consideration of the research gaps identified from available literature and discussion in above section.

The objective of this study is to develop predictive model for analyzing the influence of process parameters on bending force. The broad objectives of the present work are enlisted as:

1. To experimentally investigate the bending force for AISI 304 material during V-bending process.
2. To develop a regression model for the prediction of bending force for AISI 304 material during V-bending process using Taguchi's experimental design.
3. To perform the analysis of variance (ANOVA) to check the feasibility and adequacy of the developed model.
4. To determine the effect of significant parameters on bending force in V-bending process.
5. To determine optimum process parameters leading to minimum bending force in a given specified environment.
6. To determine percentage variation between experimental values and predictive model of bending force to check the correctness of applied methodology.

RESEARCH METHODOLOGY

The systematic and scientific research is reflected in its methodology. Methodology is usually a guideline system for solving a problem, with specific components such as phases, tasks, methods, techniques and tools. This chapter deals with methods undertaken to achieve the goals of the study. It includes discussion about different phases of research work, theories of experimentation and design of experimentation method to be applied for data collection.

Different phases of Present Research Work

To accomplish the defined objectives, present research work has been classified into eight phases. Figure 3.1 shows flow chart of research work.

Phase 1: Study of V- Bending Process

- At outset, approximately 20 research articles are studied to understand air bending process. More research articles needs to be studied to acquire in-depth knowledge about the process.
- Different industries, where V- bending machines are available will be visited to study the actual process.

Phase 2: Identification of Key Parameters, Working Ranges and Levels

Various key parameters and materials, affecting the performance of air bending process, will be identified through:

- Available related literature
- Discussion with experts
- Actual process observation
- Performing preliminary experimentations

Working ranges and levels will be decided based on preliminary experimentations.

Phase 3: Experimentation

- Appropriate design of experimentation technique will be selected.
- Experiments will be performed for each combination of input parameters for AISI 304.
- Experimental results will be observed and noted for further analysis and discussion.

Phase 4: Analysis of Experimental Results

- Regression model of experimental values for predicting bending force will be formulated using Minitab 16.
- Analysis of variance (ANOVA) will be performed to check the adequacy of the results.
- Optimum solution will be determined based on the analysis.

Phase 5: Prediction and Validation of Output Results

- Output results of optimum solutions will be predicted.
- Predicted results will be validated by performing conformation tests.
- Percentage variation will be determined to check the correctness of the methodology.

Phase 6: Conclusion and Future Scope

- Based on above 5 phases, different conclusions will be drawn.
- At the end, future scope in this area will be presented.

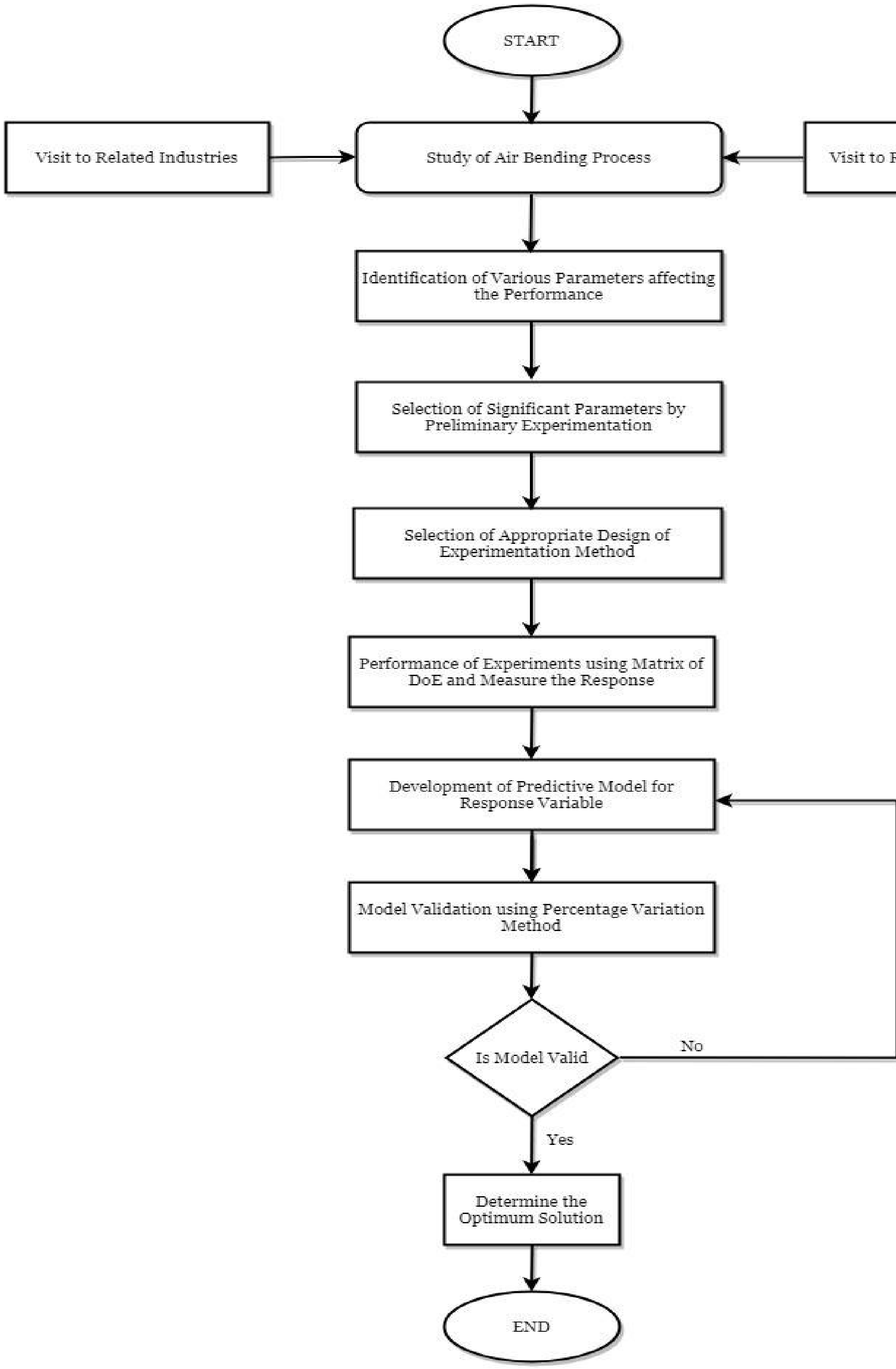

Figure 3.1: Flow Chart of Methodology applied for the Present Work

Design of Experimentation

An experiment is a test or series of tests conducted under controlled conditions made to demonstrate a known truth, examine the validity of a hypothesis, or determine the efficacy of action previously untried. In an experiment, one or more input process variables are changed deliberately in order to observe the effect on one or more response variables. Experiments are performed a number of times in order to evaluate the output response variables under the different input process variable conditions. The design of experiments (commonly referred to as DOE) is an efficient method for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions. In other words, Design of experiments is a systematic method to determine the relationship between factors affecting a process and the output of that process. The method for conducting designed experiments begins with determining the objectives of an experiment and selecting the process factors for the study. A designed experiment requires establishing a detailed experimental plan in advance of conducting the experiment, which results in a streamlined approach in the data collection stage. Appropriately choosing experimental designs maximizes the amount of information that can be obtained for a given amount of experimental effort. Experimental designs are used to investigate industrial systems or processes. A typical process model is given in figure 3.2.

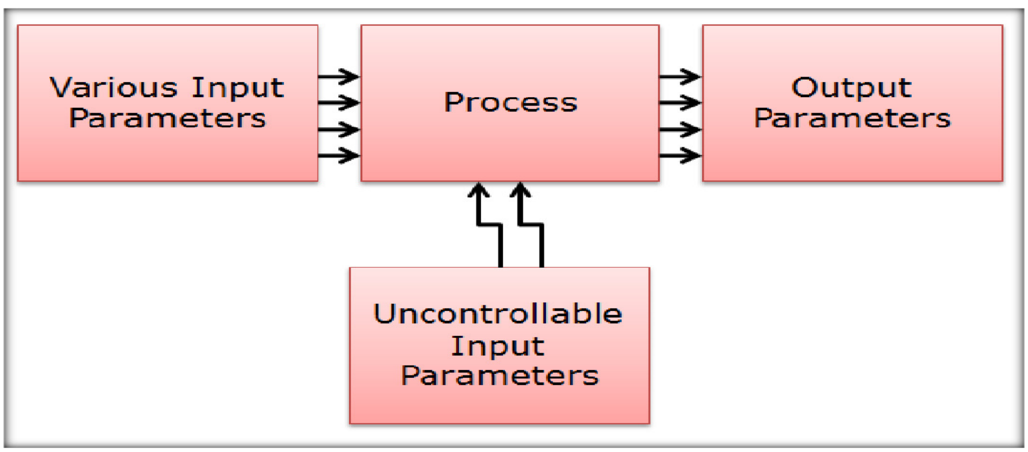

Figure 3.2: Generalized Process Model

The most commonly used terms in the DOE methodology include: controllable and uncontrollable input parameters and output parameters.

Purposeful changes are made to the controllable input factors of a process so as to observe and identify the reasons for changes that may be observed in the output responses. The uncontrollable factors are considered as random effects that cannot be controlled. The controllable input factors can be modified to optimize the output. Experimental data are used to derive a statistical empirical model relating the outputs and inputs.

Taguchi Method

Dr. Genichi Taguchi introduced use of several orthogonal arrays (L_9, L_{16}, L_{27}, and L_{36}) w hich consist of combination of input parameters for the purpose of experimentation. The Taguchi approach is more effective method than traditional design of experiment methods such as classical and factorial design, which is resource and time consuming. For example, a process with 8 variables, each with 3 states, would require 3^8=6561 experiments to test all variables (full factorial design). However, using Taguchi's orthogonal arrays, only 18 experiments are necessary, or less than 0.3% of the original number of experiments.

Taguchi approach provides a new experimental strategy in which a modified and standardized form of design of experiment (DOE) is used. This technique helps to study effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined. Taguchi designs experiments using specially constructed tables known as "ORTHOGONAL ARRAY" (OA). The use of these tables makes the design of experiments very easy and consistent and it requires relatively lesser number of experimental trials to study the entire parameter space. As a result, time, cost, and labor saving can be achieved. The method explores the concept of quadratic quality loss function and uses a statistical measure of performance called Signal-to-Noise (S/N) ratio. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics.

The standard S/N ratios generally used are as follows: -

1) Nominal is Best (NB)
2) Lower the Better (LB)
3) Higher the Better (HB)

The optimal setting is the parameter combination, which has the highest S/N ratio.

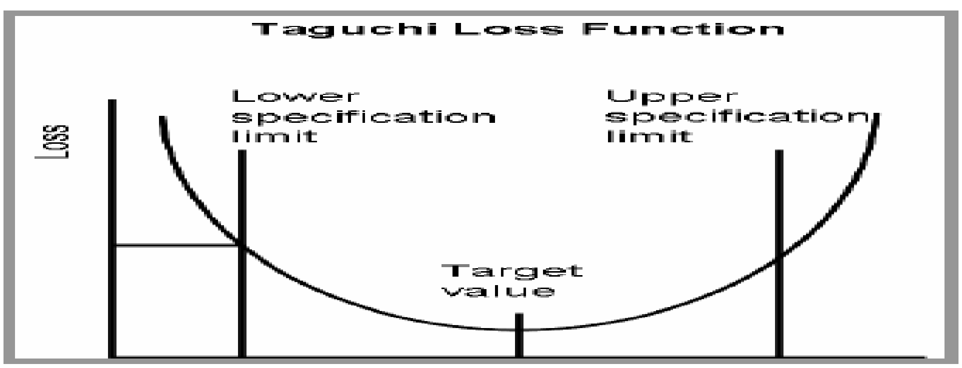

Figure: 3.3: Taguchi's quadratic loss function

Taguchi's S/N Ratio for (HB) Higher-the-better

(Quality characteristics is usually a nominal output, say Current)

$$\eta = -10\ log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \quad (3.1)$$

Taguchi's S/N Ratio for (LB) Lower-the-better

(Quality characteristics is usually a nominal output, say Defects)

$$\eta = -10\ log_{10}\frac{1}{n}\sum_{i=1}^{n}y_i^2 \quad (3.2)$$

Taguchi's S/N Ratio for (NB) Nominal-the-best

(Quality characteristics is usually a nominal output, say Diameter)

$$\eta = 10\ log_{10}\frac{1}{n}\sum_{i=1}^{n}s2 \quad (3.3)$$

Table 3.1: Generalized Process Parameters with their values at three level parameters

Sr. No	Level→	Low	Medium	High	Ranges
	Code	1	2	3	
1	A	A1	A2	A3	A1 – A3
2	B	B1	B2	B3	B1 –B3
3	C	C1	C2	C3	C1 – C3
4	D	D1	D2	D3	D1 – D3

Table 3.2: Generalized Design Matrix of L-9 Orthogonal Array

Run No.	Input Parameter (Coded Form)				Input Parameter (Un-Coded Form)			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**

1	1	1	1	1	A1	B1	C1	D1
2	1	2	2	2	A1	B2	C2	D2
3	1	3	3	3	A1	B3	C3	D3
4	2	1	2	3	A2	B1	C2	D3
5	2	2	3	1	A2	B2	C3	D1
6	2	3	1	2	A2	B3	C1	D2
7	3	1	3	2	A3	B1	C3	D2
8	3	2	1	3	A3	B2	C1	D3
9	3	3	2	1	A3	B3	C2	D1

RESULT AND DISCUSSION

Nowadays the AISI 304 sheets are in great demand due to its important properties like higher corrosion resistance, heat resistance and attractive surface finish. This chapter comprises of the experimental setup, tooling geometries and process parameters used for conducting the experiments.

1 EXPERIMENTAL SETUP

Hydraulic type Universal Testing Machine (UTM) of 400kN capacity was used to conduct the V- bending experiments in which the specifications are mentioned in Table 4.1. The experimental setup consists of die and punch, in which the die made up of EN8 hardened steel. The die was fastened to the bed of the UTM whereas the punch was placed above the die at a particular distance in the cross head of UTM. They were positioned as if the centre of punch and die coincides each other. The tooling geometries and process parameters required for conducting the bending experiments are provided. The tests were performed in such a way to learn the effect of the process parameters on the bending behaviour of the AISI 304 steel sheet.

Table 4.1: Specifications for Universal Testing Machine

Maximum capacity	400KN
Type	Hydraulic type, Electrical supply 1.75 kW, 3 phase, 440 V, 50Hz
Ram stroke	200 mm
Dimensions	2050 x 750 x 2540 mm
Average thickness of the sheets in mm	0.7 mm
Length of the sheets in mm	120 mm
Punch travel in mm	10,15,20
Punch velocity(v) in mm/s	0.333,0.499,0.666
Holding time (t) in min	2.5,5,7.5

Figure 4.1: Universal Testing Machine

Figure 4.2: AISI 304 material after bending

Experimental Results of Bending Force

Based on the experimental layout depicted in Table 3.2, the experiments are performed in sequence. Bending force is measured for different combinations of input variables as per L9 orthogonal array. Measured experimental response is shown in Table (4.2) and Figure (4.3) shows the trend of response for respective experimental trials.

Table 4.2: Taguchi L_9 Orthogonal Array and Experimental Results

	Independent Variables				Bending Force		
Sr. No	Punch Travel (mm)	Holding Time (min)	Punch Velocity (mm/s)	Width of Sheet (mm)	Run 1	Run 2	Average
1	10	0.25	0.333	40	243	247	245
2	10	5	0.499	50	212	218	215
3	10	7.5	0.666	60	190	196	193
4	15	0.25	0.499	60	213	217	215
5	15	5	0.666	40	210	216	213
6	15	7.5	0.333	50	205	209	207
7	20	0.25	0.666	50	210	216	213
8	20	5	0.333	60	198	202	200

9	20	7.5	0.499	40	201	207	204

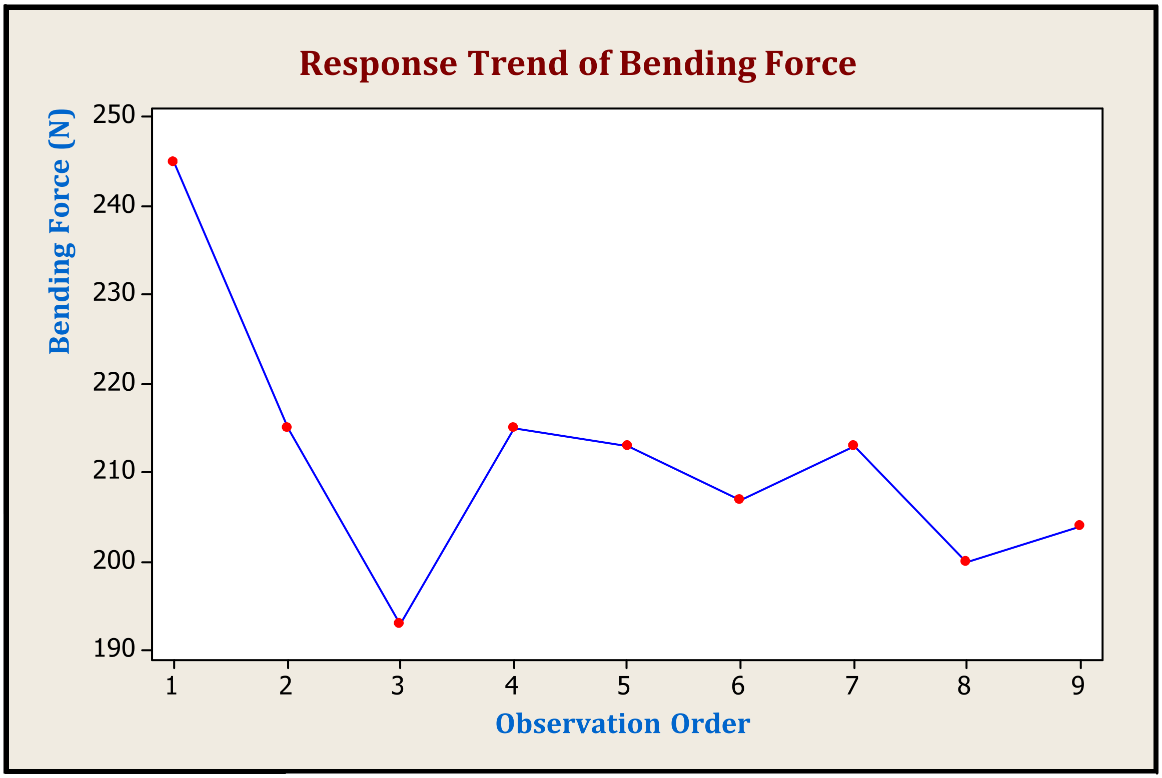

Figure 4.3: Response Trend for Bending Force

Analysis and Discussion of Results of Bending Force

The experiments are conducted on V-bending machine by using the parametric approach of Taguchi's method. Using Taguchi approach, only main effect of individual parameters has been evaluated. The effects of individual process parameters on bending force have been discussed in this section. Experimental data have been converted into signal to noise (S/N) ratio as suggested by Taguchi method. As objective function is to minimize the bending force, "smaller the better" characteristics type is chosen to estimate S/N ratios. Therefore equation 3.2 has been used for converting experimental data into S/N data, presented in Table 4.3

Table 4.3: Signal-to-Noise ratios of Response Parameters

Sr. No	Punch Travel (mm)	Holding Time (min)	Punch Velocity (mm/s)	Width of Sheet (mm)	Bending Force	Signal to Noise Ratio (db)
1	10	0.25	0.333	40	245	-47.7833
2	10	5	0.499	50	215	-46.6488
3	10	7.5	0.666	60	193	-45.7111
4	15	0.25	0.499	60	215	-46.6488
5	15	5	0.666	40	213	-46.5676
6	15	7.5	0.333	50	207	-46.3194
7	20	0.25	0.666	50	213	-46.5676
8	20	5	0.333	60	200	-46.0206
9	20	7.5	0.499	40	204	-46.1926

EXPERIMENTAL SETUP

Hydraulic type Universal Testing Machine (UTM) of 400kN capacity was used to conduct the V- bending experiments in which the specifications are mentioned in Table 4.1. The experimental setup consists of die and punch, in which the die made up of EN8 hardened steel. The die was fastened to the bed of the UTM whereas the punch was placed above the die at a particular distance in the cross head of UTM. They were positioned as if the centre of punch and die coincides each other. The tooling geometries and process parameters required for conducting the bending experiments are provided. The tests were performed in such a way to learn the effect of the process parameters on the bending behaviour of the AISI 304 steel sheet.

Table 4.1: Specifications for Universal Testing Machine

Maximum capacity	400KN
Type	Hydraulic type, Electrical supply 1.75 kW, 3 phase, 440 V, 50Hz
Ram stroke	200 mm
Dimensions	2050 x 750 x 2540 mm
Average thickness of the sheets in mm	0.7 mm
Length of the sheets in mm	120 mm
Punch travel in mm	10,15,20
Punch velocity(v) in mm/s	0.333,0.499,0.666
Holding time (t) in min	2.5,5,7.5

Figure 4.1: Universal Testing Machine

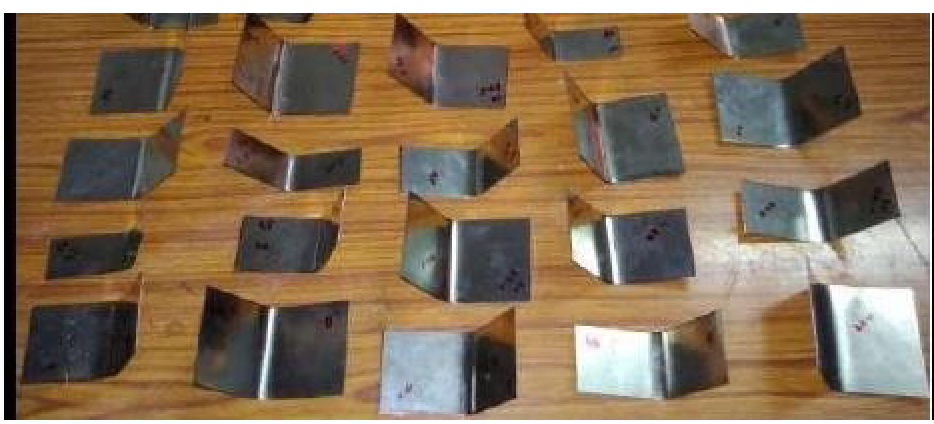

Figure 4.2: AISI 304 material after bending

Experimental Results of Bending Force

Based on the experimental layout depicted in Table 3.2, the experiments are performed in sequence. Bending force is measured for different combinations of input variables as per L9 orthogonal array. Measured experimental response is shown in Table (4.2) and Figure (4.3) shows the trend of response for respective experimental trials.

Table 4.2: Taguchi L_9 Orthogonal Array and Experimental Results

	Independent Variables				Bending Force		
Sr. No	Punch Travel (mm)	Holding Time (min)	Punch Velocity (mm/s)	Width of Sheet (mm)	Run 1	Run 2	Average
1	10	0.25	0.333	40	243	247	245
2	10	5	0.499	50	212	218	215
3	10	7.5	0.666	60	190	196	193
4	15	0.25	0.499	60	213	217	215
5	15	5	0.666	40	210	216	213
6	15	7.5	0.333	50	205	209	207
7	20	0.25	0.666	50	210	216	213
8	20	5	0.333	60	198	202	200
9	20	7.5	0.499	40	201	207	204

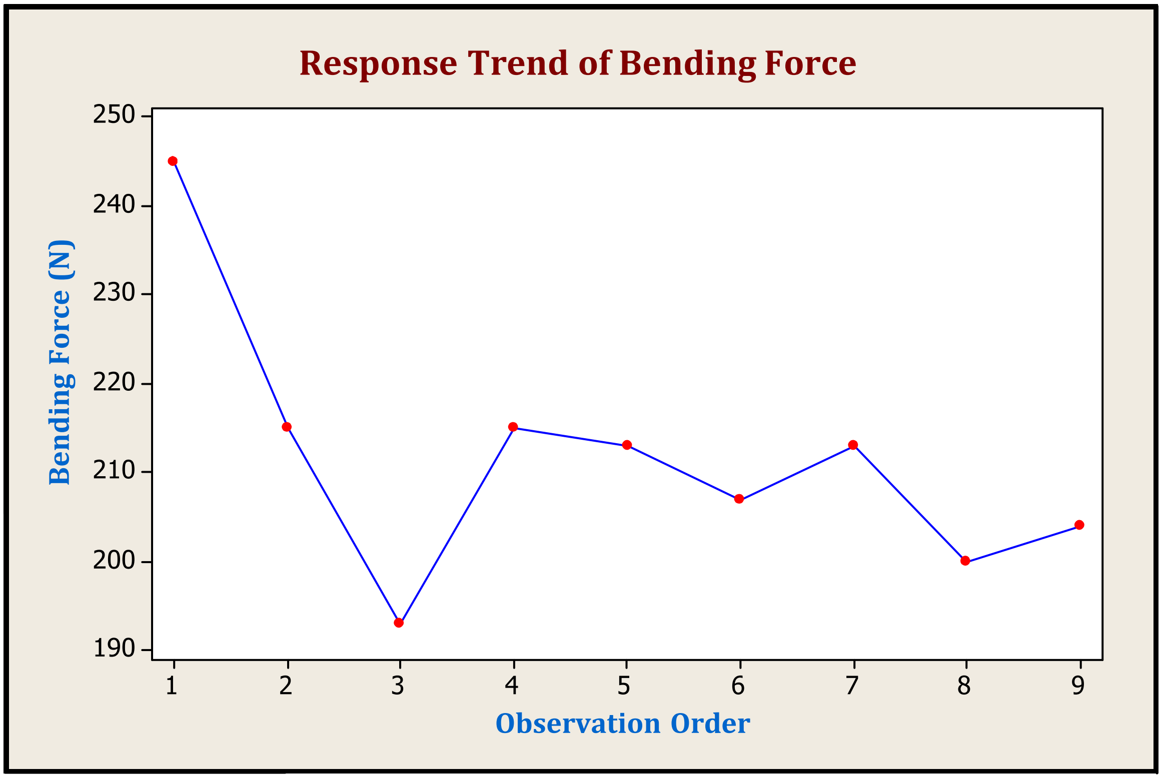

Figure 4.3: Response Trend for Bending Force

4.3 Analysis and Discussion of Results of Bending Force

The experiments are conducted on V-bending machine by using the parametric approach of Taguchi's method. Using Taguchi approach, only main effect of individual parameters has been evaluated. The effects of individual process parameters on bending force have been discussed in this section. Experimental data have been converted into signal to noise (S/N) ratio as suggested by Taguchi method. As objective function is to minimize the bending force, "smaller the better" characteristics type is chosen to estimate S/N ratios. Therefore equation 3.2 has been used for converting experimental data into S/N data, presented in Table 4.3

Table 4.3: Signal-to-Noise ratios of Response Parameters

Sr. No	Punch Travel (mm)	Holding Time (min)	Punch Velocity (mm/s)	Width of Sheet (mm)	Bending Force	Signal to Noise Ratio (db)
1	10	0.25	0.333	40	245	-47.7833
2	10	5	0.499	50	215	-46.6488
3	10	7.5	0.666	60	193	-45.7111
4	15	0.25	0.499	60	215	-46.6488
5	15	5	0.666	40	213	-46.5676
6	15	7.5	0.333	50	207	-46.3194
7	20	0.25	0.666	50	213	-46.5676
8	20	5	0.333	60	200	-46.0206
9	20	7.5	0.499	40	204	-46.1926

Conclusions

Based on the experimental investigation of bending force on V-bending process, following conclusions are drawn:

1. It is observed from the present work that the signal to noise ratio of bending force varies strongly with the variation in holding time, width of sheet, punch travel and punch velocity respectively, whereas bending force of V-bending process decreases with decrease in process parameters namely in holding time, width of sheet, punch travel and punch velocity respectively.
2. ANOVA table clearly reveals that the holding time (min) is most significant parameter (p

value < 0.05) for bending force with the highest percentage contribution of 49.75 % followed by width of sheet (mm) (29.10 %), punch travel (11.75 %), and punch velocity (10.14 %).

3. R-Squared and R-Squared (adj) for S/N data are 98.74 % and 97.48 %, respectively which is quite good.
4. From signal to noise graph and response table, it is clear that third level of punch travel (20 mm), third level of holding time (7.5 min), third level of punch velocity (0.666 mm/s), and third level of width of sheet (60 mm) shows the highest S/N ratio. Therefore, the optimal setting of process parameters which minimizes the bending force (or maximizes S/N ratio) is A_3 B_3 C_3 D_3.
5. Regression model for the bending force is also derived based on the experimental data. Experimental results are then compared with values obtained from regression model. Percentage variation between in the results is found to be less than 10%, which shows the correctness of methodology for the presented work.

Final Conclusion:

a. It is found from the results that overall methodology used for the analysis of the process is accurate and reliable. This work can be useful for forming industries to enhance the productivity by reducing bending force, which in turn reduces the power consumption

Future Scope

During the process of research work and exhaustive study of literature, few thrust areas are identified for possible future development to be treated as future scope. The proposals for the future work are listed below:

1. Though through the proposed research work, it is found that controlling bending force is necessary for the V-bending process, other operational parameters needs to be control to optimize the process like spring back effect of material, mechanical properties of material, and so on.
2. In the research work, punch travel, holding time, punch velocity and width of the material are chosen as process parameters. Researchers can extend the present work considering machine and component parameters.

   Researchers can extend the present work using different methodology of experimentation like RSM, full factorial, partial factorial, etc

REFERENCES

[1] Choudhury, Imtiaz A., and VahidGhomi. "Springback reduction of aluminum sheet in V-bending dies." Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 228.8 (2014): 917-926.

[2] Karaağaç, İbrahim. "The experimental investigation of springback in V-bending using the flexforming process." Arabian Journal for Science and Engineering 42.5 (2017): 1853-

1864.
[3] Saravanakumar S, Srinivasan S, Muthukannan M, Sankarkannan P, “Analysis of spring back and bend power of galvanized iron sheet in V-Die Bending Phase”, Journal for the Study of Research, Volume XII, Issue V, May-2020, 221-230.
[4] Khadra, Fayiz Abu, and Abdel-Wahab El-Morsy. "Prediction of springback in the air bending process using a Krigingmetamodel." Engineering, Technology & Applied Science Research 6.5 (2016): 1200-1206.
[5] Karaağaç, İbrahim. "The evaluation of process parameters on springback in V-bending using the flexforming process." Materials Research 20.5 (2017): 1291-1299.
[6] ÖZDEMİR, Mustafa. "Optimization of Spring Back in Air V Bending Processing Using Taguchi and RSM Method." Mechanics 26.1 (2020): 73-81.
[7] Panda, Navajyoti, and R. S. Pawar. "Optimization of process parameters affecting on springback in v-bending process for high strength low alloy steel HSLA 420 using FEA and Taguchi technique." World Academy of Science, Engineering and Technology International Journal of Aerospace and Mechanical Engineering 12.1 (2018): 28-34.
[8] Tarun.K.Jadhav and Kumar.K.Bhatt, “Optimization of Springback Effect in Air Bending Process for Tin Coated Perforated Sheet by Taguchi Approach”, International Journal of Advance Research in Engineering, Science & Technology, Volume 3, Issue 5, May-2016
[9] Eltantawie, ManarAbdelhakim, and EldesokyElsayedElsoaly. "A STATIC APPROACH FOR DETERMINATION OF BENDING FORCE AND SPRING-BACK DURING PUNCHING PROCESS." (2012).
[10] Alhammadi, Aysha, et al. "Experimental investigation of springback in air bending process." IOP Conference Series: Materials Science and Engineering. Vol. 323. No. 1. IOP Publishing, 2018.
[11] Gupta, Tilak Raj, and H. S. Payal. "Investigation of spring back in air bending of electrogalvanized CR4 steel." Indian Journal of Science and Technology 10 (2017): 16.
[12] Badrish, Anand, et al. "Parameter Optimization in the Thermo-mechanical V-Bending Process to Minimize Springback of Inconel 625 Alloy." Arabian Journal for Science and Engineering (2020): 1-15.
[13] Khleif, Ali Abbar, Lujain H. Kashkool, and O. H. Hassoon. "Experimental Investigation of Hold Time Effect on Springback in V-Bending Sheet Metal Forming Process." IOP Conference Series: Materials Science and Engineering. Vol. 881. No. 1. IOP Publishing, 2020.
[14] Ahmed, GM Sayeed, et al. "Experimental evaluation of springback in mild steel and its validation using LS-DYNA." Procedia materials science 6 (2014): 1376-1385.
[15] Wasif, Muhammad, et al. "Experimental Analysis and Prediction of Springback in V-bending Process of High-Tensile Strength Steels." Transactions of the Indian Institute of Metals 73.2 (2020): 285-300.
[16] N. Ramu, “Study of Springback and Bend Force in V-Bending Process of Perforated Steel Sheets”, International Journal of Engineering and Applied Sciences (IJEAS) ISSN: 2394-3661, Volume-5, Issue-6, June 2018, 57-59.
[17] Malikov, Viatcheslav, et al. "Experimental investigation and analytical calculation of the bending force for air bending of structured sheet metals." Advanced Materials Research, Vol. 418, Trans Tech Publications Ltd, 2012.
[18] Trzepiecinski, Tomasz, and Hirpa G. Lemu. "Prediction of springback in V-die air bending process by using finite element method." MATEC Web of Conferences, Vol. 121, EDP

Sciences, 2017.

[19] Pritima, D., and P. Padmanabhan. "Investigation of sheet bending parameters on springback in nickel coated mild steel sheets using response surface methodology." Mechanics & Industry 19.2 (2018): 206.

[20] Srinivasan, R., D. Vasudevan, and P. Padmanabhan. "Prediction of bend force and bend angle in air bending of electrogalvanized steel using response surface methodology." Journal of Mechanical Science and Technology 27.7 (2013): 2093-2105.