International Journal of Engineering, Science and Mathematics
Vol. 7,Issue 12, December 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

OPTIMIZING BENDING PARAMETERS TO IMPROVE THE BENDING QUALITY OF TUBE

M.Venkatesan *
Lakshmi Krishnakumar **
Viswa Mohan Pedagopu ***
D.Raja Joseph ****

Keywords:

Optimization
Improve bending quality
defect wrinkling
mandrill diameter

Abstract

Tube bending is one of the branches of metal forming process used in different application areas like manufacturing sectors, in automobile and petroleum industry. During tube bending defects are obvious some of them are wrinkling, oval and thinning. The impacts of those problems were weakening the strength; reduce aesthetic value of the tube after bending.

In this research several works related to the optimization process has been done to improve the bending quality of the tube. Before the tube bend operation was done selection of the design of experiment were performed. There were four control factors & three responses. The mechanical properties of the tube were tested using tensile test machine & using the spectrometer machine from this result the material were srt37.2. Using rotary draw tube bending machine experiments were carried out based on the selected design of the experiment L9 octagonal array for 25mmx 90^o st 37-2 steel tubes. Data

* Associate professor, Mechanical Engineering, College of Engineering, Wolaita sodo Universitt, Ethiopia
** Professor, Head of Department, D.G.Vaishnava College, Chennai, India
*** Assistant Professor, Mechanical Engineering, College of Engineering, Wolaita sodo University, Ethiopia
**** Assistant Professor SG, Aeronautical Engineering, Hindustan Institite of Technology, Chennai, India

were gathered using digital vernier calipers & micrometers from the experiments & analyzed mathematically using Minitab 16 software.

Using response surface optimizer of Minitab 16 software the multi response of tube bending parameter was optimized.The optimal control factors, significant factors &optimal results were determined. Experiments were done using the optimal control factors for validation. The study shown that setting of optimum parameters using the developed model is a good method in minimizing the responses or improving the quality of the tube bend .

Author correspondence:
M.Venkatesan, Associate Professor, Mechanical Engineering, College of Engineering, Wolaita Sodo University, Ethiopia

1. INTRODUCTION

Tube bending is one of the branches of metal forming process used in different application areas. The tube bending process is the most important in our daily life activity; it is used in different applications areas like manufacturing sectors, production area, in automobile, aerospace, petroleum industry, in water supply and generally uses in many practical applications areas. Tubes are bent to different angles based on its application. During the bending process the feature of the tubes are changed from its original shapes, size and strength. The outside wall of the tube is elongated and become thin, while the inside of wall of the tube compressed and become thick, the inner surface of the tube and the interior pars of the curve is subjected to Compressive stress. When the tubes are bent into a tight radius, high compressive stress developed in the interior pars of the curve, which leads to buckling and wrinkle of the tube. Wrinkles are curvy types of surface distortions. As tubes are used in many applications areas it needs tight dimensional tolerances. Wrinkles, thinning and oval of the tubes are unacceptable defects and should be eliminated. Furthermore, wrinkles and surface distortion of the tube spoil the aesthetic appearance of the tube and thinning decreased the strength of the tube. So thinning, Wrinkling and surface distortions (buckling) are the main failure occurrence during the tube bending process Wang .X and Cao .J (2001).

Wang et al. (2000) established an energy approach to minimize wrinkling of tube and provide a stress-based criterion for the general double-curvature sheet under compression. The critical buckling stress is found as a function of local curvatures, material properties, geometrical dimensions and stress ratio. The listed criteria listed in the above used to predict the starting of wrinkling in tube bending. They also discussed effects of tube thickness, tube radius and material properties on the minimum bending radius without the occurrence of wrinkling. They minimize the winkling by using the energy method and they conclude if the external energy were greater than the internal energy the tube wrinkled. To minimize the wrinkling external energy applied on the tube should haveless than the internal energy found in the tube.

Wang X. and Cao j.(2001) provide the minimum bending radius, which does not yield wrinkling in the bending process as a function of tube and tooling geometry and material properties.

Orban et al. (2007) developed a finite element model to simulate rotary draw tube bending for wrinkling detection and 2nd-order normal velocity difference has been used among neighboring points. The assessment of wrinkling indicator has been related with the starting and growing of wrinkling in simulation. At the present time, rotary tube bending machines are typically incorporated with computerized numerical control (CNC) to automate the process and improve the bending quality .An energy approach has been used to calculate the minimum wrinkling free bend radius as a function of tube and tool geometry. There were two methods for indicating the wrinkling using FE simulations that can be either energy-based or geometry-based.

Orban et al. (2008) determined the quality of the tube bend by the material characteristics, geometry of the component, and method of bending. Unbalanced interaction among these influences increases the tendency to failures generation. This is the first step studded the materials "forming" suitability reflecting the quality of seam weld and its position with respect to the bending plane.

Hasanpour et al. (2012) developed an analytical model for thin-walled tube bending based on ABAQUS platform, a series of 3D-FE models to simulate the bending process with large diameter and small bending radiuses also numerical study on the deformation behaviors of bending process.

Zhan et al. (2013) describes the effect of the bending velocity, push assistance velocity of the pressure die and the mandrill diameter on the thinning of the tube and oval or surface distortion of the tube on the NC bending process for the large diameter of aluminum tube. Mandrill diameter generally used for protecting from wrinkling surface distortion (oval) but it induce wall thinning of the tube if the parameters were not properly used.

2. PROBLEM STATEMENT

Improving quality and increasing productivity are the main and important goals in any industry. During the tube bending process defects are obvious, because of those defects the quality of the tube bend were low. Some of the defects were wrinkling, oval and thinning. The impact of those defects are weaken the strength, reduce aesthetic value, leads to leakage fluids, leads to leakage gas, low stress distribution on the tube and difficult for installation. The reason to create for these defects were operator ,machines and material property and elongation of the tube and several factors which affect the quality of the tube. So those defects must be avoided by optimizing the tube bending parameters.

Fig.1 defects (wrinkling ,thining &oval) of the tube

3. SIGNIFICANCE OF THE STUDY

The result of the multi response optimization of the tube bent were help to identify the optimal control factors which minimize the quality characteristics (oval, thinning and wrinkling) of the tube during the bending process. Improve the quality of the circular tube bend by optimizing the bending parameters and set mathematical model and the optimal parameters for improvement of the quality of the tube during the bending process.

4. METHODOLOGY

Using Spectrometer and tensile test machine the material property of the tube were identifying. The mechanical properties of the tubes were tested using the tensile test machine and materialcompositions of the tubes were determined using spectrometer machine which is to identify chemical composition and grade of the tube) from this the materials of the tube were st37.2 st

The designs of the experiment were selected based on the taguchi orthogonal array. The design of the experiment were consists of four control parameters and three levels. The four control parameters were mandrill diameter, thickens of the tube, bending die diameter and bending time. The experiment were Conducting based on the selected design of the experimentL9 orthogonal array. To conduct the experiment (bending operation) the following machines and tools were used .Rotary draw tube bending machine with its accessory, circular tube, digital Vernier caliper for measurement of the tube bend response, fine blade hack saw for cutting purpose and stop watch for recording of the operation time .Totally nine experiments were conducted using the selected design of the experiment.

Analysis of the result: the data were analyzed using the Minitab 16 software. Regression analysis and a nova analysis were done to model mathematically for oval, thinning and winkling of the tube in terms of the four control factors & to determine the R-squared &R-prediction of the responses respectively.

The regression analysis is used to estimate the quality of the tube bent mathematically by inserting the control factors.

Using the response surface optimizer of Minitab 16 software the tube bending parameters were optimized, the optimal control factors, the significant factors optimal result were identified. Using the optimal control factorsthree experiments were performed for validation of the result.

5. SELECTION OF DESIGN AND CONDUCTING EXPERIMENTS

The following parameters have been identified for optimization of the tube bending process; those are the control factors and the responses. After define the input variables and output variables, a multi- objective or response optimization are takes place. All input factors were controlled by the designer during the experiment. The output factor consider as the response of the experiment.

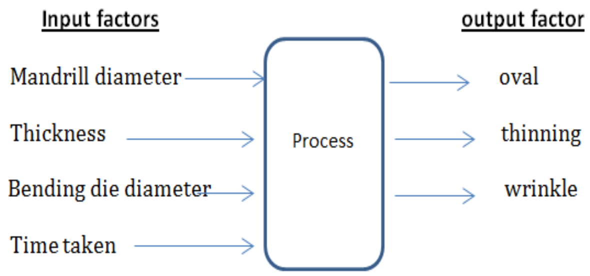

Fig 2 Mode of input and output factors

5.1 Selecting the control factors and their corresponding levels

The key input factors were selected based on the effect they bring on the key output factors when they were changed. Setting of the levels of the factors depends on the range of the value and sensitive of the factor, their levels. According Yang .et al. (10 February 2013) the size of the mandrill diameter found using this equation

$$mandril diameter = D_0 - 2t - 0.2t$$

D_o –tube diameter- Thickness of the tube, 0.2t clearance of the tube &mandrill

Table1: Control factors with their levels for 25mm Ø x 90^0

S.No	Levels	Control factors			
		Mandril Diameter (mm)	Thickness (mm)	Bending die diameter (mm)	Time taken (min)
1	1	20.6	2	100	0.5
2	2	19.5	2.5	105	1
3	3	18.4	3	110	1.5

This table shows the 4 control factor and 3 levels for st37.2 steel circular tube.

5.2 DETERMINE THE DEGREE OF FREEDOM

The degree of freedom for each factors were given by the following formula

$$DM = \sum_{1}^{Nf} Df$$

$$Df = L - 1$$

Where, Dm=degree of freedom for each factor,Nf=the number of factors, L=the number of levels for each factor. Based on the above formula the selected degree of freedom for each factor described in the table below

Table 2: degree of freedom for 25mm Ø x 90^0

Sps.n	Specification	Factor	level	DOF for each factor	DOF for each specification
1	25mmᶲ x 90^o	MD	3	2	8
		Thick	3	2	
		BDD	3	2	
		Time T	3	2	

5.3 Confirming feasibly of the selected design

In order to select the orthogonal array for the experiment the total degree of freedom available in an orthogonal array must be greater than or equal to the degree of freedom.

Table 3: feasibility of the selected orthogonal array

Specification	Orthogonal array	DA (L-1)	Dm	DA> Dm	Feasibility of selected OA
25mmᶲ x 90^{o}X st37.2 steel	19	8	8	Satisfied	feasible

This table indicates the feasibly of the selected orthogonal array

5.4 MATERIAL TESTING EXPERIMENT (TENSILE TEST)

The following Machines and tools were used during the material test.

Tensile test machine, electric powers, flat jaw, Hacksaw bled with fine blade and alien key. The material test was performed by sectioning the tube in to two, using the fine blade hacksaw. At both end of the half section the tube was pressed and hammered to become flat using press machine and soft hammer, this is used for gripping. The total length of the tube was 200mm, from this 100mm used for griping.

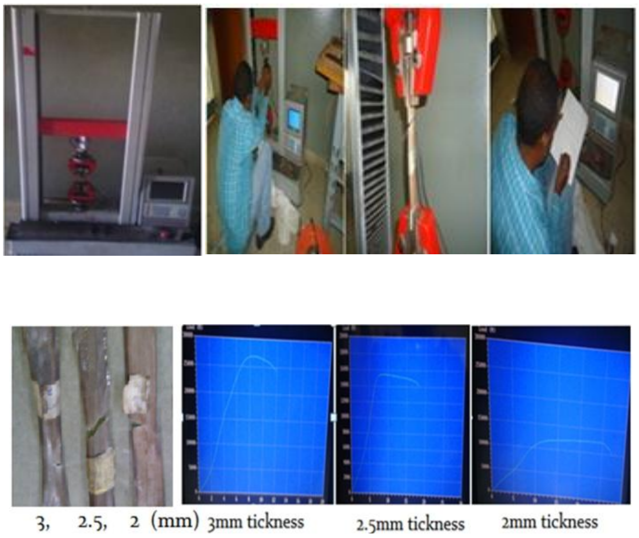

Fig.3 tensile test result

5.5 CONDUCTING THE EXPERIMENT (BENDING OPERATION)

The tube bending operations were conducted based on the design of the experiment.

5.6 DATA COLLECTED FROM THE EXPERIMENT

The data has been collected for different specification of the tube from the experiment based on the selected design. The data were categorized as raw data and calculated data. Mathematically the responses were described using the following equations

$$OVAL= \left(\frac{D_{n\ max} - D_{n\ min}}{D_0}\right) x100\%$$

$$\text{Thinning}= \left(\frac{t_0 - t_{min}}{t_0}\right) 100\%$$

$$\text{Wrinkling}=D\ s_{max} - D\ s_{min}$$

International Journal of Engineering, Science and Mathematics
Vol. 7,Issue 12, December 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Table 4: experimental data gathered for 25mmx90^o st37-2 steel

Specification of the tube						25mm Øx90°x st37.2		
Raw data(mean of @Left , @Center&@Right)						Calculated value /response		
Expl.n	Max D	Min D	T min	Max sD	Min sD	Oval	Thinning	Wrinkling
1	28.480	20.910	1.320	22.420	19.340	30.280	34.000	4.500
2	27.500	21.160	1.740	21.380	18.500	25.360	30.400	4.100
3	26.820	21.620	2.220	21.980	20.210	20.800	26.000	2.100
4	27.400	21.140	1.360	22.320	19.420	25.040	32.000	2.900
5	26.120	21.060	1.860	22.860	20.600	20.240	25.600	2.260
6	26.240	21.920	2.310	21.980	20.800	17.280	23.000	1.980
7	27.600	21.980	1.420	21.420	19.500	22.480	29.000	2.500
8	25.580	22.160	1.890	21.130	19.500	13.680	24.400	2.100
9	25.360	22.410	2.340	20.680	19.420	11.800	22.000	1.260

5.7 Data analysis from the excrement for 25mmØx90o xst37-2

The estimated regression coefficient and analysis of variance for oval, thinning and wrinkling versus MD, tick, BDD, was described below respectively.

Table 5: Estimation regression coefficient for 25mmx90^o st37-2 steel

Estimated Regression Coefficients for 25mmx90°					Estimated Regression Coefficients for 25mmx180°				
oval					oval				
Term	Coef	SE Coef	T	P	Term	Coef	SE Cef	T	P
Constant	-2.624	13.891	-0.189	0.859	Constant	-45.912	16.748	-2.741	0.052
MD	2.260	0.285	7.943	0.001	MD	4.315	0.5435	7.940	0.001
Tick	-9.307	1.195	-7.787	0.001	Tick	-9.307	1.1956	-7.784	0.001
BDD	0.076	0.120	0.636	0.559	BDD	0.076	0.120	0.636	0.560
Time. T	-0.933	1.195	-0.781	0.478	Time. T	-0.933	1.196	-0.781	0.479
S = 1.46377		PRESS = 43.2280			S =	1.464	PRESS = 42.161		
R-Sq = 96.89%		-Sq(pred) = 84.33%			R-Sq = 96.89%		-Sq(pred) = 84.72%		
R-Sq(adj) = 93.79%					R-Sq(adj) = 81.64%				
Thinning					Thinning				
Term	Coef	SE .Cef	T	P	Term	Coef	SE .Cef	T	P
Constant	29.155	11.303	2.579	0.061	Constant	5.098	11.975	0.426	0.692
MD	1.184	0.232	5.114	0.007	MD	2.323	0.389	5.978	0.004
Tick	-8.000	0.973	-8.226	0.001	Tick	-7.780	0.855	-9.101	0.001
BDD	-0.027	0.097	-0.274	0.798	BDD	-0.027	0.086	-0.312	0.771
Time.T	0.267	0.973	0.274	0.798	Time. T	0.376	0.855	0.441	0.682
S = 1.19106		PRESS = 26.8826			S =1.04699		PRESS = 20.1700		
R-Sq = 95.92%		R-Sq(pred) =80.66%			R-Sq = 96.74%		R-Sq(pred) = 85.02%		
R-Sq(adj) = 91.84%					R-Sq(adj) = 93.49%				
wrinkling					wrinkling				
Term	Coef	SE Cef	T	P	Term	Coef	SE Cef	T	P
Constant	6.080	4.251	1.430	0.226	Constant	-9.129	9.254	-0.987	0.380
MD	0.381	0.087	4.376	0.012	MD	0.733	0.300	2.442	0.071
Tick	-1.520	0.366	-4.156	0.014	Tick	-1.520	0.661	-2.301	0.083
BDD	-0.057	0.0366	-1.568	0.192	BDD	0.020	0.066	0.303	0.777
Time. T	-0.307	0.3658	-0.838	0.449	Time. T	1.080	0.661	-1.635	0.177
S = 0.447960 PRESS = 2.67966					S = 0.809 PRESS = 16.999				
R-Sq = 90.82% %		Sq(pred) = 69.36%			R-Sq = 77.81%		R-Sq(pred) = 70.70%		
R-Sq(adj) = 81.64%					R-Sq(adj) = 55.61%				

International Journal of Engineering, Science and Mathematics
Vol. 7,Issue 12, December 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

6. MATHEMATICAL MODELLING OF STEEL

6.1 MATHEMATICAL MODELING OF 25mmx90^{0}x st37.2STEEL

The response were modeled mathematically interns of the four parameters. From table 5 for 25mmx90^{o}xst37.2 steel circular tube

Let oval=x, thinning =y, wrinkling=z

x= $-2.624 + 2.260xMD - 9.307xthicknes + 0.076xBDD - 0.933\,xt.takn$

y= $29.155 + 1.184xMD - 8xthicknes - 0.027xBDD + 0.267xt.takn$

z= $6.080 + 0.381xMD - 1.52xthicknes - 0.057xBDD - 0.307xt.takn$

6.2 Optimization of 25mmØx 90^{0}using response optimizer of Minitab 16 software

Optimization of 25Ø mm x 90^o x ST 37 steel circular tube using the response optimizer of Minitab 16 software was done as follow. Insert the response data in the work sheet of Minitab based the proposed design L9 orthogonal array with their control factors and the responses.

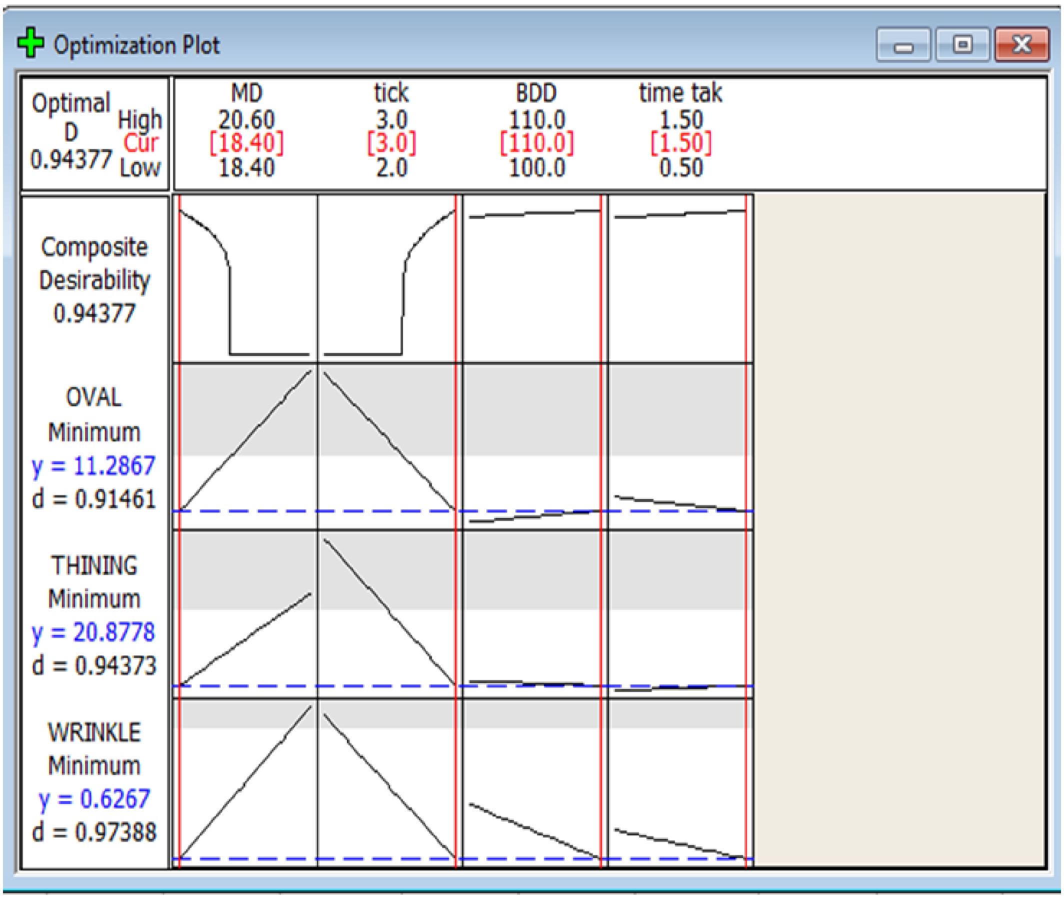

Fig. 4 optimization result

International Journal of Engineering, Science and Mathematics
Vol. 7,Issue 12, December 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijesm.co.in, Email: ijesmj@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

6.3 EXPERIMENT VERIFICATION OF THE RESULT

Once the optimal control factors have been selected the last step is to validate the result using the optimal control factors. Using the optimal control factors the following experiments have been performed & the optimal value of the response was determined as follow.

Using the optimal parameters ($A_3B_3C_3D_3$) the following response were found

Table 6: Results from the experimental

Specification of the tube						25mm Ø x90 °x st37.2			Picture
Raw data(mean)						Calculated value /response			
replication	Max D	Min D	T min	Max sD	Min sD	Oval	Thinning	Wrinkling	25mm diam x3mm thick x90 degree 
1	26.12	23.05	2.36	20.68	20.12	12.28	21.33	0.56	
2	25.31	22.3	2.32	20.68	19.86	12.04	22.67	0.82	
3	25.82	22.42	2.38	20.68	19.64	13.60	20.67	1.04	
	Average					12.64	21.56	0.81	

6.4 COMPARING THE EXPERIMENTAL AND SOFTWARE RESULT

Using the optimal parameters ($A_3B_3C_3D_3$), the optimal value of the response before and after optimization presented in the following table

Table 7: Results before &after optimization

Oval				
Before optimization	Result using experimental	Result using Minitab 16 software	Improvement using experiment	Improvement using software
15	12.640	11.287	2.360	3.787
Thinning				
25	21.560	20.878	3.444	4.178
Wrinkling				
2	0.807	0.628	1.193	1.912

Using the experimental verification the quality of the tube is improved. Oval is improved by 15.733% .Thinning is improved by 13.776% and wrinkling is improved by 59.65%.Using the Minitab 16 software the quality of the tube is improved. Oval is improved by 25.246%, Thinning is improved by 16.712% and wrinkling is improved by 95.6%.

7. RESULTS AND DISCUSSION

This research improves the quality of the tube bent using the optimal bending parameters. The multi responses were optimized using response surface Minitab 16 software. The optimal parameter for 25mmØx90^{o} circular tube were mandrill diameter = 18.4mm, thickens = 3mm,

Bending die diameter = 110mm and the time taken 1.5 minute. All the responses were improved using the experimental and response surface of Minitab 16 software but the response were more optimize using response surface Minitab software than the actual experimental. Using the actual experimental for 25mmØx90^{o} oval, thinning & wrinkle were improved by 15.73%, 59.65% & 13.78% respectively.

The study shown that setting of optimum parameters using the developed model is a good method in minimizing the responses or improving the quality of the tube bend

REFERENCES

[1] Abed A. H (2013) DETERMINATION OF THE OPTIMAL SPRING- BACK PARAMETERS USING TAGUCHI METHOD , Al-Qadisiya Journal For Engineering Sciences, Vol. 6, No. 1, Year 2013.

[2] Aslan, N. and Unal, I. (2010), Multi-response Optimization of oil Agglomeration with Multiple Performance characteristics, Fuel Processing Technology, Ankara, Turkey

[3] Anisotropy on Thin-walled Tube Bending, Vol. 26, No.1, (January 2013) 83-89

[4] Yang He, Lin Yan, "Wrinkling Analysis for Forming limit of tube Bending processes,"

[5] Chen .J, Daxin .E & Zhang .J "Effect of process parameter on Wrinkling of thin walled circular tube under rotary draw bending", 9 April-2013

[6] Gaitonde V., Karnik S. and Achyutha B. (2006) Multi Response Optimization in Drill Using Taguchi Quality loss function ,11 September 2006

[7] Gaitonde V. N., Karnik S. R., Achyutha, B.T. And Siddeswarappa, B. (2006), Multi-response Optimization in drilling using Taguchi's quality loss function, Indian journal of Engineering and Material Sciences, Vol. 1

[8] Kumar A. and Ishtiaque S. M. (2009), Optimization of a Textile Process Using Taguchi Method, the Open Textile Journal, Vol. 2

[9] Lazarescu L.(2010) "FE Simulation and Response surface Methodology for optimization of the tube Bending Process", L 2010.

[10] Naresh K. Sharma, E. A. (2007, Fall) Quality Loss Function – A Common Methodology for Three Cases. Journal of Industrial and Systems Engineering, pp 218-234.

[11] Poursina M, Aminb B, Hasanpourea K , Baratic M "The Effect of Normal Anisotropy on Thin-walled Tube Bending", November2012.

[12] Podany K., Samek R., Matousek .K (2010-2011, ''MECHANICS OF SQUARETUBES BENDING AND CROSS SECTION DISTORSION'',December| 2010 | 210/211.

[13] Shuji .S and Noah .U,(2006) Factors Causing Undesirable Deformations during the Bending of Extruded", Vol. 47, No. 5 (2006) pp. 1354 to 1359).

[14] Sinha, P. (2010), A Search Method for Process Optimization with Designed Experiments and Some Observations, International Journal of Quality & Reliability Management, Vol. 28 No. 5

[15] Taguchi G (1986)"The development of quality engineering", Vol. 1 No . 1.

[16] Wang X., Cao J. "Wrinkling Limit in Tube Bends Bending", 434, Vol1, 2& 3 October-2001.

[17] Orban H. , Lin G., "WRINKLING DETECTION IN TUBE NBENDING SIMULATIONS'', Vol. 35.2007.

[18] Xiao .Y & Liu .Y & Yang .H &Ren .J (10 November 2013),Optimization of processing parameters for double-ridged rectangular tube rotary draw bending based on grey relational analysis, Int J Adv Manu Techno (2014) 70:2003–2011.