Synopsis

Investigation & Optimization of process parameters of Roll Bending machine in realizing Conical Shells in Aluminium 6063

A synopsis

Submitted to Gujarat Technological University for the Award of

Doctor of Philosophy

in

Mechanical Engineering

By

Nimesh Patel
Enrollment No. 179999919037

Guided by

Dr. Jeetendra A. Vadher
Professor in Government Engineering College
Modasa

GUJARAT TECHNOLOGICAL UNIVERSITY AHMEDABAD

INDEX

Thesis Title:

Investigation & Optimization of process parameters of Roll Bending machine in realizing Conical Shells in Aluminium 6063.

Abstract:

In the current research, : For the sheet metal forming by roller bending machine, achieving the accurate geometry of components is the crucial task of many manufacturing industries. This is because of the "Springback" which refers to the elastic recovery of the deformed component. The microstructure and macroscopic mechanical properties of the sheet undergo changes during its forming process which results in inaccurate geometry of the component. These changes are common and inevitable in each phase of the production process. Hence to predict and controlling the Springback as per the geometrical shape requirements is one of the key factors influencing the quality of rolled sheet metal parts. In this research work, the investigation is made on realizing accurate conical shell-shaped components by roller bending machine for the material of construction (MOC) Aluminium 6063. Effects of sheet metal thickness, number of passes, roller pressure, and roller rpm on Springback for Aluminium 6063 are analyzed. After the testing of the spring back analysed with the regression analysis. In the validation work, Select the one input parameter range to develop a abaqus model. This model has been generated on the Abaqus software and after getting the result validate the result. Validation of the work has been compared the analytical work and practical work. Also find the errors between practical and analytical work.

Introduction:

The word manufacture is derived from two Latin words, manus (hand) and factus (make). As a field of study in the modern era, manufacturing is defined two ways, one technologic and the other economic. Technologically, manufacturing is the application of physical and chemical processes to alter the geometry, properties, and appearance of a given starting material to make parts or products. Manufacturing also includes assembly of different parts to make products. The processes to accomplish manufacturing involve a combination of machinery, tools, power, and labour, as depicted in Figure 1.1.

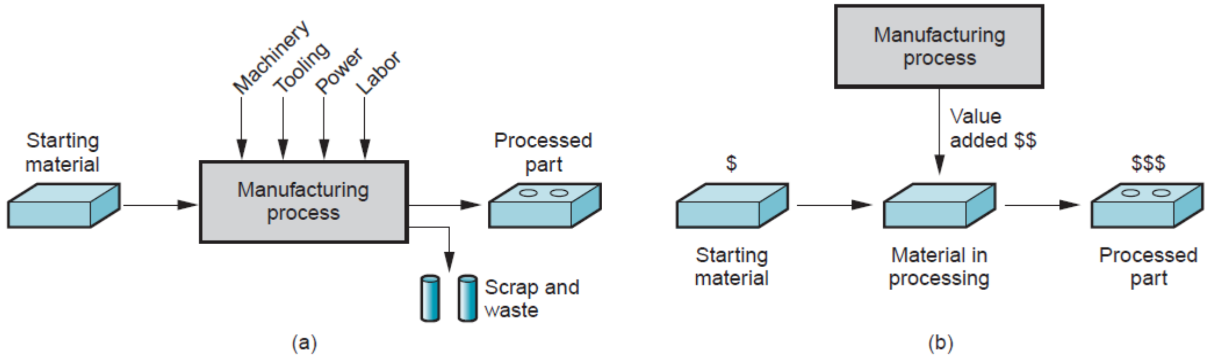


Fig 1 Manufacturing system (a) technical process (b) Economic process

Manufacturing is carried out as a sequence of operations. Each operations bring the material closer to the desired final state. Economically, manufacturing is the transformation of materials into items of greater value by means of one or more processing of assembly operations. The key point is that manufacturing adds value to the material by changing its shape and size by combining processes. The material has been made valuable product through the manufacturing operations performed on material. Some of examples of manufacturing process such as iron ore is converted into steel, sand is transformed into glass, petroleum is refined into plastic, Plastic is moulded into the complex geometry of a patio chair, it is made for valuable products. The words manufacturing and production are often used interchangeably. The author's view is that production has a broader meaning than manufacturing.

Manufacturing may produce many products, meaning individual parts or pieces of parts or it may produce continuous products. Nails, gears, steel balls, beverage cans and engine blocks are example of products. Metal or plastic sheet, wire, hose and pipe are continuous products that may be cut into individual pieces and thereby become discrete products. Because a manufactured item has undergone a number of changes during which raw material has become a useful product, it has added value, defined as monetary worth in terms of price.

Three roller bending

The three roller bending process is one aimed at producing materials with various curvatures by a set of three rollers.

In roller bending forces acting on plate, rolls undergo changes in shape during rolling. Just as a straight beam deflects under a transverse load, roll force tend to bend the rolls elastically during rolling. As expected, the higher the elastic modulus of the roll material, the smaller the roll deflection. As a result of roll bending, the rolled strip tends to be thicker at its center than at its edges. The usual method of avoiding this problem is to grind the rolls in such a way that their diameter at the center is slightly larger than at their edges.

In this, plate is fed by two side rollers and bends to a desired curvature by adjusting the position of center top roller in one or several passes. Distance between the bottom rollers can also be varied. In three rollers bending machine desired curvature is function of thickness (t). width (b)of plate, material properties, center distance between the two bottom rollers and positionof the top roller. The involvement of so many parameters together makes the problem complex and till now experience on the shop-floor is taken as guide lines for a process planning. Any change in shape, material, machine required the similar experience to be developed again before satisfactory production can be obtained. Three roller bending process shown in the figure no. 1.4.

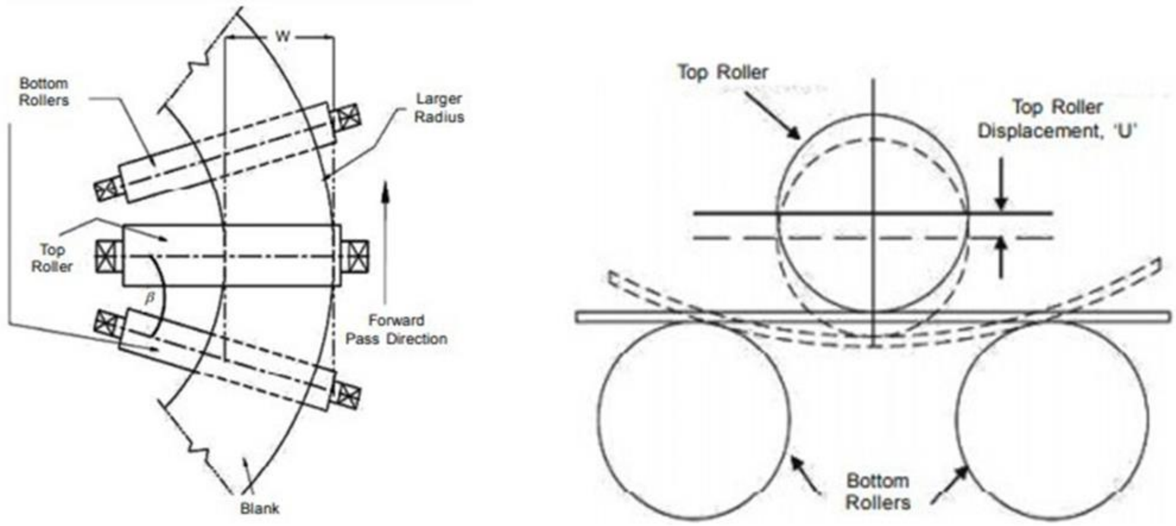


Fig 2 Three roller bending process

Problem statement

In present days manufacturing industries, Aluminium has been a regular and extensively used material. Especially in aerospace, defense, and automotive industries, Aluminium alloys are favorable materials because of their comparatively light in weight and agreeable durable properties. Despite the fact that, Aluminium alloys have moderately lowered tensile strengths in comparison to steel, their strength to weight ratio seems adequate. As the punch is withdrawn from the sheet during the bending process, and elastic recovery happens because the elastic stresses are released. This elastic recovery is called spring back. Springback is a significant and dominant criterion in deriving the required form configurations of the part and design of the corresponding tooling. It is still an on-the-job production problem to predict the semi-finished geometry of the part after spring back and to design the appropriate tools to compensate for the spring back. Common techniques, which require using firsthand formulae and some heuristic procedures, result in the expenditure of efforts, time and raw material. From some recent years, with Taguchi, ANOVA and Optimization techniques have been appraised as an effective approach of describing bending processing and predicting spring back. Design of Experiments facilitates numerical analysis, which cause to shorter duration and more cost-effective design approach. In addition, Finite Element Analysis tools are used to represent and simulate numerous operations of tools and environments for metal-forming applications.

So above discussion, we make a statement “Investigation & Optimization of process parameters of Roll Bending machine in realizing Conical Shells in Aluminium 6063”.

Objectives of research

Objectives of research work as per the given below

- To Find out an optimum process parameter to improve Spring back effect of Material Al 6063 by bending operation with three roller bending process.
- Identify number of Parameters responsible for Spring back effect for Al 6063 Material using 3 roll Bending machine during Rolling Process.
- Application of Taguchi method to identify effectiveness of identified parameters with experimental Result.
- Develop mathematical model to check effectiveness of Parameters identified by experimental method for Al 6063 for 3 roll bending Process.
- Identify (% error) between experimental Result and mathematical model.
- Develop an approach to simulate the 3 Roller cone bending and Springback effect in FEA Analysis.
- Study the Springback effect in simulation results from FEA Analysis.
- Validation of experimental result, and mathematical model by using FEA Analysis.

Methodology of research

In general, ‘methodology’ is the strategy that outlines the way in which research work is to be undertaken and identifies the methods used in it. It does not define a specific method but conveyed the nature of the processes followed by the objectives. This chapter describes methodology and experimental work of three roller bending process. To select the materials as per the application. Three roller bending process select process, number of pass, roller pressure, pilot test with different input parameters and final experiment with Design of experiment (D.O.E) and characteristics are discussed here.

This section describes the methodology used in current research.

- Identification of independent, dependent, and independent extraneous variables.
- Reduction of independent variables adopting dimensional analysis.
- Determination of test envelope, test points, test sequence, and experimentation plan.
- Physical design of an experimental set up.
- Execution of experimentation for data collection.
- Purification of experimentation data.
- Analysis of practical data.
- Model optimization.
- Sensitivity analysis and validation of the model.

Pilot test

In this research work total 3 pilot runs have been performed with different input parameters. A successive pilot test has been performed to overcome the limitations of previous test. All the results such as inner and outer diameter of the cone plate, bending process, number of pass, thickness of the plate etc. of the third pilot test have been founded satisfactory. Final process parameter ranges has been finalized based on all positive aspects of three pilot tests. Pilot test image shown in the figure no 3.2.

(i)

(ii)

Fig 3 Pilot test images (i) top view (ii) bottom view

Testing

Spring back

Spring back is the geometric change made to a part at the end of the forming process when the part has been released from the forces of the forming tool. Upon completion of sheet metal forming, deep-drawn and stretch-drawn parts spring back and thereby affect the dimensional accuracy of a finished part. The final form of a part is changed by spring back, which makes it difficult to produce the part. As a result, the manufacturing industry is faced with some practical problems: Firstly, prediction of the final part geometry after spring back and secondly, appropriate tools must be designed to compensate for these effects.

Through the application of new materials, the number of problems increases. Forming parts made of these materials are more affected by spring back than parts made from conventional deep-drawn steel. Concerning classic sheet metal defects such as splits and wrinkles, strain in the sheet metal is decisive. If spring back occurs, such models are not enough to predict a deformation. In this case, the stresses are decisive and a considerably higher accuracy is crucial.

During the development of tools, spring back is compensated by software in order to remove the part from the tool straight away in the required dimensions. Intense tryout loops, which occur at a very late stage in the development of the tool, are reduced to a minimum.

Result and discussion

The result of the spring back has been shown in the below table 1

Table 1 result of spring back

SR NO.	ROLLER SPEED (RPM)	PRESSURE(KG/CM^2)	THICKNESS (MM)	NO.OF PASS	SPRINGBACK (mm)
1	8	1200	1	1	1.206
2	8	1200	1	1	1.237
3	8	1200	1	1	1.223
4	8	2400	2	2	0.932
5	8	2400	2	2	0.957
6	8	2400	2	2	0.926
7	8	3600	3	3	0.856
8	8	3600	3	3	0.844
9	8	3600	3	3	0.801

10	9	1200	2	3	0.794
11	9	1200	2	3	0.789
12	9	1200	2	3	0.798
13	9	2400	3	1	0.979
14	9	2400	3	1	0.963
15	9	2400	3	1	0.954
16	9	3600	1	2	1.075
17	9	3600	1	2	1.089
18	9	3600	1	2	1.099
19	10	1200	3	2	0.934
20	10	1200	3	2	0.918
21	10	1200	3	2	0.907
22	10	2400	1	3	0.931
23	10	2400	1	3	0.945
24	10	2400	1	3	0.967
25	10	3600	2	1	1.084
26	10	3600	2	1	1.087
27	10	3600	2	1	1.071

Optimization problem formulation

The present study aimed to determine the set of optimal parameters of the bending process to ensure springback condition. The optimization obtained in terms of roller speed, Pressure, Thickness and number of pass. After generated equations, it is implement in the regression equation:

Spring back(mm) = 0.0036 +0.0227 × Roller Speed (Rpm) - 0.0014 ×Pressure (kg/mm2) -0.1973 ×Thickness(mm) -0.1284 × No. Of Pass

As per ANOVA analysis, test experiment articulates that the chording experimental combination is a top-notch condition of optimization and offers better product quality. Further, the approximation of marginal effect as well as the determination of exceptional proportion for all governable factors can be achieved from the established. Since it is known that elevated value of ANOVA will provide the best value of spring back. Therefore, it is exhibited that the response will be the best at Roller Speed: 8 Rpm, Roller Pressure: 3600 kg/cm2, thickness: 3 mm, and a number of passes.

Table 2 Response table for signal to noise ratios

Level	*Roller speed (RPM*	*Pressure (KG/CM²)*	*Thickness (mm)*	*No. of pass*
1	2.3.10	2.2007	-0.6893	0.2085
2	2.1538	1.4383	3.2744	2.5954
3	1.4572	2.2734	3.3272	3.1084
Delta	0.8441	0.8351	4.0166	2.8999
Rank	3	4	1	2

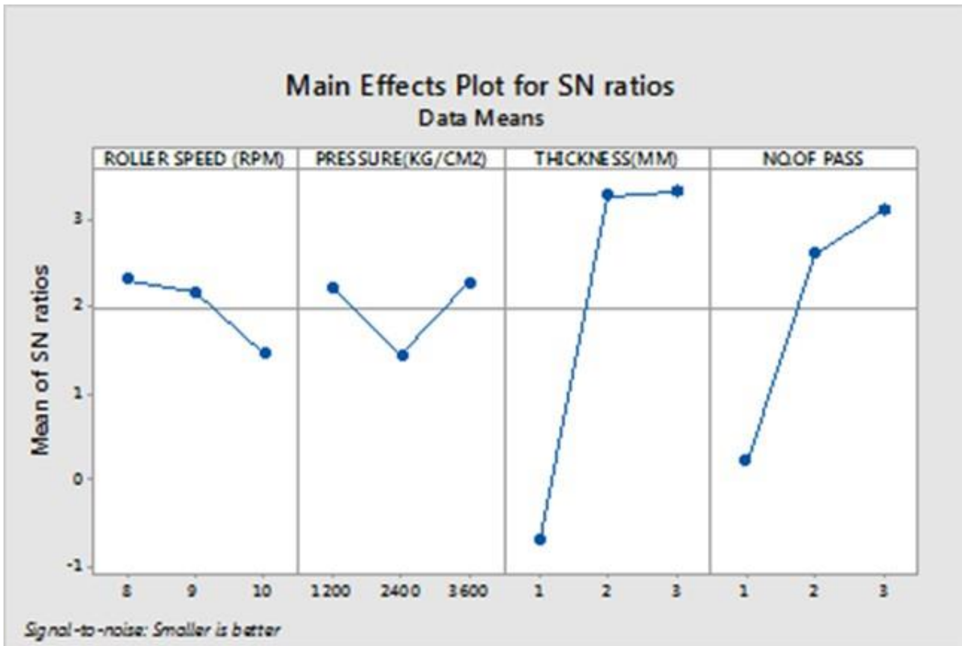


Fig. 4. Spring back signal to Noise Ratios

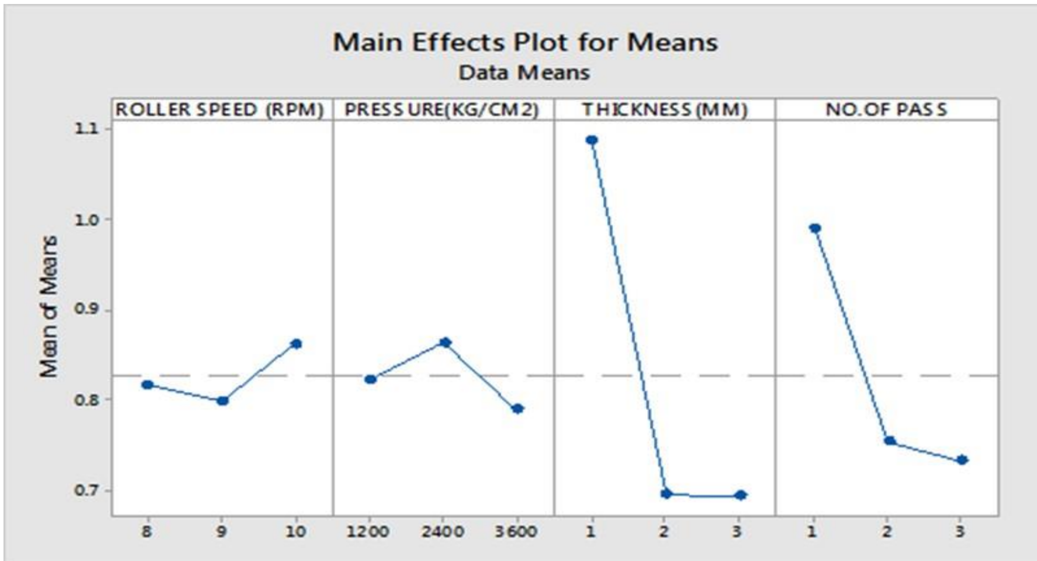


Fig. 5 Main effect Plot of SN ratio for spring back

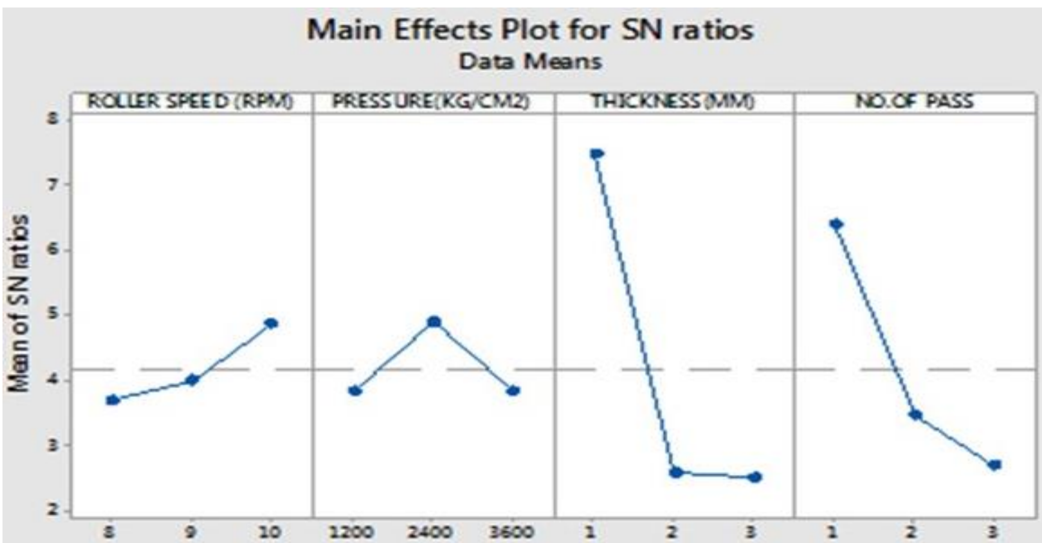


Fig. 6 Main effect Plot for Means for spring back

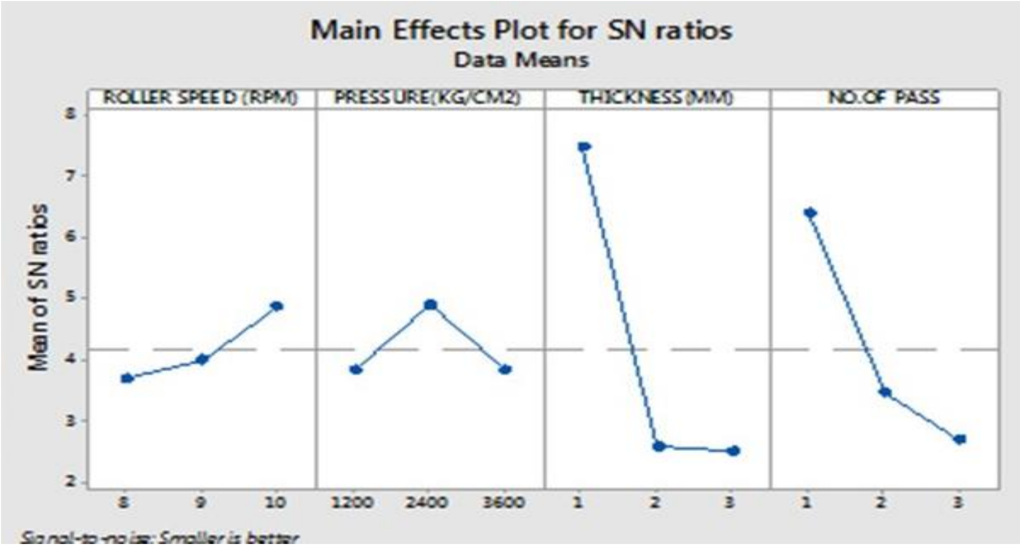


Fig 7 Main effect Plot of Grey Relational Grade

Finite element analysis

In this research work validation of the work with the help of the finite element analysis. Firs generate 3D CAD model of 3-Roll Bending Assembly Setup which consists asymmetric arrangement of rollers and a flat sheet made from Al 6063-T5. It is subjected to rolling and bending forces exerted on it due to rollers during its forming operation for producing cone. The present FEA analysis simulate the rolling bending operation for producing cone and measuring Springback effect in sheet for the given operating parameters. All guiding, rolling and bending rollers are considered rigid bodies as 2D surfaces and only sheet is analyzed as solid flexible body.

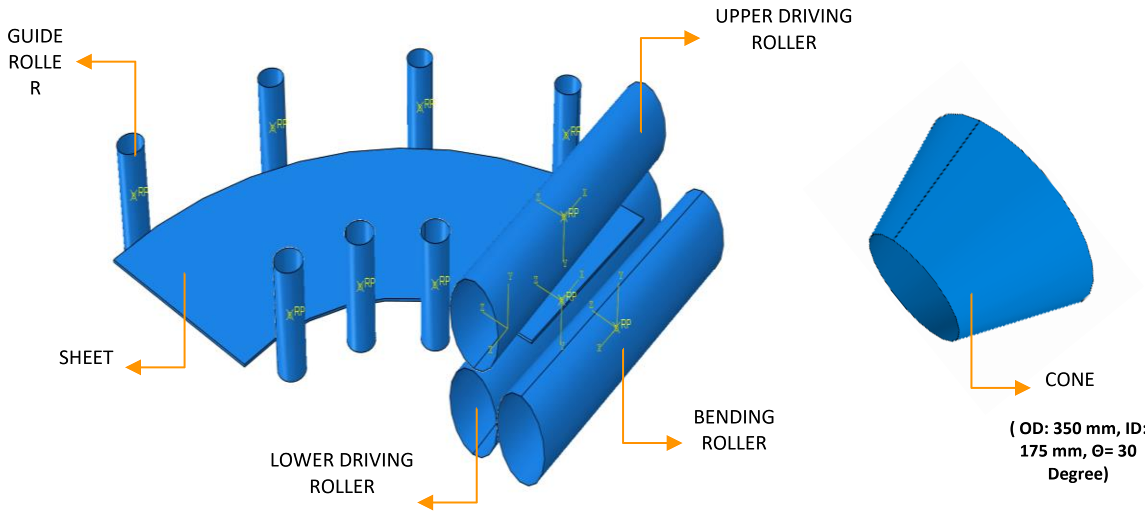
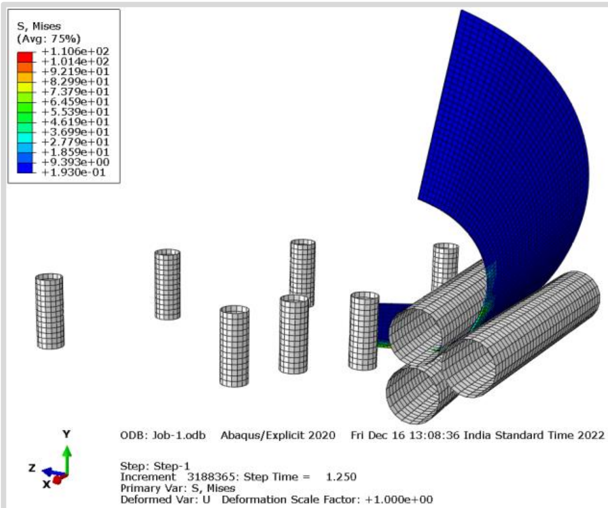
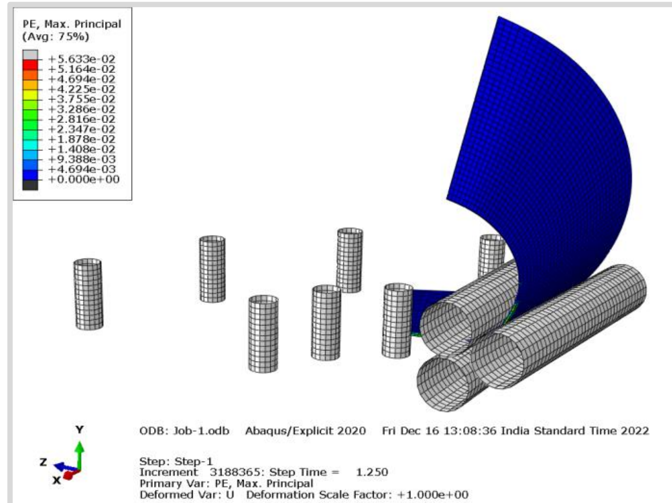


Fig 8 ROLL BENDING ASSEMBLY SETUP

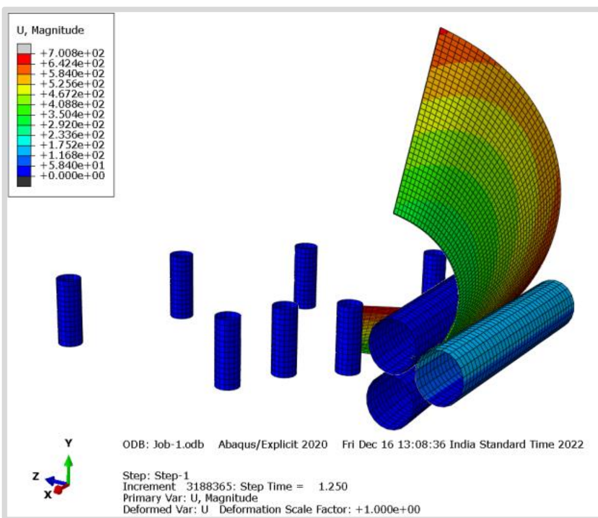
In this model document the finite element analysis results of 3-Roll Bending operation to form a cone for the given operating parameters (1) Sheet thickness: 2 mm, (2) Roller Speed: 9 RPM, (3) No. of Pass: 1 and (4) Roller displacement: 52.5 for the desired cone dimensions (OD: 350 mm, ID: 175 mm, Θ= 30 Degree). After the analysis of the work found the some Equivalent elastic stress in figure (i) and the figure (ii) permanent elastic strain. In the below figure (iii) is deformation. It is found maximum deformation 642 mm. In figure (iv) gives information about the spring back effect. In the whole process put the input parameters and found total deformation, and spring-back effect on the Aluminium plate.



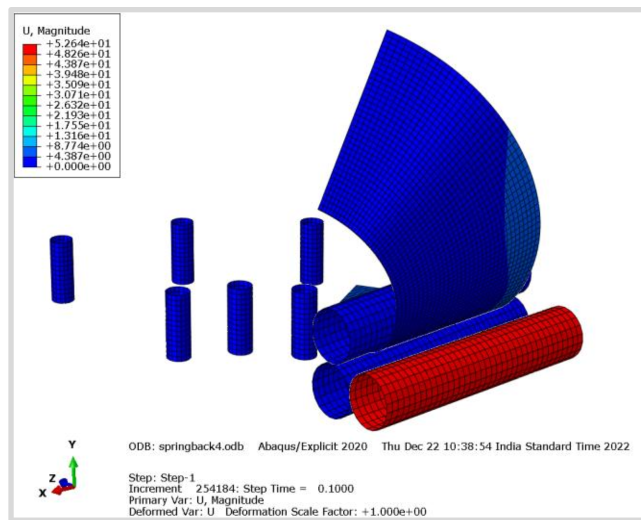
(i)



(ii)



(i)



(iv)

Fig 9 (i) Equivalent elastic stress (ii)Permanent elastic strain (iii)Deformation (iv) Spring back effect

Result of the finite element analysis

Table 3 Result of finite element analysis

CASE	COMPONENT	SHEET THK (MM)	ROLLER SPEED (RPM)	NO. OF PASS	ROLLER DISPLACEMENT (MM)	ANALYSIS RESULTS				
						MAX. STRESS VALUE (MPA)	MAX. STRAIN VALUE	MAX. DEFORMATION (MM)	MAX. SPRINGBACK, U1 (MM)	MAX. SPRINGBACK, U3 (MM)
1	FEA_3-ROLL BENDING_13	3	9	1	52.51	110	0.05	642	2.72	3.16

Mathematical model

The main objective of this section is to formulate a mathematical model to predict Spring Back effect of Al6063 in three-roller bending machine using dimensional analysis. A mathematical model is a description of a system or a process in mathematical forms. A model helps to explain a system or a process and to study the effects of different parameters influencing the response. Dimensional analysis is a powerful tool for understanding and analyzing engineering problems. Dimensional analysis computes dimensionless groups of parameters and provides information to what group of parameters affects the response. To formulate the mathematical model, Buckingham pi theorem is used. Buckingham's Pi Theorem [10] states that if there is a physically meaningful equation involving a certain number n of physical variables, then the original equation can be rewritten in terms of a set of $p=n-k$ dimensionless parameters $\pi 1$, $\pi 2$, …, πp constructed from the original variables. To calculate dimensionless pi terms, all dependent and independent parameters are expressed in terms of fundamental [MLT] physical quantities.

D = Top Roller Diameter in mm

E = Young's Modulus of Material N/mm2

T = Thickness of Plate in mm.

σ = Yield Strength of Material N/mm2

n = Number of Passes

k = Curve Fitting Constant

a to d = Exponents of Independent Parameters

S = Spring Back in mm.

G = Acceleration due to gravity of Top Roller in mm/sec^2

For three-roller bending process, total 08 parameters are selected, out of which 03 are selected as repeating variables (*D*, σ ,*G*). Hence, 05 independent pi groups are formed. Here the development of mathematical model is for Spring back . So, for model development, 05 independent pi groups are used. Description of parameters with fundamental form and dimensionless pi groups are as shown in Table.

Each dependent pi term is the function of the available independent Pi terms.

Hence,

$f(\pi 1, \pi 2, \pi 3, \pi 4, \pi 5) = 0$ ………………………………………………………………………….………………..*(1)*

A probable exact mathematical form for the dimensional equations of the phenomenon could be assumed to be of exponential form as

$\pi_1 = k(\pi_2)^a (\pi_3)^b (\pi_4)^c (\pi_5)^d$

In this modelling total variable 8, Repeating variable is 3 so total pi terms are 5. $\pi 1$ = Spring Back, $\pi 2$ = Effect of Roller Pressure, $\pi 3$ = Effect of Roller Rpm, $\pi 4$ = Effect of Thickness of Material, $\pi 5$ = Effect of No. of Passes.

$$\pi 1 = S \; D^a \sigma^b G^c$$

$$M^o L^0 T^0 = M^o L^1 T^0 \; (M^o L^1 T^0)^a \; (M^1 L^{-1} T^{-2})^b (M^0 L^1 T^{-2})^c$$

After Solving above equation,

a = -1,b=0,c=0.

$$\boldsymbol{\pi 2 = P \; D^a \sigma^b G^c}$$

$$\boldsymbol{M^o L^0 T^0 = M^1 L^{-1} T^2 \; (M^o L^1 T^0)^a \; (M^1 L^{-1} T^{-2})^b (M^0 L^1 T^{-2})^c}$$

After Solving above equation,

a = 0,b=-1,c=0.

$$\boldsymbol{\pi 3 = N \; D^a \sigma^b G^c}$$

$$\boldsymbol{M^o L^0 T^0 = M^o L^0 T^{-1} (M^o L^1 T^0)^a \; (M^1 L^{-1} T^{-2})^b (M^0 L^1 T^{-2})^c}$$

After Solving above equation,

a = 1/2,b=0,c=-1/2.

$$\pi 4 = T \; D^a \, \sigma^b \, G^c$$

$$M^o L^0 T^0 = M^o L^1 T^0 \; (M^o L^1 T^0)^a \; (M^1 L^{-1} T^{-2})^b \, (M^0 L^1 T^{-2})^c$$

After Solving above equation,

a = -1,b=0,c=0.

$\pi 5$ **= Effect of No. of Passes**.

$$\pi 5 = n \; D^a \, \sigma^b \, G^c$$

$$M^o L^0 T^0 = M^o L^0 T^0 \; (M^o L^1 T^0)^a \; (M^1 L^{-1} T^{-2})^b \, (M^0 L^1 T^{-2})^c$$

After Solving above equation,

a = 0,b=0,c=0.

A probable exact mathematical form for the dimensional equations of the phenomenon could be assumed to be of exponential form as

$$\pi_1 = k \, (\pi_2)^a \, (\pi_3)^b \, (\pi_4)^c \, (\pi_5)^d$$

$$S/D = K \, (P/\sigma)^a \; (N \sqrt{D/G})^b \; (T/D)^c \; (n)^d$$

Here, K is curve fitting constant and *a* to *d* be indices which needs to be calculated by multi variable regression analysis at 95 percent confidence interval.

By using data obtained in experimental part of this investigation and substituting these parameters in equation number (A).The predictive model for spring back follow as .

$$\log \pi_1 = \log k + a \log \pi 2 + b \log \pi 3 + c \log \pi 4 + d \log \pi 5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

As per multi variable regression analysis at 95 percent confidence interval using data obtained in experimental part of this investigation

Spring back(mm) = 0.0036 +0.0227 Roller Speed (Rpm) - 0.0014 Pressure(kg/Mm2) - 0.1973 Thickness(mm) -0.1284 No.Of Pass ……………………………………………(3)

By analyzing above equations,

The constant **K = 0.0036**

a = -0.0014 , b = 0.0227 , c = -0.1973 , d = -0.1284

$$S = K\ D\ (P/\sigma)^{a}\ (N \sqrt{D/G})^{b}\ (T/D)^{c}\ (n)^{d}$$

$$S = K\ D\ (P/\sigma)^{-0.0014}\ (N \sqrt{D/G})^{0.0227}\ (T/D)^{-0.1973}\ (n)^{-0.1284} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Developed model for *π1* related to spring back of three-roller bending machine is analyzed by calculating percentage error between experimental values and values obtained from mathematical model. Values of dependent parameter *π1* from mathematical model are obtained by putting the experimental values of independent variables in mathematical model formed. Deviation of the values obtained from mathematical model from actual experimental values of dependent parameters shows closeness of the mathematical model with real-life process. Deviation of the values can be obtained in terms of percentage error. Following mathematical relationship will give percentage error between actual values and mathematical values.

$$\text{Percentage Error} = \left(\frac{\textit{Experimental values} - \textit{Model values}}{\textit{Experimental values}}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Percentage error for *π1* related to spring back obtained is less than 10%.In the below table shows that values obtained from mathematical model are close with actual experimental values.

Table 4 Validation of experimental and model value

SR. NO.	SPRING BACK (MM)	$(P/\sigma)^{-0.0014}$	$(N \sqrt{D/G})^{0.0227}$	$(T/D)^{-0.1973}$	$n^{-0.1284}$	K	Model SPRINGBACK (MM)	Perce. error(%)
1	1.206	1.000289	1.027584272	2.57171276	1.000	0.0036	1.14195	5.31
2	1.237	1.000289	1.027584272	2.57171276	1.000	0.0036	1.14195	7.68
3	1.223	1.000289	1.027584272	2.57171276	1.000	0.0036	1.14195	6.62
4	0.932	0.999322	1.027584272	2.24299984	0.915	0.0036	0.9103	2.32
5	0.957	0.999322	1.027584272	2.24299984	0.915	0.0036	0.9103	4.88

6	**0.926**	**0.999322**	**1.027584272**	**2.24299984**	**0.915**	**0.0036**	**0.9103**	**1.69**
7	**0.856**	**0.998755**	**1.027584272**	**2.0705534**	**0.868**	**0.0036**	**0.79723**	**6.86**
8	**0.844**	**0.998755**	**1.027584272**	**2.0705534**	**0.868**	**0.0036**	**0.79723**	**5.54**
9	**0.801**	**0.998755**	**1.027584272**	**2.0705534**	**0.868**	**0.0036**	**0.79723**	**0.47**
10	**0.794**	**1.000289**	**1.030335374**	**2.24299984**	**0.868**	**0.0036**	**0.86727**	**9.22**
11	**0.789**	**1.000289**	**1.030335374**	**2.24299984**	**0.868**	**0.0036**	**0.86727**	**9.92**
12	**0.798**	**1.000289**	**1.030335374**	**2.24299984**	**0.868**	**0.0036**	**0.86727**	**8.68**
13	**0.979**	**0.999322**	**1.030335374**	**2.0705534**	**1.000**	**0.0036**	**0.92099**	**5.92**
14	**0.963**	**0.999322**	**1.030335374**	**2.0705534**	**1.000**	**0.0036**	**0.92099**	**4.36**
15	**0.954**	**0.999322**	**1.030335374**	**2.0705534**	**1.000**	**0.0036**	**0.92099**	**3.46**
16	**1.075**	**0.998755**	**1.030335374**	**2.57171276**	**0.915**	**0.0036**	**1.0459**	**2.70**
17	**1.089**	**0.998755**	**1.030335374**	**2.57171276**	**0.915**	**0.0036**	**1.0459**	**3.95**
18	**1.099**	**0.998755**	**1.030335374**	**2.57171276**	**0.915**	**0.0036**	**1.0459**	**4.83**
19	**0.934**	**1.000289**	**1.03280256**	**2.0705534**	**0.915**	**0.0036**	**0.8454**	**9.48**
20	**0.918**	**1.000289**	**1.03280256**	**2.0705534**	**0.915**	**0.0036**	**0.8454**	**7.90**
21	**0.907**	**1.000289**	**1.03280256**	**2.0705534**	**0.915**	**0.0036**	**0.8454**	**6.79**
22	**0.931**	**0.999322**	**1.03280256**	**2.57171276**	**0.868**	**0.0036**	**0.99579**	**6.95**
23	**0.945**	**0.999322**	**1.03280256**	**2.57171276**	**0.868**	**0.0036**	**0.99579**	**5.37**
24	**0.967**	**0.999322**	**1.03280256**	**2.57171276**	**0.868**	**0.0036**	**0.99579**	**2.97**
25	**1.084**	**0.998755**	**1.03280256**	**2.24299984**	**1.000**	**0.0036**	**0.99951**	**7.79**
26	**1.078**	**0.998755**	**1.03280256**	**2.24299984**	**1.000**	**0.0036**	**0.99951**	**7.28**
27	**1.071**	**0.998755**	**1.03280256**	**2.24299984**	**1.000**	**0.0036**	**0.99951**	**6.67**

Conclusions

In three roller bending process is a high potential in the field of the metal bending with various metals. This research presents an investigation & Optimization of process parameters of Roll Bending machine in realizing Conical Shells in Aluminium 6063. In this work design of the three roller bending has been done using Abaqus to analyze the shear stress and strain. A systematic approach has been adopted for the perform the bending. Experiments have been conducted for various combinations of parameters. Three levels of roller pressure, roller speed, sheet thickness, number of pass have been taken during experimental investigation using a taguchi L9 Method of experiment. The spring-back of the bending plate has been analyzed by quantitative method. Pie-theorem has been used for the generate mathematical model for the work. Regression analysis has been done for the which parameter is highly impact on the three roller bending process. Experimental validation has been done using Abaqus analysis work. The following conclusions are derived.

- From the above work first generate design of three roller bending machine with abaqus software to analysis of the work.
- From the ANOVA it is found that the main factor of the spring back is thickness of the material, second number of pass, third roller speed and last pressure.
- For all parameters p value is below than 5% so work is accepted.
- In FEA analysis maximum stress found as 110 Mpa, Max strain is 0.05, Max spring back U1 and U3 have 2 to 3 mm
- It also validate this work with FEA to experimental work .
- The curve fitting constant in the model is 0.0036 This value represents the effect of clearances and other factors which affect the phenomena.
- Percentage error for Spring back obtained is less than 10%. It shows that values obtained from mathematical model are close with actual experimental values.
- A generalized field data-based model is developed to predict Spring back effect. Methodology of dimensional analysis is used. It is found that the independent pi terms influencing the dependent pi term $\pi 1$ in descending order. The following primary conclusions appear to be justified from the above model.
- The absolute index value of $\pi 3$(Rpm) is highest and is equal to 0.0227 Thus, terms used in $\pi 3$ group are most influencing. The value of the index is positive indicating $\pi 1$ directly varying with respect to $\pi 3$.

- The absolute index value of π4 (Thickness) is lowest and is equal to −0.1973. Thus, terms used in π4 group are least influencing. The value of the index is negative indicating π1 inversely varying with respect to π4.
- The sequence of influence of the other independent pi terms present in the model are π5(No. of pass) and π2(roller pressure) having absolute indices −0.1284 and −0.0014 respectively.
- Above details presented a new methodology of dimensional analysis to develop relationship of various parameters of bending process. It is concluded that dimensional analysis is simple and excellent when functional relationship among variables is unknown.

Future scope

- Further research on the different inlet and outlet diameter of the cone.
- Different materials will be use for the further study of the research with different parameters.

List of publications:

- Investigation of roll bending machine in realizing conical shells: AEGAEUM journal: Volume X issues IX September 2022

- Review on spring back effect in bending of conical shells in roll bending machine: Gradiva review journal : volume 8 issue 10 october 2022: GRJ4135

- Investigation and optimization of process parameters of roll bending machine in realizing conical shells in Aluminium 6063 : International Multi- disciplinary engineering conference (IMEC-2022) 4^{th}- 6^{th} August 2022.

References:

- A Mercuri, P Fanelli, F Giorgetti, G Rubino and C Stefanini: Experimental and numerical analysis of roll bending process of thick metal sheets : IOP Conf. Series: Materials Science and Engineering 1038 (2021) 012067
- A. H. Gandhi, A. A. Shaikh, and H, Formulation of Springback and machine setting parameters for multi-pass three-roller cone frustum bending with change of flexural modulus, Inter- national Journal of Material Forming 2 (1).
- A. H. Gandhi, and H, Analytical and empirical modeling of top roller position for three-roller cylindrical bending of plates and its experimen- tal verification, Journal of Materials Processing Technology 197 (1-3) (2008) 268–278.
- Chudasama, M. K., & Raval, H. K. (2014). Bending force prediction for dynamic roll-bending during 3-roller conical bending process. Journal of Manufacturing Processes, 16(2), 284–295. doi:10.1016/j.jmapro.2013.09.008
- D. E. Hardt, C. E. Wright, and A, A model of sequential bending process for manufacturing simulation, J Eng Ind 114 (1992) 181–187.
- E. A. Kulikov, Y. I. Berliner, and G. I. Shevyakov, bending thick-walled conical vessel sections on roll bending machines, Chemical and Petroleum Engineering 5 (12) (1969) 977–979.
- Feijun, X., He, Y., & Hongsheng, X. (2000). Finite element analysis of effects of parameters on in-plane bending process of strip metal. Journal of Materials Processing Technology, 102(1-3), 78–83. doi:10.1016/s0924-0136(00)00460-x
- G. Pradeep Dev, P. Sam Livingston, M. Shunmuganathan, R. Surendar, A. Siva Subramanian, A. Simon Christopher, K. C. Ganesh. Analysis of 6061 Aluminium Alloy Sheet Metal Bending Process for Various Thickness Using Finite Element Modelling. International Journal of Theoretical and Applied Mathematics. Vol. 2, No. 2, 2016, pp. 93-99. doi: 10.11648/j.ijtam.20160202.20
- Gattmah, J., Ozturk, F., & Orhan, S. (2019). Numerical Simulation of Bending Process for Steel Plate Using Finite Element Analysis. Arabian Journal for Science and Engineering. doi:10.1007/s13369-019-04119-8

- Gavrilescu, I.; Boazu, D.; Stan, F. Estimating of Bending Force and Curvature of the Bending Plate in a Three-Roller Bending System Using Finite Element Simulation and Analytical Modeling. Materials 2021, 14, 1204. https://doi.org/10.3390/ ma14051204
- H. Huh, J. H. Heo, and H. W. Lee, Optimization of a roller levelling process for Al7001T9 pipes with finite element analysis and Taguchi method, International Journal of Machine Tools and Man- ufacture 43 (4) (2003) 345–350.
- Hai Gong, Xiaoliang Sun, Yaoqiong Liu, Yunxin Wu, Yanan Wang and Yanjie Sun : Residual Stress Relief in 2219 Aluminium Alloy Ring Using Roll-Bending: Materials 2020, 13, 105; doi:10.3390/ma13010105
- Hu, Z. Q., Li, M. Z., Cai, Z. Y., & Gong, X. P. (2009). Continuous flexible forming of three-dimensional surface parts using bendable rollers. Materials Science and Engineering: A, 499(1-2), 234–237. doi:10.1016/j.msea.2007.11.107
- Hua, M., Sansome, D. H., Rao, K. P., & Baines, K. (1994). Continuous four-roll plate bending process: Its bending mechanism and influential parameters. Journal of Materials Processing Technology, 45(1-4), 181–186. doi:10.1016/0924-0136(94)90338-7
- J. Zeng, Z. Liu, and H. Champliaud, FEM dy- namic simulation and analysis of the roll-bending process for forming a conical tube, Journal of Materials Processing Technology 198 (1-3) (2008) 330–343.
- Jan SLOTA, Ivan GAJDOS, Emil SPIŠÁK, Marek ŠISER: Springback prediction of stretching process using finite element analysis for dp600 steel sheet: acta mechanica et automatica, vol.11 no.1 (2017)
- Jenan Mohammed Naje: Effect of radius and angle of bending on the concentration of stresses in the Aluminium sheet: ISSN (Online) : 2454 -7190 Vol.-14, No.-5, September - October (2019) pp 379-395
- Ktari, A., Abdelkefi, A., Guermazi, N., Malecot, P., & Boudeau, N. (2021). Numerical investigation of plastic flow and residual stresses generated in hydroformed tubes. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 235(5), 1100–1111. doi:10.1177/1464420721989746

- Ktari, A., Antar, Z., Haddar, N., & Elleuch, K. (2012). Modeling and computation of the three-roller bending process of steel sheets. Journal of Mechanical Science and Technology, 26(1), 123–128. doi:10.1007/s12206-011-0936-4
- M. Hua, D. H. Sansome, and K. Baines, Mathe- matical modeling of the internal bending moment at the top roll contact in multi-pass four-roll thin- plate bending, Journal of Materials Processing Technology 52 (2-4) (1995) 425–459. G. Kajrup, and A. Flam
- M. K. Chudasama, and H, Bending force pre- diction for dynamic roll-bending during 3-roller conical bending process, Journal of Manufactur- ing Processes 16 (2) (2014) 284–295.
- Nejad, M. Z., Jabbari, M., & Ghannad, M. (2015). Elastic analysis of FGM rotating thick truncated conical shells with axially-varying properties under non-uniform pressure loading. Composite Structures, 122, 561–569. doi:10.1016/j.compstruct.2014.12.
- Park, S.-M., Lee, J., Park, S., Lee, J.-W., Park, M., Kim, Y., & Noh, G. (2020). Practical bending-angle calculation for an automated surgical plate bending apparatus. Journal of Mechanical Science and Technology, 34(5), 2101–2109. doi:10.1007/s12206-020-0432-9
- Peng, J., Li, W., Wan, M., Zhang, C., Li, J., & Sun, G. (2017). Investigation on three-roller cylindrical bending of 2060-T8 Al-Li alloy plate for aircraft fuselage skin components. International Journal of Material Forming, 11(2), 269–278. doi:10.1007/s12289-017-1350-y
- Péter Máté András Szek rényes: Numerical modelling of the three-roll bending process of a thin plate : Műszaki Tudományos Közlemények vol. 13. (2020) 133–136.
- R. I. Nepershin, Bending of a thin strip by a circular tool, Mechanics of Solids 42 (4) (2007) 568–582.
- Rameshwar J. Sherepatil , Prof. R. L. Karwande , Prof. P. S. Thakare : The optimization of Three roller bending process parameter by using the Taguchi method : IJARIIE-ISSN(O)-2395-4396- Vol-6 Issue-6 2020
- Rameshwar J. Sherepatil, R. L. Karwande, Prafull S. Thakare, Mohamad Javed: Comprehensive review on three roller bending operation; International Journal of Advance Research, Ideas and Innovations in Technology; volume 5 issue 6 2020

- S. L. Zang, J. Liang, and C. Guo, A constitu- tive model for spring-back prediction in which the change of Young’s modulus with plastic de- formation is considered, International Journal of Machine Tools and Manufacture 47 (11) (2007) 1791–1797.
- Sutasn Thipprakmas and Arkarapon Sontamino: Spring-Back Characteristics on Bent Holed Parts in V-Die Bending Process : Hindawi Advances in Materials Science and Engineering Volume 2022, Article ID 6488261, 11 pages https://doi.org/10.1155/2022/6488261
- Thakare, P. S., Salodkar, S. M., & Handa, C. C. (2018). Development of Mathematical Model for Top Roller Displacement of Three-Roller Bending Machine Using Dimensional Analysis. Lecture Notes in Mechanical Engineering, 125–132. doi:10.1007/978-981-13-2490-1_12
- Thakare, P. S., Salodkar, S. M., & Handa, C. C. (2019). Experimental Investigation of Three-Roller Bending Operation for Multi-Pass Cylindrical Forming of Plates. Materials Today: Proceedings, 18, 2779–2786. doi:10.1016/j.matpr.2019.07.143
- Tran, Q. H., Champliaud, H., Feng, Z., & Dao, T. M. (2014). Analysis of the asymmetrical roll bending process through dynamic FE simulations and experimental study. The International Journal of Advanced Manufacturing Technology, 75(5-8), 1233–1244. doi:10.1007/s00170-014-6176-x

- Tran, Q. H., Champliaud, H., Feng, Z., & Dao, T. M. (2014). Analysis of the asymmetrical roll bending process through dynamic FE simulations and experimental study. The International Journal of Advanced Manufacturing Technology, 75(5-8), 1233–1244. doi:10.1007/s00170-014-6176-x

- Vaibhav Suresh Deore, Gauri Rajendra Bauskar, Karan Sanjay Bhadane, Siddhesh Mukesh Gaikwad: pyramid type plate bending machine: International Journal of Research in Engineering and Technology: Volume: 04 Issue: 10 | OCT-2015
- Viswanathan Shrinaath, Ramalingam Vairavignesh, Ramasamy Padmanaban : Parametric study on the spring-back effect in aa5052 alloy in the course of three-point roll bending process: SCIENDO: DOI 10.2478/ama-2020-0019
- Waheed, R., Saeed, H. A., Butt, S. U., & Faraz, Z. (2021). Process Optimization of Bending SS 304L Sheets using Multi-Objective Genetic Algorithm and FEA. 2021 International

Bhurban Conference on Applied Sciences and Technologies (IBCAST). doi:10.1109/ibcast51254.2021.9393

- Wang, Y., Zhao, L., Cui, X., & Zhu, X. (2019). Research on numerical simulation and process parameters of three-roll bending based on thickness characteristics of extra-thick plate. Advances in Mechanical Engineering, 11(4), 168781401984786. doi:10.1177/1687814019847861
- Wang, Y., Zhu, X., Wang, Q., & Cui, X. (2018). Research on multi-roll roll forming process of thick plate. The International Journal of Advanced Manufacturing Technology. doi:10.1007/s00170-018-3200-6
- X. Li, Y. Yang, Y. Wang, J. Bao, and S. Li, Effect of material hardening mode on the Springback simulation accuracy of V-free bending, J Mater Process Technol 123 (2002) 209–211.R. Hill, The mathematical theory of plasticity, (Lon- don, 1950).
- Yang, H., Feijun, X., & Hongsheng, X. (2000). Instable modes of in-plane bending of strip metal under unequal compressing. Journal of Materials Processing Technology, 99(1-3), 197–201. doi:10.1016/s0924-0136(99)00420-3
- Yu, G., Zhao, J., & Xu, C. (2019). Development of a symmetrical four-roller bending process. The International Journal of Advanced Manufacturing Technology. doi:10.1007/s00170-019-04104-3
- Z. Fu, X. Tian, W. Chen, B. Hu, and X. Yao, An- alytical modeling and numerical simulation for three-roll bending forming of sheet metal, In- ternational Journal of Advanced Manufacturing Technology 69 (5-8) (2013) 1639–1647.
- Zhao, J., Yu, G., & Ma, R. (2016). A mechanical model of symmetrical three-roller setting round process: The static bending stage. Journal of Materials Processing Technology, 231, 501–512. doi:10.1016/j.jmatprotec.2016.01.002
- Zhao, W., Warren Liao, T., & Kompotiatis, L. (2016). Stress and Springback Analyses of API X70 Pipeline Steel Under 3-Roller Bending via Finite Element Method. Acta Metallurgica Sinica (English Letters), 30(5), 470–482. doi:10.1007/s40195-016-0527-6
- Sweeney, K., & Grunewald, U. (2003). The application of roll forming for automotive structural parts. Journal of Materials Processing Technology, 132(1-3), 9–15. doi:10.1016/s0924-0136(02)00193-0.