GEOMETRIC SPECIFICATION OF BEVEL WRAPPING OF DOUBLE WALLED TUBES, PREDICTION OF FAILURE FROM MATERIAL PROPERTIES

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Abstract

Bundy tube, is type of double-walled low-carbon steel tube manufactured by rolling a copper-coated steel strip through 720 degrees and resistance brazing the overlapped seam in a process called Bundy welding. Double wall brazed steel tubing is constructed from copper coated steel strip which is rolled twice around laterally, then furnace brazed to produce a tube of double wall structure, with a clear, scale free coppered bore, a plated external surface and a consistently uniform wall thickness. PROBLEM BY BUNDY TUBEING INDIA LIMITED Given 17 parameters namely level, pH, chemicals (KCN(Potassium cyanide), CuCN(Copper Cyanide), Rochelle Salt, carbonate) each in tank number 8 and 9 respectively with strip thickness, strip hardness, plating thickness at left, centre and right to predict the percentage of wastage in the tube production. Prediction of wastage by company: Nominal diameter(d) Wall Thickness(e), Strip thickness (f), Bevel angle (θ), Bevel outer angle(θ_o), Bevel inner angle (θ_i), Bevel outer length (l), Circumference (cf)

Data for Bundy Project (17 inputs & 1 output)																	
Leval T 8 & 9		PH T 8 & 9		KCN T 8 & 9		CuCN T 8 & 9		R Salt T 8 & 9		Carbonate T 8 & 9		S. H. Max	S. T. Max	L	C	R	Waste %
79	75	12.56	12.61	4.16	5.2	19.21	20.1	20.62	19.68	117.30	120.06	44	0.35	4.49	4.04	4.37	39.06883
79	75	12.56	12.61	4.16	5.2	19.21	20.1	20.62	19.68	117.30	120.06	43	0.35	5	4.26	4.41	59.01328
83	83	12.63	12.65	5.72	5.46	18.31	18.76	20.62	19.68	118.68	115.92	43	0.35	4.54	4.07	4.35	53.44828
83	83	12.63	12.65	5.72	5.46	18.31	18.76	20.62	19.68	118.68	115.92	43	0.35	4.51	4.07	4.31	40.84881
83	83	12.63	12.65	5.72	5.46	18.31	18.76	20.62	19.68	118.68	115.92	42	0.352	5.03	4.35	4.6	69.30946
83	83	12.63	12.65	5.72	5.46	18.31	18.76	20.62	19.68	118.68	115.92	42	0.352	4.94	4.38	4.63	51.31965
83	83	12.63	12.65	5.72	5.46	18.31	18.76	20.62	19.68	118.68	115.92	44	0.35	4.88	4.05	4.77	49.89247
80	80	12.57	12.6	5.59	5.85	19.21	18.81	20.62	19.68	127.65	134.55	43	0.35	4.65	4.02	4.49	61.42241
80	80	12.57	12.6	5.59	5.85	19.21	18.81	20.62	19.68	127.65	134.55	43	0.35	4.47	4.16	4.41	60.23622
83	83	12.68	12.61	6.5	6.63	18.76	19.21	20.62	19.68	113.85	125.58	43	0.35	4.16	3.79	4.04	60.1518
83	83	12.68	12.61	6.5	6.63	18.76	19.21	20.62	19.68	113.85	125.58	43	0.35	4.47	4.1	4.35	45.88859
83	83	12.68	12.61	6.5	6.63	18.76	19.21	20.62	19.68	113.85	125.58	43	0.35	4.57	4.19	4.47	40.21505
83	83	12.68	12.61	6.5	6.63	18.76	19.21	20.62	19.68	113.85	125.58	43	0.35	4.54	4.23	4.47	71.19816
83	83	12.68	12.61	6.5	6.63	18.76	19.21	20.62	19.68	113.85	125.58	44	0.35	4.16	3.79	4.04	54.60829
83	83	12.68	12.61	6.5	6.63	18.76	19.21	20.62	19.68	113.85	125.58	44	0.35	4.16	3.79	4.04	54.60829

82	80	12.67	12.62	7.02	8.84	18.76	23.23	20.62	19.68	109.02	115.92	44	0.35	4.16	3.79	4.04	54.60829
81	80	12.77	12.7	3.9	6.11	20.1	26.8	23.53	22.31	107.64	123.51	44	0.35	4.91	4.34	5.14	47.76786
83	83	12.57	12.54	5.2	9.1	19.65	29.04	23.53	22.31	102.81	113.85	44	0.35	6.03	4.92	5.87	50.75269
83	83	12.57	12.54	5.2	9.1	19.65	29.04	23.53	22.31	102.81	113.85	45	0.35	6.32	5.07	5.95	60.47619
83	83	12.57	12.54	5.2	9.1	19.65	29.04	23.53	22.31	102.81	113.85	45	0.35	5.92	4.78	5.78	71.33333

Keywords: *Mathematical solution, Mat lab, Bundy tube.*

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1. INTRODUCTION

- **Bundy Tube**
  Bundy tube, is type of double-walled low-carbon steel tube manufactured by rolling a copper-coated steel strip through 720 degrees and resistance brazing the overlapped seam in a process called Bundy welding.

- **Double wall Brazed Steel Tube**
  Double wall brazed steel tubing is constructed from copper coated steel strip which is rolled twice around laterally, then furnace brazed to produce a tube of double wall structure, with a clear, scale free coppered bore, a plated external surface and a consistently uniform wall thickness.

1.1 Manufacturing of the tube

Raw Material: Steel (Given by the supplier)
Electroplating: Here steel strip is coated with copper on both the sides in the Electroplating division of the plant.
Making of Tube: It is divided into 3 stages.
They are as follows:
Stage-1: Un-Brazed Tube
Stage-2: Brazed Tube
Stage-3: Eddy Current Testing

1.1.1 Stage-1:Un-Brazed Tube

In stage-1, the un-brazed tube is made by the 7-mill process. These 7-mill processes are introduced by following:

1) Beveling
2) 1st forming
3) 2nd forming
4) 3rd forming
5) 4th forming
6) 1st finishing
7) 2nd finishing

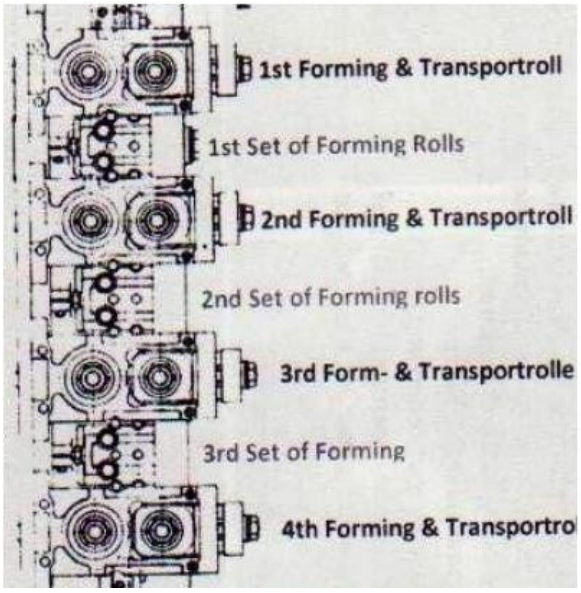


Fig 1 Finishing

This process is mainly divided into 5 main groups.

a) Beveling Roll: It has the task to bevel the outside edges of the strip as to form properly the area of the inside and outside seam of the double wall tube.
b) Forming and transporting rolls: The main task of these rolls is the transport of the strip through the roll mill. Additionally, they contribute to forming the strip.
c) Set of forming rolls: There are 3 sets of forming rolls and every single one consists out of vertical and horizontal rolls the task of which is to continue forming the strip from the drive side from roll to roll.
d) Set of 8: In the 1st set of forming and transporting a U shape is formed. The 90^o arms of the U on the operator side have the function as so-called supporting edge (strip guidance) up to the set of 8. The set of 8 has the task to smooth the 90^o arm (supporting edge) and then to form the strip from the operator side to a tube.
e) 1st and 2nd finishing rolls: The 1st and 2nd finishing rolls have the task to implement the calibration to achieve the required diameter and to take the strip layers of the double wall tube completely to the line system. In order to guarantee this, a so-called

swimmer is necessary in the inside of the tube, which has two olives (thickening) which have the same axis distance than the 1st and 2nd finishing rolls. When these olives are correctly positioned under the 1st and 2nd finishing rolls, they make sure the optimal strain hardening of the strip layers which will later resulting in a positive brazing quality.

1.1.2 Stage-2: Brazed Tube

In this stage we have a batch of 31 un-brazed tubes which can easily break so to make it hard and usable for brake and fuel tubes we pass these tubes through different furnaces where brazing takes place. This batch of 31 tubes is made to pass through a furnace which has 5 different zones without any physical barrier and having different temperature between 950°~1130°.

After getting heated in different furnaces, following to it there is a cooling section. In the cooling section the tube heated up to the brazing temperature (approx 1130° C) is cooled down on a length of 62 meters in a forming gas atmosphere to approximately 60°~70° C.

Forming gas is a collective term for gas mixture with a slight reducing effect out of nitrogen (N2) and hydrogen (H2).

Our Forming gas is used for cooling down consists of 90% nitrogen and 10% hydrogen (H2).

After passing through these furnaces, tubes becomes capable for use and after that they take random pieces of 10 tubes and they check manually in three different processes the quality of the tube in the Quality Section of the plant. The following three different processes are:
1) Flaring (end forming)
2) Flattening
3) Pressure-test

Afterwards, if they detect defect in more than 4 to 5 tubes they reject the whole batch of tubes otherwise that batch of tubes is then pass through next testing as this testing is not 100%.

Fig 2

1.1.3 Stage-3: Eddy Current Testing

The Eddy Current Test is an electrical method for non-destructive material testing. It is applied for testing electrically conductive materials, i.e. CuNi dw tube.

During testing by means of an excitor coil (testing coil) an alternating current in the coil generates changing magnetic field which interacts with tube and generates eddy current. By means of a sensor which mostly contains the excitor coil (testing coil), during measuring the eddy current density is detected generated by the magnetic field of the eddy current.

If the eddy current faces a brazing defect, this leads to a failure of the magnetic field which is then registered by the testing coil. This kind of failure is processed to a signal in the testing coil and transferred to the eddy current test device (Eddy Check) where it is displayed as amplitude on the screen. Simultaneously, we use this for activating an edge and tube cutter which has the task to cut out the defect tube zone.

In the below figure, a defect is exemplarily displayed. Brazing defects are smaller and bigger spots where the brazing is missing, also called cavities, as well as lifting are of the outside and inside seam.

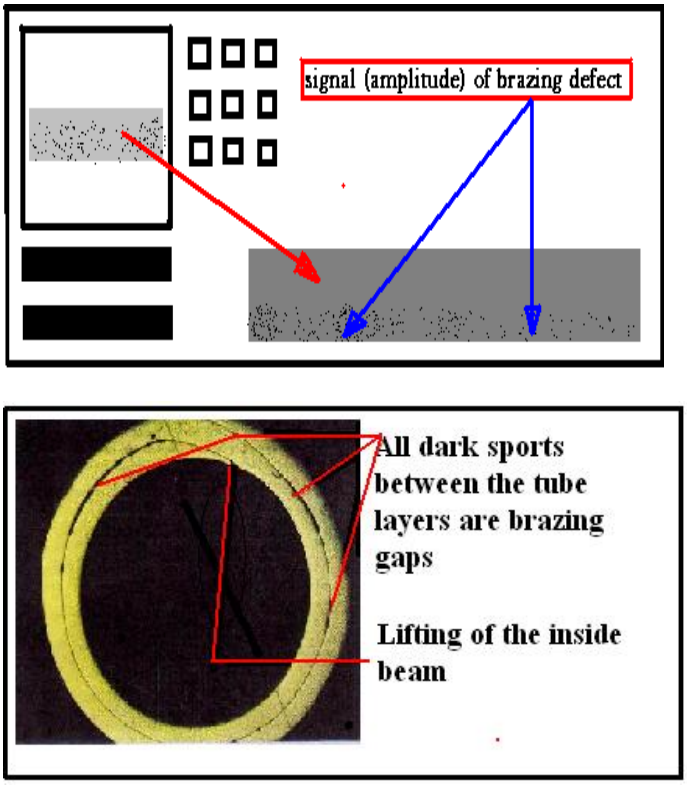


Fig 3 Bundy tube

- In Bundy Ltd. they uses the eddy current testing in which when a tube is passed, it detects the void space left in between the two layers, copper lumps and brazing defect of the tube or any flaws left in the tube in the manufacturing process.

- This testing is done by passing 1 tube at a time through the testing machine.
- If a void or any flaw is detected then the tube gets crimped and then it is cut 6cm from both the sides.
- If more than 5 crimps are detected then the tube is discarded otherwise the tube is used.

From the previous 8 parameters, 5 parameters are given namely nominal diameter, wall thickness, strip thickness, bevel outer angle and bevel inner angle. From these 5 parameters we will determine bevel outer length, circumference, inner radius, outer radius and bevel wrap of the tube.

The calculations for these 5 parameters are given below.

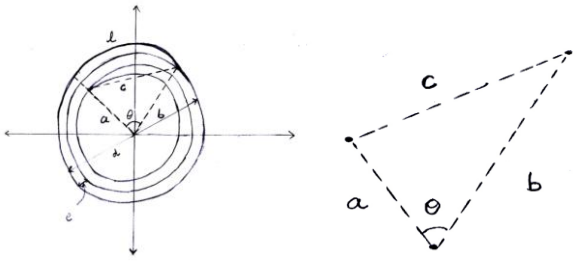


Fig 5 Tube angle

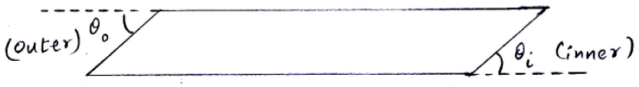


Fig 5 Tube wound

From the above figures:
a = the inner radius of the double wall tube
b = the outer radius of the double wall tube
c = the bevel wrap (the distance between the end Points of The inner crimp and outer crimp after the tube Formation).

2. PARAMETER

Table 1

Parameters	Corresponding Values
Nominal diameter(d)	4.76 mm
Wall Thickness (e)	0.71 mm
Strip thickness (f)	0.355 mm
Bevel angle(θ)	43.95˚
Bevel outer angle(θ_o)	11˚
Bevel inner angle (θ_i)	15˚
Bevel outer length (l)	1.826 mm
Circumference (cf)	14.96 mm
The inner radius a	1.67 mm
The outer radius b	2.38 mm
The bevel wrap c	1.653 mm
Divisions for corresponding percentage	43 divisions (for 60%)

2.1 Geometrical Representation

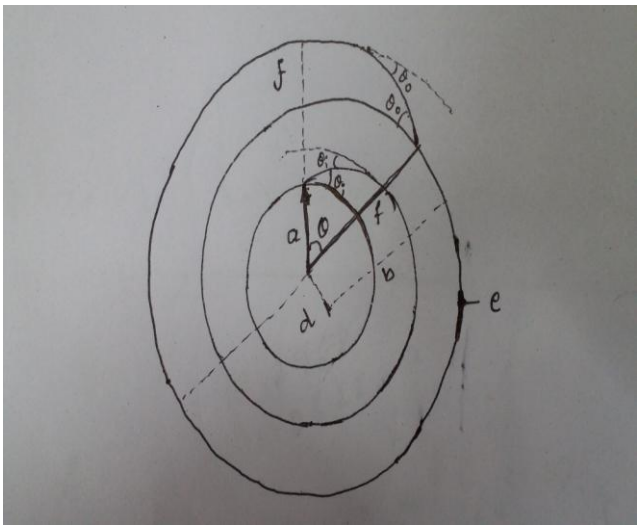


Fig 6 Geometric

Description

Where,
- Nominal diameter(d)
- Wall Thickness (e)
- Strip thickness (f)
- Bevel angle (θ)
- Bevel outer angle(θ_o)
- Bevel inner angle (θ_I)
- Bevel outer length (l)
- Circumference (cf)

2.2 Mathemetical Calculation

Equation

$$\tan\theta_i = \frac{f}{r\theta}$$

$$\tan\theta_o = \frac{f}{(r+f)\theta}$$

$$l = (r+2f)\theta$$

$$cf = 2\pi(r+2f)\theta$$

$$\theta = \frac{2\pi l}{cf}$$

$$\tan\theta_o = \frac{fb}{(b-f)l}$$

$$c = \sqrt{(a^2+b^2-2ab\cos\theta)}$$

Using the above equations the following tables are derived:

Table 3

Given Data				Calculated Data			
Outer Diameter(d) (mm)	Bevel Inner (Θi) (in degree)	Bevel Outer(Θ0) (in degree)	Angle (Θ) (in degree)	Outer Diameter(d) (mm)	Bevel Inner (Θi) (in degree)	Bevel Outer(Θ0) (in degree)	Angle (Θ) (in degree)
4.76	15	11	43.95	4.76	15	12.87	45.45
4.76	17	12	40.2	4.76	17	14.027	39.83
6	12	10	38.44	6	12	11.31	41.78
6.35	12	10	36.32	6.35	12	11.71	38.81
7.94	12	10	29.05	7.94	12	10.96	29.245
9.53	12	10	24.2	9.53	12	10.78	23.595
10	12	10	23.06	10	12	10.74	22.303
4.76	10	10	36.44	4.76	10	11.235	46.142
4.76	17	12	38.84	4.76	17	13.953	38.486

2.3 Covariance Matrix

$$S_x = X^T X = \begin{bmatrix} X^{(1)T} \\ X^{(2)T} \\ \vdots \\ X^{(m)T} \end{bmatrix} \begin{bmatrix} X^{(1)} & X^{(2)} & \dots & X^{(m)} \end{bmatrix}$$

$$= \begin{bmatrix} < X^{(1)}, X^{(1)} > & < X^{(1)}, X^{(2)} > & \dots & < X^{(1)}, X^{(m)} > \\ < X^{(2)}, X^{(1)} > & < X^{(2)}, X^{(2)} > & \dots & < X^{(2)}, X^{(m)} > \\ \vdots & \vdots & \ddots & \vdots \\ < X^{(m)}, X^{(1)} > & < X^{(m)}, X^{(2)} > & \dots & < X^{(m)}, X^{(m)} > \end{bmatrix}_{m \times m}$$

The covariance matrix Sx is a symmetric positive semi definite matrix with nonnegative eigenvalue. The diagonal entries Sii give the variance and off-diagonal entries Sij the covariance. We define the parameter set Y as

Y=XU

$$\Rightarrow S_Y = Y^T Y = U^T (X^T X) U = U^T S_X U$$

= D

The new covariance matrix SY is a diagonal matrix D:

$$S_y = D = \begin{bmatrix} \lambda_1 & 0 & \dots & 0 \\ 0 & \lambda_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \lambda_m \end{bmatrix}$$

The dimension can be reduced by computing the relative measure of variation

$$R_k = \frac{\lambda_k}{tr(D)}, 1 \leq k \leq m$$

If R_k is less than some tolerance level Є for the last r set of variables, we eliminate these (m-r) set of variables. Retain the first r set of variables. So the reduced dimension is r.

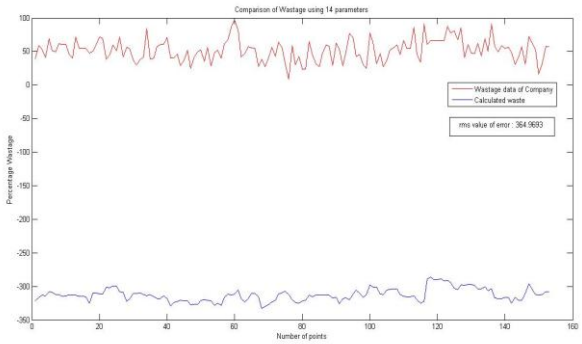
Table 4

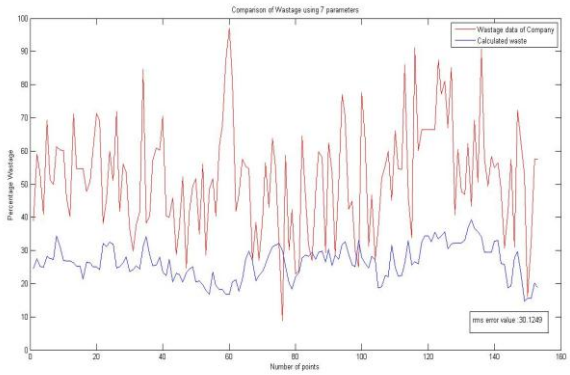
K	CALCULATED VALUE R_k
1	0
2	0
3	0
4	0.0001
5	0.0001
6	0.0016
7	0.0021
8	0.004
9	0.0058
10	0.0089
11	0.01
12	0.0154
13	0.0178
14	0.0283
15	0.0448
16	0.3006
17	0.5605

It can be observed from the table that the relative measure of variation for the first three parameters is zero so we can neglect them for further calculations.

Similarly, we can assume the value of ε to be 0.05 and thus we can reduce 12 parameters more.

The following graphs show the relationship between the company's wastage and calculated wastage derived from these assumptions.





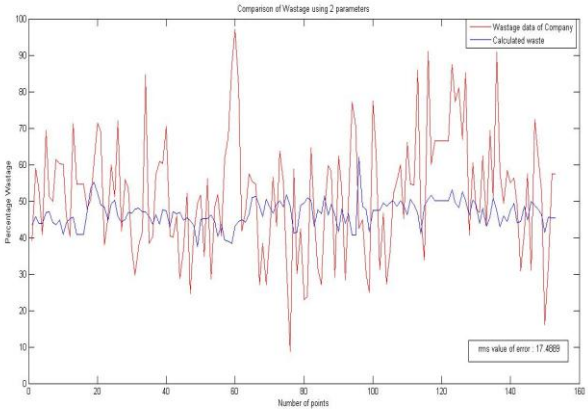


Fig 7 Graph for wastage derived

3. CONCLUSION

Thus from the geometry, we derived the relationship between bevel inner (Θi), bevel outer ($Θ_0$) and bevel angle (Θ) in such a way that the error difference between theoretical value and given data is minimized.

Hence we have fitted the linear model for the given set of parameters by considering only two set of data values that affects the most to the percentage of wastage.

$$W=C_1X_{16}+C_2X_{17}$$

Where C_1=10.7988
C_2= 1.0622

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