

The Key to Successful Bending Practices

unedited version -

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Gordon A. Aaker., Jr., P.E. with **ENGINEERING SERVICES, L.P.**, USA, explain simple and very basic rules to avoid unnecessary failures due to poor bending practices.

There continue to be needless failures in pipeline bends due to casual compliance by pipeline contractors and the failure of the operator to verify the contractor's performance. Repeated failures in pipe bends are not necessary. A few basic rules beginning with an accurate Manufacturing Procedures Specification (MPS) combined with an approved Inspection Test Plan (ITP) will ensure success.

In an effort to promote responsible bending practice and in cooperation with **BENDCO**, Pasadena (Houston), Texas, **ENGINEERING SERVICES, L P.**, has developed a detailed MPS/ITP based on recognized industrial standards. The results of the combined efforts are documented herein.

PIPE BENDS

Bends are important construction components in any pipeline project. Bends are typically provided by manufacturers of the pipe, or alternatively, the pipe purchased from the pipe mill is bent by an independent fabricator selected by the contractor/owner. The pipe used to fabricate the bends is often referred to as "Mother Pipe".

INDUCTION BENDING

Induction bending utilizes a process which employs an induction-heating coil to create a narrow, heated, circumferential band around the pipe to be bent. When the appropriate temperature is reached, the pipe is pushed forward through the coil at a consistent speed while a bending moment is applied to the line pipe as it emerges from the heated coil. After the material passes through the coil, the pipe can either be quenched with a water spray or be allowed to cool in still air (normalized).

Wall-thinning will occur during induction bending which can have an impact on the overall performance of the pipe. This article provides recommendations on how to optimize the induction bending process and what steps can be adopted to avoid any adverse effects of wall thinning and loss of strength caused during the induction bending process.

STRENGTH - The induction bending process heats the pipe steel to over 1800°F. This process can affect properties such as yield strength, tensile strength, and toughness of the steel. This effect has been observed whether the mother pipe is made using the TMCP (Thermo-Mechanically-Controlled Process) or the QT (Quenched and Tempered) process.

To minimize the potential for strength reduction, the facilities that provide induction bending will rapidly cool the pipe immediately after the induction bend heating phase. While this rapid cooling helps to regain the desired strength and hardness properties, it is not a perfect process. This issue is more pronounced in high strength steels like API X-70. Therefore, if this cooling process is not controlled properly, the result could be induction bends that do not meet all of the originally-specified technical requirements.

The strength issue can also be addressed by using mother pipe with slightly higher chemistry (higher alloy content). By carefully selecting the chemical composition of the mother pipe used for induction bends, the desired mechanical properties (after the heat

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induction bending process has taken place) may be attained. For example, a higher CE (Carbon Equivalent) of the pipe steel will enhance the strength properties of the steel during the quenching stage of the bending process. Knowing this, the metallurgists at the mill can add chemical elements to the raw steel to improve grain structure while keeping the CE content acceptable for welding.

To strike a balance between high-strength and weldability, the pipe mill may need to engage in a trial and error process with the induction bending facility to arrive at the best pipe chemistry for the final delivered induction bends. If the pipe mill is tasked with the responsibility of providing the induction bends, the pipe mill and induction bender will need to work together to refine the steel chemistry and test trial induction bends to make sure the required strength and weldability properties are attained in the production run of induction bends.

Should a pipeline company choose to contract directly with an independent facility to provide the induction bends, the aforementioned trial and error process will not be a feasible option. However, the pipe mill can still be tasked with providing superior chemistry, strength, and additional wall thickness for the pipe joints being designated for third-party induction bending.

OVALITY - Induction bending larger diameter pipe (such as 30" OD) is a challenging process due to the difficulty in maintaining the required line pipe roundness. If the bending processes aren't carefully controlled, ovality will occur. This problem, however, is resolved by carefully checking the line pipe ovality calibration throughout the bending process and by using internal and external dies to remove the ovality after bending. With the aid of third-party inspection agency (TPIA), the induction bending facility and processes can be inspected continuously and thoroughly enough to ensure that appropriate measures are in place to minimize the incidence of ovality in the fabricated induction bends. Ovality concerns can be mitigated by adopting quality control procedures and inspection methods during the induction bending process.

WALL THINNING - From a geometric standpoint, during the induction bending process there are two critical surfaces along the pipe that must be continuously inspected to insure that the integrity of the pipe bend is not compromised. The inside radius of the pipe bend (the intrados) can develop wrinkles during the bending process. This can be controlled during the induction bending process by limiting the speed that the pipe passes through the induction coil. The outside radius of the pipe bend (the extrados) can also develop wall-thinning which can compromise the overall pressure-rating of the pipe bend. To ensure that the pipe bends have sufficient wall thickness to match the mother pipe pressure requirements, thicker line pipe steel can be specified for the line pipe joints that are to be designated for induction bending.

SAMPLE CALCULATION - Assume API X-70 with a required wall thickness of 0.375" for a project. For 3-D bends (the bend radius typically established) the wall thinning expected as a percentage of the original wall thickness is 15% (worst case). It is likely that 10% to 12 % is typical thinning, in most cases.

Taking into consideration the 15% expected wall thinning, the pipe wall thickness required to achieve the final desired effective 0.375" wall thickness after bending is: $0.375" / (100\% - 15\%) = 0.441"$

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The above calculation indicates that pipe with a minimum wall thickness of 0.441" will be required to arrive at a final post-bend wall thickness of 0.375".

Since the wall thickness of the "mother pipe" that will be purchased for induction bending purposes will be 0.625", which is thicker than the required 0.441" wall thickness, this line pipe is considered adequate for the expected amount of wall thinning.

However, the calculation still needs to be performed to confirm adequate pipe strength (minus 15% thinning):

$$(0.625") - (0.625 \times (15\%)) = 0.625" - 0.094 = 0.531" \text{ (eq. 1)}$$

The Barlow's Equation calculation for this wall thickness results in the following: $2 \times 72,000 \times 0.531 \times 0.72 / 36" = 1,529 \text{ psi}$ (eq.2)

In consideration of the potential strength-reduction effect of the induction bending process, the Barlow's equation (eq.2) can be performed for varying yield strengths to determine the pressure capacity of the induction bend.

YIELD STRENGTH (psi)	MAXIMUM WORKING PRESSURE (PSI)
65,000	1,380
60,000	1,274
56,000	1,189
52,000	1,104*
46,000	977
<i>*Based on the above calculations, selecting the 0.625" thick wall for the line pipe will permit a tensile strength reduction in the mother pipe to as low as 52,000 psi and still be acceptable (1,104 psi) for the required 1,050 MOP of the pipeline.</i>	

Though the induction bending process reduces pipe strength and causes wall thinning of the mother pipe, measures can be easily adopted to minimize the impact of these effects. Wall thinning can be addressed by specifying heavier wall pipe. Reduced pipe steel strength can be addressed by adjusting the metallurgy of the mother pipe. The pipe mill should be advised of the intent to perform induction bending so that selected pipe joints can be manufactured with higher-chemistry, higher-alloy steel.

COLD BENDING

"After cold bending and forming, heat treatment is required (for all thicknesses, and with temperature and duration as given in Table 331.1.1) when any of the following conditions exist: (a) for P-Nos. 1 through 6 materials, where the maximum calculated fiber

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elongation after bending or forming exceeds 50% of specified basic minimum elongation (in the direction of severest forming) for the applicable specification, grade, and thickness. This requirement may be waived if it can be demonstrated that the selection of pipe and the choice of bending or forming process provide assurance that, in the finished condition, the most severely strained material retains at least 10% elongation.” (ASME B31.3 Section 332.4.2 Cold Bending and Forming)

For API X-70 for example, as per the above paragraph from ASME B31.3 for Carbon Steels (included in P-Nos 1-6 material) fiber elongation should not exceed 50% of the specified basic minimum elongation.

API 5L states that the specified minimum elongation for X-70 pipe with 0.469” wall thickness can be calculated using the following formula:

$$\% \text{ Elongation } A_f = C \frac{A_{xc}^{0.2}}{U^{0.9}}$$

Where:

C=625,000

A_{xc} = applicable tensile test piece cross sectional area, 0.10 in² for round tensile specimens for 0.469” wall

U= min tensile strength, 82,700 psi for X-70 pipe

% Elongation = 14.7% or

50% of the calculated % elongation = 7.35%

Fiber elongation can be calculated using the formula given in ASME Section VIII-Division 1, UCS-79 Forming Shell sections and heads as follows:

For single curvature (for example, cylinders),

$$\% \text{ extreme fiber elongation} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right)$$

Where:

R_f = final centerline radius, in. (mm)

R_o = original centerline radius (equals infinity for flat plate), in. (mm)

t= plate thickness, in. (mm)

Applying this formula for 36” API 5L X70 pipe with a wall thickness of 0.469” pipe

$$7.35\% \text{ extreme fiber elongation} = \frac{50 \times 0.469}{18} \left(1 - \frac{R_f}{18} \right)$$

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INSPECTION AND TESTING OF COLD BEND PIPE

To ensure the quality of the field bends after the cold bend operation the following actions are recommended.

- If the pipe contains a longitudinal weld, this weld should be located in the neutral zone of the bend. If the pipe will be installed horizontally, the longitudinal weld should be located on the top of the pipe. If one spool is bent in various planes, the longitudinal weld should be 45° from the top of the pipe. No girth weld shall be located in the bend.
- Weld repairs of cracks in pipe bends are not permitted.
- Bends intended for use in pipes that require pigging should be checked for correct bore and radii to allow the passage of the pig.
- After cold bending no additional heat treatment is required if the following requirements are met:
 - Hardness <240 HV10
 - $R_m > 1.3 \times D_n$

Where:

R_m is the mean radius of the bend and

D_n is the nominal diameter of the pipe.

INSPECTION

The following inspection requirements apply only to the cold bend pipe.

VISUAL EXAMINATION - After bending, the bent items should be visually inspected for laminations, cracks, notches, gouges, or other injurious defects. There SHALL be no cracks or linear indications.

DIMENSIONAL MEASUREMENTS - Each completed single bend should be dimensionally checked for the following:

ANGLE OF BEND	TANGENT POINT – FRONT AND REAR
RADIUS OF BEND	TANGENT LENGTH – FRONT AND REAR
PLANE OF BEND	CENTER TO CENTER DISTANCE ON 180 BENDS

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For each successive bend on a single length of pipe the following dimensions should also be checked:

DISTANCE BETWEEN BENDS - CENTER TO CENTER	DISTANCE BETWEEN TANGENT POINTS	ANGLE (S) OF CHANGES(S) OF PLANE
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OVALITY MEASUREMENTS - 10% of bends should be checked by the fabricator at the 45-degree point on the bend. The fabricator should make a notation on the shop copy as to which bend was checked. The fabricator should keep a log as to quantity of bends on the job by size, quantity of bends checked and piping isometric drawings on which bends were checked.

THICKNESS (THINNING) MEASUREMENTS -If the wall thickness after bending is be within 5% of the calculated minimum wall (i.e., nominal wall thickness minus the combined loss due to mill tolerance, bending tolerance and corrosion allowance), it is recommended that the fabricator check the wall thicknesses of 100% of the bends at 150 mm (6 in) from each tangent point and at the 1/4, 1/2 and 3/4 points of the bend.

For bends in which the wall thickness after bending will not be within 5% of the calculated minimum wall, the fabricator should check wall thicknesses on the first 10 bends of each material, size, and wall thickness at 150 mm (6 in) from each tangent point and at the 1/4, 1/2 and 3/4 points of the bend.

If none of the limits on thinning as set out (by client's specification) are exceeded, 10% of the remaining bends should be checked at the point where the maximum thinning occurred on the first 10 bends. The fabricator should document as to which bends were checked. Also, the fabricator should be required to keep a log as to quantity of bends on the job by size, quantity of bends checked, and piping isometric drawings on which bends were checked.

WALL THICKNESS, FLATTENING & WRINKLE OF BENDS

WALL THICKNESS, see ASME B31.3.

FLATTENING TOLERANCES, see ASME B31.3.

WRINKLE TOLERANCES (recommended) should be as follows:

- a) all wave shapes should blend into the pipe surface in a gradual manner.
- b) the maximum vertical height of any wave, measured from the average height of two adjoining crests to the valley, should not exceed 3 % of the nominal pipe size.

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c) the minimum ratio of the distance between crests as compared to the height between crests and the valley in between should be 12 to 1.

d) the maximum ovality should be as follows: Without mandrel – 8 % and with mandrel – 5 %

e) Other post bend dimensions should be as follows:

- Radius of bend - plus or minus 12.5 mm (1/2 in)
- Degree (or angle) of bend - plus or minus 1/2 degree
- Plane of bend - plus or minus 1 degree
- Flat plane of bend - plus or minus 1% of centerline radius
- Linear tolerance - plus or minus 3.2 mm (1/8 in) (not accumulative)

LIQUID PENETRANT EXAMINATION

For welded pipe, the weld seam of the first bend for each nominal size and wall thickness should be 100% liquid penetrant examined to ASTM E 165 after bending. Thereafter, the welds of 5% of all bends made from welded pipe should be liquid penetrant examined to ASTM E 165 after bending. There should be no linear indications. The method used and the results are to be shown on the material certificate.

COLD BEND TESTING

It is recommended that hardness testing be carried out to ensure the mechanical properties of the pipe after the cold bending process. Hardness measurements need to be taken to qualify a bending process and/or the bending equipment.

Hardness measurements for procedure qualification should be performed by the Vickers method, in accordance with ASTM A 370.

The hardness measurements should be recorded in the outer radius of the pipe, the inner radius of the pipe, welds (if any) and transition zones of the weld. The hardness values should not exceed 240Hv.

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Manufacturing Procedure Specification/ Inspection Test Plan (MPS/ITP)

The Pipe Manufacturer shall submit bending, heat treatment and non-destructive examination procedures for acceptance. These procedures should, as a minimum, include the following.

OPERATING SEQUENCE	METHOD OF TEMPERATURE MEASUREMENTS AND RECORDING
FORMING PROCESS	BEND DIMENSION AND TOLERANCES
PRODUCTION PARAMETERS	NON DESTRUCTIVE EXAMINATION PROCEDURES
WIDTH OF HEAT BAND	POST FORMING
HEATING RATE AND METHOD	FABRICATION PROCEDURES QUALIFICATIONS
BENDING TEMPERATURE RANGE	PRODUCTION CONTROL PROCEDURES
COOLING RATE, COOLANT METHOD AND COOLANT FLOW RATE	CALIBRATION OF EQUIPMENT AND TOLERANCES

Notable standards for bending practices relied on included ASME B 16.49 and ISO 15990.

NOTE: All calculations shown in this article are hypothetical and are intended for information purposes only and should only be relied on as a reference.