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(Research Article)

Study of effect on parameters of bend quality for tubes

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Abstract

Tube bending is a metal forming process that is used to shape pipes or tubing. Bending machines take straight tube stock and create a shape involving single or multiple bends. This allows the tubing to be formed in any fashion to fit the application's specific needs. The process of tube bending involves using mechanical force to push stock material pipe or tubing against a die, forcing the pipe or tube to conform to the shape of the die.

There are three basic bends that are commonly used: the 90° bend, the common offset, and the saddle. Wrinkles occur when the mandrel inside the tube is no longer able to provide enough counteractive force. Wipers are always used in combination with mandrels inserted inside the tube during bending. The mandrel's primary job is to control the shape on the outside radius of the bend. They are excessively used in everything from the automotive industry to aviation, shipbuilding, aerospace, oil and gas, etc. The automotive sector heavily relies on mandrel bending machines to minimize thin wall tubing's ovality when it's bent.

Keywords: Outer diameter; Bend close radius; Revolution per minute; ID outer diameter

1. Introduction

Bending is a manufacturing process that produces a different degree and radius along a straight axis in ductile materials. Generally, bent tubes are used for structural purposes or as passageways carrying fluids or gases. Structural bent tubes: bicycle handlebars, furniture frames, grab bars, roll bars, etc. Passageways: hydraulic lines, fuel lines, exhaust pipes, water lines, etc. Industries typically using bent tube/pipes are automotive, aircraft, off-road and farm equipment, boiler, air conditioning, ship building, furniture, power generation, recreational vehicle, railroad, etc.

2. Materials and methods

When a tube is bent, the wall which forms the outside of the bend elongates and thins while the wall which forms the inside of the bend compresses and thickens. A common objective in tube bending is to form a smooth round bend. This is simple when a tube has a heavy wall thickness and it is bent on a large radius. To determine if a tube has a thin or heavy wall, its wall thickness to its outside diameter is compared. The result is called the tube's wall factor. The same type of comparison is made to determine if a bend radius is tight or large (D of bend). So, two ingredients - the wall factor and the D of bend – are used to determine the severity of a bend. As an example: a 2 in OD tube with a 0.200 in WT has a wall factor of 10. If the tube was bent on an 8 in centerline radius, the D of bend would be 4. In this case, an attractive bend can be formed with three basic tools: the bend die, around which the bend is formed; the clamp die, which grips the tube and holds it in position as the bend is formed; and the pressure die, which forces the tube into the bend die groove so it can be formed. Figure 1illustrates the basic tools. Unfortunately, all too often, bending requirements are not this simple. As the tube wall becomes thinner (the wall factor number becomes larger) and the

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bend radius tighter (D of bend number becomes smaller) a flat toned bend may result. This happens because the wall along the outside of the bend is not thick enough to support itself and collapses. To prevent this a mandrel is required. The mandrel is placed inside the tube and supports it during bending. Mandrels can be either a simple plug type or a segmented ball type.

In the latter type the ball segments extend into the area of tube which is to be bent and flex with it during the bending process. A tube with an outside diameter of 2 in. and a wall thickness of 0.100 in. has a wall factor of 20. When bent of a 5 in. radius (2.5 D of bend) a mandrel with three ball segments would be required to form a smooth round bend.

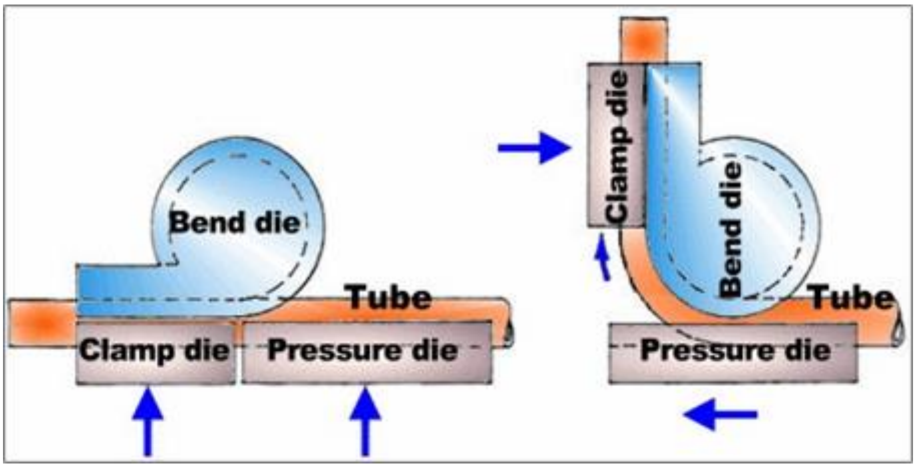

Figure 1 Positioning of tube bending

If bending conditions become even more severe, for example, a 2 in. OD tube with a 0.05 in. wall (40 wall factor) were bent on a 4in. radius (2 D),a fifth tool, called the wiper die, would be required. It was said in this article that the tube wall along the inside of the bend compressed and thickened; but, when the tube wall is thin and the bend radius tight, as in the example above, it will not compress evenly, but will instead wrinkle. The wiper die is made so that it can nest in the bend die groove with its very thin tip extending to the bend tangent point (the point where the tube will begin to bend). In doing so, it fills up the gap normally left by the bend die. Therefore, the tube is completely confined and does not have space in which to wrinkle. Elongation refers to the amount the material can stretch before it fractures. As was noted in the previous section, the tighter the bend radius, i.e. the smaller the D of bend, the more the material will be required to stretch. steel; therefore, it is much easier to bend on a tight radius. But, if the end product is a bicycle handlebar, stainless is too costly and; therefore, mild steel would be selected. The bend radius is also dictated by the end use, since it must create a shape which is functional and has aesthetic quality. Hopefully, the material which is selected and the bend radius which is chosen will be compatible.

2.1. Common Bending Styles of operation

There are several types of tube bending machines available today, each of which has its own particular advantage. Basically, three types are the 'work-horses' of the bending process.

2.1.1. Press-type bending

The press-type bending machine is similar to a vertical press machine used in the sheet metal forming industry. Press bending is one of the oldest forms of tube bending. As with most vertical presses, power is transferred through a vertical ram cylinder to which a bend former dismounted. The bend former is 'rammed' into the wing dies which then give way to the force of the ram and wrap the tube around the bend former. Press bending was very popular in the automotive exhaust pipe bending industry. In many instances an exhaust pipe manufacturer would set up a dedicated line of press benders.

Each bender would perform one bend of a multi-bend part and then be passed to the next machine. This process is still being used; however, due to the time necessary to perform a tool setup on a multiple press line, the cost of tooling and new faster CNC bending equipment, this type of manufacturing is becoming less and less economical. A disadvantage of the press bender is that a mandrel cannot be used. This has limited the machine to applications where out of roundness is not a critical factor.

2.1.2. Compression-style bending

Compression benders were also widely used in manufacturing exhaust pipes. This type of bender resembles the draw type benders with the exception of the roller or 'wipe shoe' used to roll or wipe the tube around the forming die. The machine had limited success with mandrel bending. The compression-style bending machine clamps the tubing to the stationary bend form and a rotating arm pushes the material around the bend form.

2.1.3. Draw-style bending

Several manufacturers offer draw style bending machines. This type of machine offers mandrel or compression bending. The machine clamps the tubing to the bend former which then rotates, 'drawing' the material around the former.

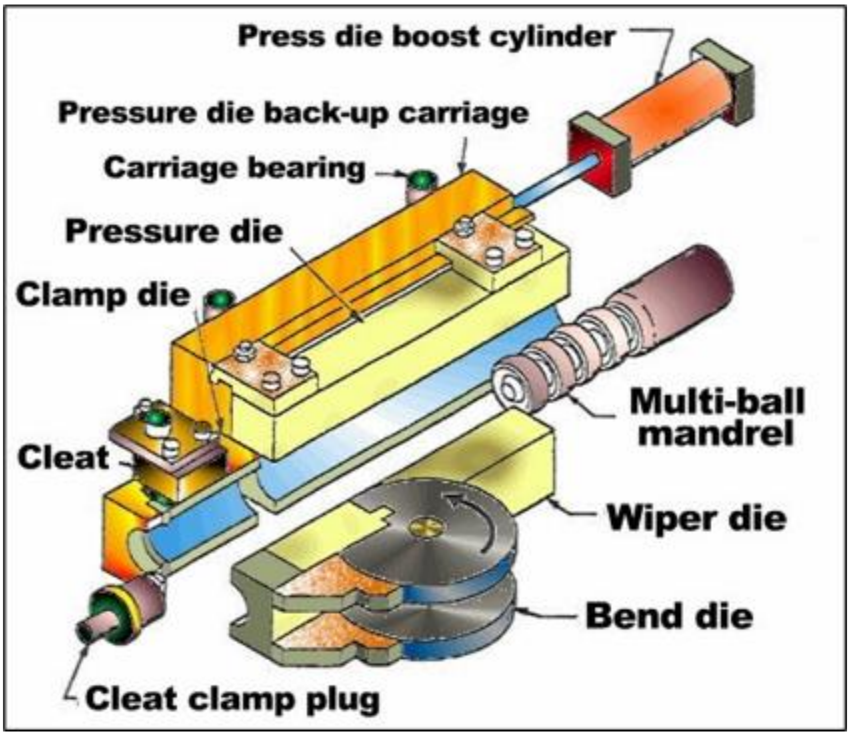

Figure 2 Pressure parts of Bending machine

2.2. Tooling definition

The types and designs of tooling commonly used in bending machines are shown below. The position the tools occupy in the bending machine are also shown.

2.3. Bend die

The forming tool which is used to make a specific radius of bend is called a bend die. The bend die usually consists of two separate pieces called the insert and the bend radius. The insert is used for clamping the tube to the bend die before forming. The bend radius forms the arc of the bend as the tube is drawn around the die. The bend radius is normally sized to two times the tube diameter. Thus, a one inch bend on a two inch radius can be referred to as a 2D bend. The insert used for clamping the tube normally has a 2D clamp length. Thus, one inch tube with a two inch insert will have a 2D grip length.

2.4. Clamp die

The clamp die works in conjunction with the bend die to ensure it clamps the tube tithe bend die. The clamp die will move in and out to allow feeding of the tube.

The pressure die is used to press the tube into the bend die and to provide the reaction force for the bending moment. The pressure die will travel with the tube as it is being formed. The pressure die boost cylinder is attached to the pressure die. The boost cylinder can assist the tube through the bend to prevent tube breakage, wall thinning and ovality.

2.5. Mandrel

The mandrel is used to keep the tube round while bending. The major components of the mandrel are the shank and balls. Mandrel balls are required when bending thin wall tube. Thicker wall tubes may be bent with compression tooling (elliptical type) or bent using a plug mandrel.

2.6. Wiper Die

With mandrel bending, it is sometimes necessary to use a wiper die. This is used when a mandrel alone will not prevent wrinkling while bending a tube. The wiper die “wipes” wrinkles from the tube. It mounts directly behind the bend die.

2.7. Types of bending machines

- Pines Machine – Left-Hand Side and Right-Hand Side
- Sundry CH6 Machine
- Herber Bending Machine
- W100 Bending Machine
- System Bender Bending Machine
- Nipple Bender Bending Machine
- Vertical off-set Bending Machine
- Panel Bending Machine
- Incremental Pipe Bending Machine

3. Results and discussion

3.1. Types Tube Bend Defects

Wrinkle

3.2. Reason for Tube Wrinkling

1. Tube slipping in clamp die
2. Mandrel not far enough forward
3. Wiper die not seated properly in bend die
4. Wiper die worn or improper fit
5. Too much clearance between mandrel and tube
6. Not enough pressure on pressure die
7. Improper or excessive amount of lubrication
8. If mandrel and wiper die are in proper locations, check inboard pressure on pressure die. You may need to apply more pressure on pressure die to hold tube into die. Adjust in slowly until you have no wrinkle. Lastly, check mandrel fit.

3.3. Flatness

3.3.1. Flatness reasons

- Tube slipping in Clamp Die
- Tube slipping in pressure Die
- Pressure die not seated properly to former. d. Pressure die improper fit
- Too much clearance in mandrel and tube.
- Excessive amount of lubrication
- If mandrel and wiper die are improper locations, check in board pressure on pressure die. You may apply to more pressure on pressure die to hold into die. Adjust in slowly until you have no flatness. Lastly check mandrel fit.

Figure 3 Defects of tube bending

Knurling (Tool Mark)

Reasons:

- More Pressure
- New tool using
- Former and clamp die mismatch setting

To avoid:

- Exact pressure
- New tool using before grinding the tool or using emery paper
- Exact setting

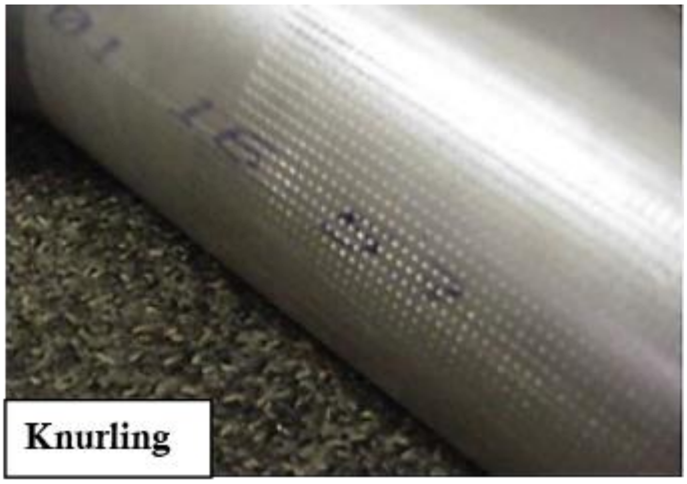

Figure 4 Defects of tube bending

3.4. Bending method

- First step is to study the drawing as per which bending has to be done.
- While studying the drawing we came across and study-
  - Work order/Project
  - Nature of Material like -Grade C, SS, T12 etc. c. Despatchable Units (DUs)
  - Circuit Number e. Bending Position
  - Length and Dia. of material going to be bend.
- The bending what we are going to do is then prepared in model form with the help of wire.

- Required type of former and die setting are arranged.
- Test piece is first taken for bending, so that our Job not get spoiled.
- Test piece is shown to the quality person for checking ovality, flatness and wrinkles.
- After QC person approval we start the bend on jobs.
- Job is marked as per the design with the help of chalk/ knife.
- Bending is done as per the drawing.
- Operator check the length; dimension and all other thing are matching as per drawing or not.
- Quality person is again called for the inspection for checking the required parameter is matching or not like length, drawing degree, ovality, flatness and wrinkles.
- Now, bending is over and job is ready.

3.5. Tube bending flow chart

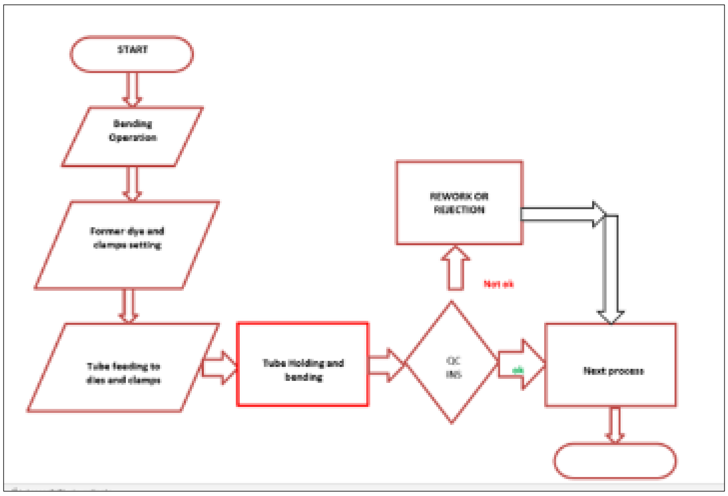

Figure 5 Flow diagram of Bending Operation

3.6. Specification of Bending Materials

- Diameter of the tube
- Wall thickness of the tube
- Length of the tube
- Nature of the Material or material type

3.7. Study of Pines Machine

Pines Machine is one of the Bending Machine which can bend these types of materials: -

Table 1 Bending Material used in tube bending

MATERIAL	GRADE /CODE
CARBON STEEL	GRADE C & A
ALLOY STEEL	T11,T12,T22,T23 & T91
STAINLESS STEEL	347 H, 304, 310S

3.8. Bending Diameter and radius used in Bending machine.

Table 2 Various diameter and radius used in PINES Bending Machine.

Diameter of Tubes for Bending (mm)	Radius of Bend (mm)
33,54,21,38,57,44,63,60,4 7,69,76,51,73	65,75,100,112,114,120,127,130,133,143,151,152, 160,200,235,240,275,300, 375,405

3.9. Specification of Pines Machine

- Maximum Length for Pines M/c- 25 Meter
- Minimum Length for Pines M/c- 1 Meter
- Maximum Speed =15 r.p.m
- Correct Bend Pressure- 8300 psi
- Ovality Pressure= 8000 psi

3.10. Case Study for three type of materials:

- Grade C material
- T91 material
- SS material

3.11. Grade C material

This type of material is used as economizer in the Boiler. As we know economizer uses exhaust gases of flue used to heat the water in to steam. Thus, same flue is used to heat the economizer and thus this process is economical. For Grade C Material Dia. 44.5 Rad. 133.5,

- If more pressure is applied flatness is more
- More pressure will result in breaking of M/c center bolt
- Right pressure can only give quality bends without any flatness.
- Flatness and ovality must not go beyond 10% of the dia. Otherwise the job cannot be accepted.

3.11.1. Squeezing bend 180 degree

Dia .44.45 Rad.44.5, Thickness 7.1 SA210 Grade-C

- Booster preload pressure-
  4800 psi, 1900 psi, 1800 psi,1700 psi, 1100 psi, 1000 psi
- Clamp die pressure - 5400 psi
- Pressure die pressure - 8300
- Machine Die efficiency Speed – 15%
- Time for 1m tube bend - 60 seconds

If all this conditions are fulfilled, **BEND is OK**.

3.11.2. T91 Material

- If more pressure is applied flatness is more
- More pressure will result in breaking of M/c center bolt
- Right pressure can only give quality bends without any flatness.
- Flatness and ovality must not go beyond 10% of the dia. Otherwise the job cannot be accepted.

3.11.3. T91 bend 180 degree

Dia .44.45 Rad.44.5, Thickness 7.1 Grade T91

- Booster preload pressure- 4800 psi, 1900 psi, 1800 psi,1700 psi, 1100 psi, 1000 psi
- Clamp die pressure - 5400 psi
- Pressure die pressure- 8300 psi
- Machine Die Efficiency Speed – 15%
- Time for 1m tube bend - 60 seconds

If all this conditions are fulfilled, **BEND is OK**.

3.11.4. SS Material

- If more pressure is applied flatness is more.
- More pressure will result in breaking of M/c center bolt
- Right pressure can only give quality bends without any flatness.
- Flatness and ovality must not go beyond 10% of the dia. Otherwise the job cannot be accepted.

3.11.5. Stainless Steel bend 90 Degree

Dia .44.45 Rad.153, Thickness 7.1 Grade 347H

- Booster preload pressure - 4800 psi, 1900 psi, 1800 psi
- Clamp die pressure - 5400 psi
- Pressure die pressure- 8300 psi
- Machine Die Efficiency Speed – 15%
- Time for 1m tube bend - 30 seconds

If all this conditions are fulfilled, **BEND is OK**.

3.12. Flatness check

Flatness problem is checked if it is below 10% bend flatness or not. If it is less than 10% , it is OK. More than percentage of flatness , ovality is more and it is not accepted.

3.12.1. Flatness calculation: Dia 51.0

IF flatness is like this, e.g.

50.2-46.5=3.7

50.6-47.8=2.8

51.1-48.0=3.1

3.7x100=370/51=7.25%

So, Below 10% bend flatness OK. This can be accepted

Above 10%, not OK.

53.2-45.1=8.1

8.1x100=810/51=15.8%

So, this can not be accepted.

3.12.2. FOT (First of Trial Bend)

FOTs are to be carried out for a bending process having a change in any of the following parameters than the existing qualified FOTs.

- Type of machine
- Material specification
- Dia of the tube
- Thickness of the tube
- Radius of the bend
- Angle of bend
- Type of heating (if applicable)

3.13. However the following exemption is permitted.

- Existing FOT qualification on a bend qualifies for any bend angle less than the qualified angle.
- FOT carried out on a combination of material, outside diameter (OD), bend radius and for minimum and maximum required thickness shall qualify for all intermediate ranges. Also, if FOT for lower R/D qualifies, then the higher R/D also qualifies if there is no change in machine, material specification, OD, thickness.

3.14. Sample inspection

- All bends shall be cut transverse to tube axis as detailed below.
- For bend angle up to and including 90 degrees, one section shall be cut at the middle of the bend. The cut sections face should be parallel to the bend radial axis
- For bend angles above 90 degrees, three sections shall be cut one at the middle and the other two sections shall be at an angle of 45 from the middle. If, maximum reduction in OD found visually anywhere in the bend, this section also to be cut and consider as a sample. The cut sections face should be parallel to the bend radial axis

The following checks shall be done.

- Minimum thickness at the cut sections.
- Maximum and Minimum diameters (OD &ID) at the cut section.
- Imprints of the cut sections (For other than Squeezed bends).
- Visual examination of the cut sections of the bend.

After recording the data, the following calculations shall be made to ensure conformance to specifications.

3.15. Acceptance

3.15.1 Unless otherwise stated in the contract, the following are the requirements to be met for accepting the FOT. The minimum required outside diameter at any part of the bend is given by the formula.

OD (MIN) = 0.895 X OD(NOM) + 0.233 X MIN. WALL THICKNESS

3.15.2 Free from harmful surface visual defects as stated in Cl 5.1.

3.15.3 % Ovality = 100 x (Max. OD - Min. OD)/ Nominal OD shall be within 10% for bends and 15% for squeezed bends, where ‘D’ is the nominal OD of the tube and R is the bend radius at neutral axis.

3.15.4 Actual Flow Area = Area calculated from the imprints.

Note: Actual flow area at any location of the tube after bending shall be 80% minimum of actual flow area of the tube before bending.

3.15..5% of Thinning = (T1-T2) /T1 X 100

And %Thinning shall not exceed = [100 / {(4R/D)+2}]

Where

- R is the mean radius of bend to the center line of the tube (in mm)
- D is the Nominal outside diameter of the tube (in mm)
- T1 is the thickness measured at the end of the tube after bending, by drawing a line parallel to tube bend axis from T2.
- T2 is the minimum thickness observed in the tube after bending.

3.15.6 Tube bends shall not have flat areas in excess of 12.5mm wide running longitudinally with the centre line of the tube.

If the requirements of 3.15.2 & 3.15.6 are not met (or) 3.15.3 to 3.15.6 is not met, the bends are to be rejected.

If the minimum available OD at any point is less than that calculated as per clause 6.1, the bend can be accepted if the requirements of clauses 3.15.2 to 3.15.5 are met.

All the 3 samples must conform to the above requirements for successful qualification of the FOT.

If one of the three samples fails to qualify, two more samples shall be taken and the conformance if established in both samples, this shall qualify the FOT.

If more than one sample fails, the FOT shall be repeated after incorporating changes as required to eliminate the cause of nonconformance

FOT – (First of Trial)

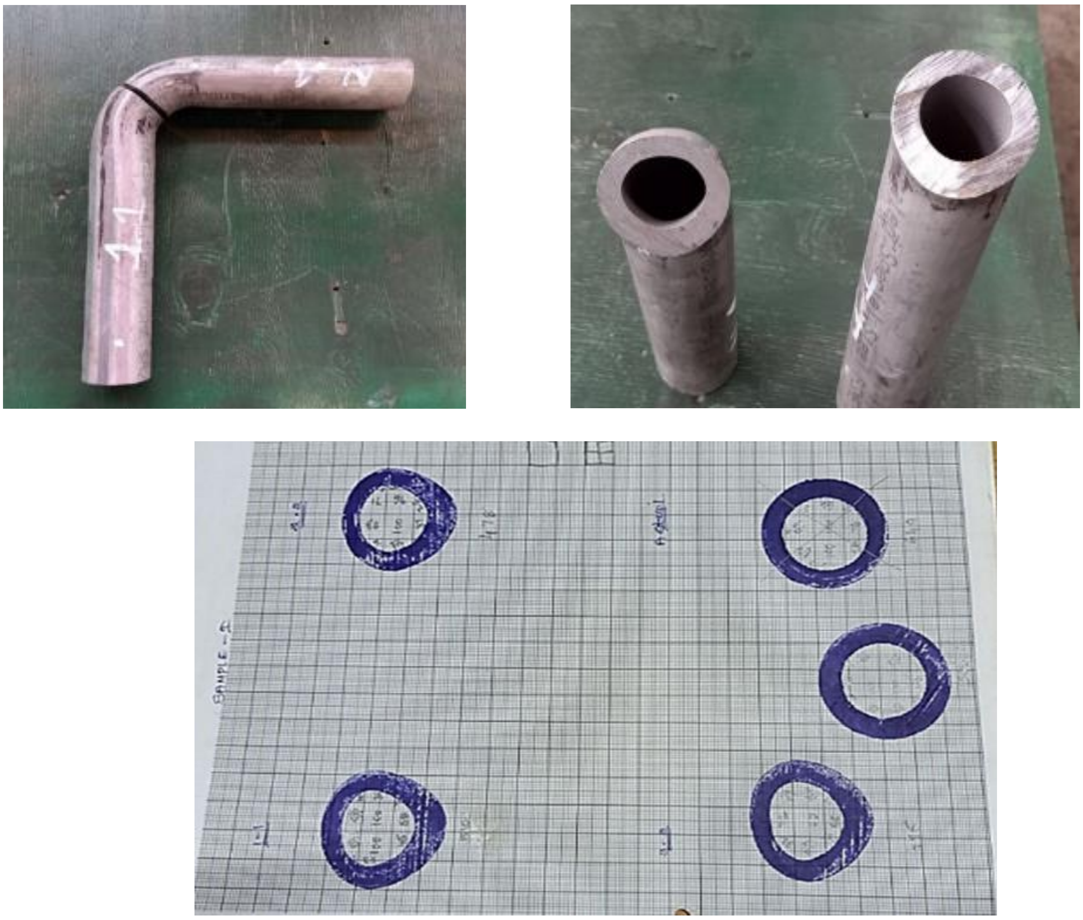

Figure 6 FOT for 90 degree Bend stainless steel material

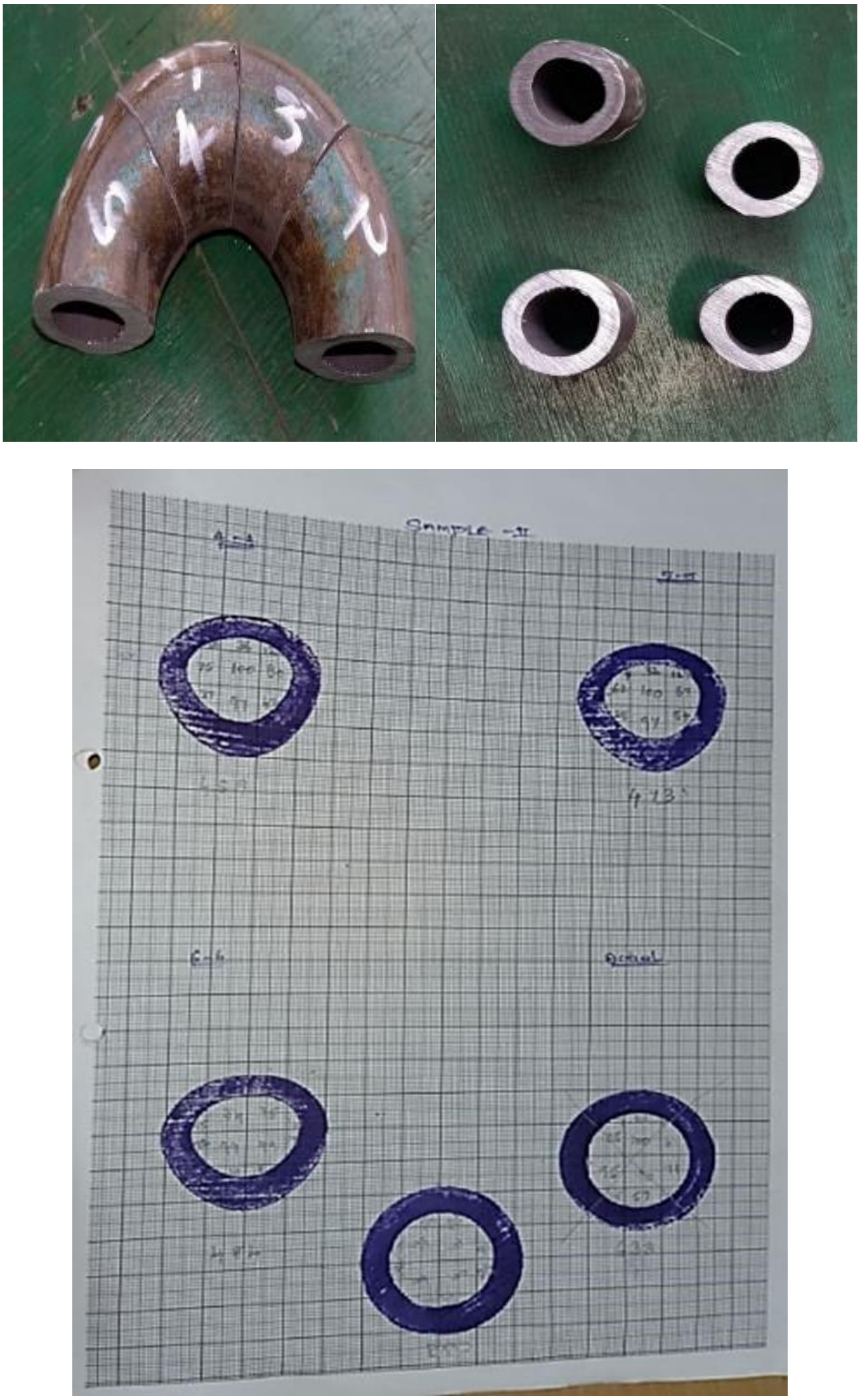

Figure 7 FOT cross section view of Carbon steel material

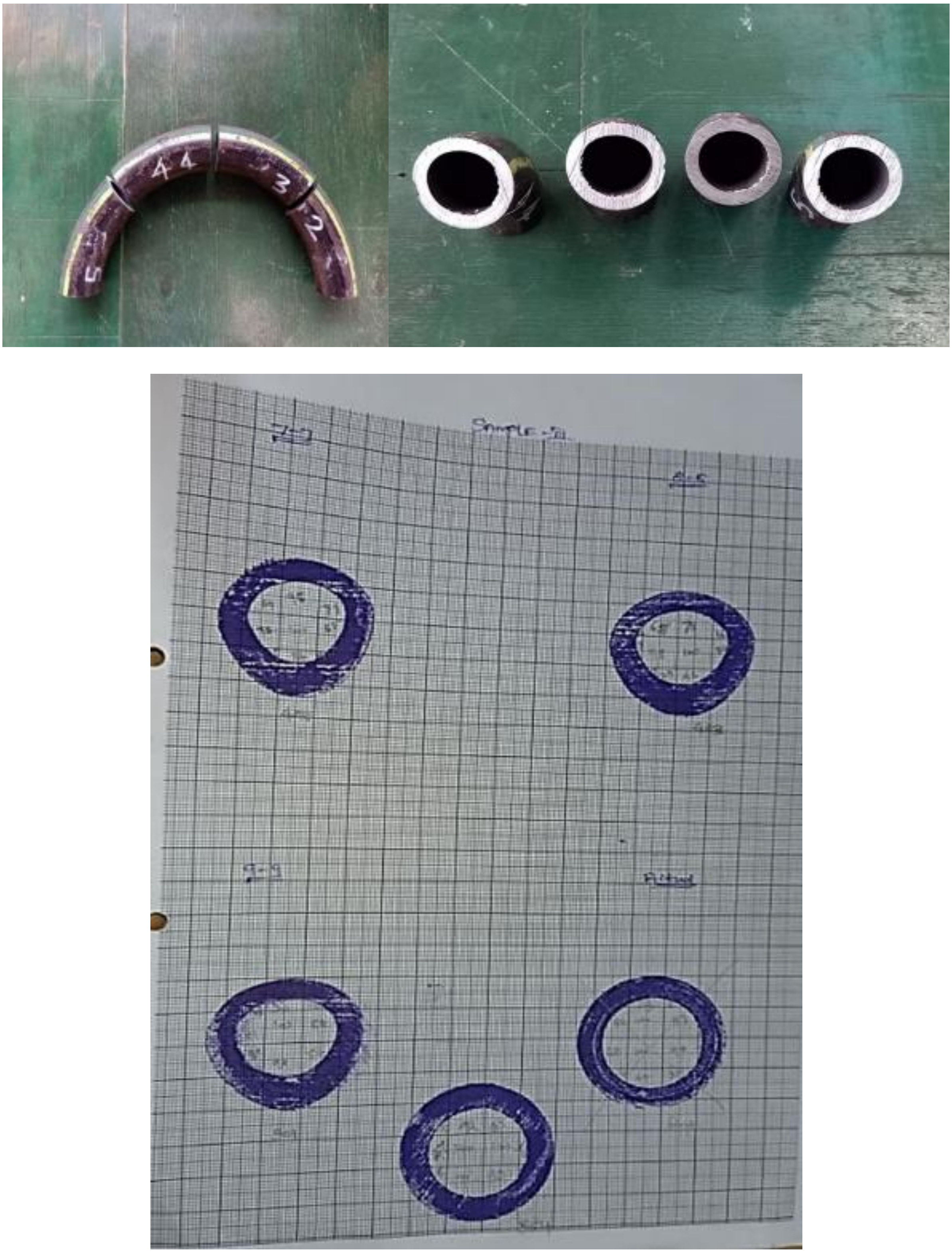

Figure 8 FOT for 180 degree/R151 Bend alloy steel (T91) material

- **Ovality calculation**

43.64-41.71=1.93

43.66-41.24=2.42

44.03-40.60=3.43

3.43*100=343

=343/44.45=7.716=7.72

- **Thinning calculation**

$$\frac{\boldsymbol{Actual\ thickness\ (T1) - Minimum\ thickness\ (T2)}}{\textbf{Actual thickness (T1)}} \times \mathbf{100}\%$$

$$\frac{\mathbf{7.64 - 6.4}}{\mathbf{7.64}} \times \mathbf{100}\%$$

= 16.2 % Acceptable

- **Percentage of thinning should not be exceeded**

= 100/{(4R/D) +2}

= 100/ {(4x44.5/44.5)+2}

= 100/6

= 16.67%

- **Flow area**

Flow area= Actual flow area/Nominal flow area

= 478/586*100

=81.57%

4. Conclusion

The Study of effect on bending parameters on bend quality for tubes for pressure parts of Super Critical Boiler has improved the quality of products, avoided rework and wastage of materials. In this study manufacturing cost are reduced. Simultaneously it ensured Safety of operation along with Quality of the job also improved.

Scope of future study

The Boiler Components are generally repetitive in nature. The New method of process can be used for upcoming or future pressure parts products of Tower type Super Critical Boiler.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest among authors.

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