Chapter - VI

Forming Procedure – Forming Tools Development

Abstract
This chapter deals with the development of the formation tools to form the LDSAW line pipe to get the desired shape/profile at various stages of the manufacturing. The most important stages are edge milling of the plate which affects the weld quality during the final submerged arc welding and this step also decides the plate width which in turn decides the percentage of expansion. Second critical formation step is plate edge crimping which decides the shape/profile around the weld of LDSAW line pipe. Third critical step is J-C-O formation which decides the overall shape/profile of the LDSAW line pipe. Last critical step is mechanical expansion which controls the shape/profile and final dimensions of the LDSAW line. The tooling has been designed and established in this chapter before the actual X-120M LDSAW line pipe manufacturing.
6.0 Introduction

The forming in the manufacturing of line pipe is a critical operation as far as the final dimensions of line pipe are concerned. The line pipe forming operation can be divided into two parts, first is to achieve the required shape in terms of curvature and ovality after formation of the line pipe. The curvature and ovality ultimately affects the final dimensional controls at the later stage i.e. after mechanical expansion of the line pipe. The second part is to make the right welding joint geometry for making the final long seam weld of line pipe. The welding joint geometry ultimately affects the final seam weld to control the soundness of the weld at the later stage i.e. during submerged arc welding of the line pipe. As far as the curvature or shape of the line pipe is concerned, the important operation are making the required curvature along the edges of the plate for line pipe (Plate Crimping press) up to the 150mm in width minimum and the forming of the line pipe at J-C-O press. The selection of tool material with proper hardness and curvature of the dies (radius of the dies) in both the operation playing a vital role in the formation of line pipes. The main parameters for selecting die (Tool) is size of the line pipe for which dies/tools are to be made i.e. the diameter of the line pipe, thickness of the line pipe and most important is grade of the line pipe (Strength level). The grade or strength level decides the amount of the spring back behavior of the steel. The spring back behavior again varies from plate mill to plate mill in the same grade of steel plate. This is because the each plate mill has its own manufacturing procedures to produce the plate. The plate for line pipe is produced through TMCP (Thermo mechanical controlled processing) and accelerated cooling process. In this process the strength level is achieved by the steel chemistry of the slab, thickness of the slab, reheating temperature, roughing temperature where the first reduction in the thickness, finish rolling temperature and finally the accelerated cooling temperature rate from 800 °C to 500 °C approximately. So spring back during the formation is unpredictable before actual formation is happening.

The line pipe made through UOE route [1], for safe pipe forming new tools for UOE process has to be developed to reduce the danger of pipe failure during mechanical expansion of the line pipe. During the mechanical expansion, the line pipe got leaner crack due to poor profile/curvature at the welding (i.e. the positive/negative peaking at the weld) at the toe of the weld i.e. from HAZ portion. A low carbon and low Pcm steel with “V-Nb-Ti-B” micro alloying concept is used. In the plate rolling the main attention is turned to the heavy accelerates cooling. The large spring back that occurs during the U-forming step of the UOE process is one of the most complex aspects in forming of X-120 line pipe. To handle this aspects FEM calculation where used to modify U-forming parameters and to optimize the shape of the U-press tool [1, 2, 3, 4, 5, 6, 7]. One of the greatest challenges in the line pipes forming of ultra –high strength plate with a relatively small wall thickness is the large spring back due to the greater elastic...
range of a material with the high yield stress. Especially the U-forming step is affected by this spring back. It could leads to shell that cannot be inserted in to the O-Press. FEM calculations were made to support the optimization of the U-ing process and the shape of the U-ing punch. The newly calculated shape of the U-Press will leads to a reduction of the spring back. Further it was assumed that ovality and peaking after O-ing were set to optimal value to avoid problems with welding and expansion step of the line pipe production. The finished line pipe shape [8] is determined during the manufacturing process and can be optimized by balancing the manufacturing parameters, line pipe compression, and expansion. Through the optimization of crimping, U-press, and O-press operations, it is possible to control pipe diameter and wall thickness (hence, ovality) to the point where the specifications of most deep water projects are met and surpassed enhanced tolerances that have been achieved for line pipe roundness, wall thickness, and diameter, have reduced design- and production- related uncertainty and resulted in optimized wall thickness. The line pipe manufactured by the UOE process undergoes various strain cycles, both tensile and compressive. The combination of these cycles affects the overall behavior of the material in compression. For standard UOE processes, the material response to these strain cycles during forming is a 15% derating of compressive strength. This is known as the Bauschinger effect. Corus Tubes, over a period of years, observed that the results obtained from the forming process often yielded higher collapse strengths than those obtained when any of the standard equations were applied. Examination of equation parameters suggested that this benefit could be the result either of greater pipe roundness or increased pipe compressive strength. This led to a research and process development program that has provided greater understanding of the mechanisms at work during pipe forming. The enhancement of collapse strength was found to be a result both of improved pipe shape and pipe strength. Work by the company has now made possible a reversal of much of the Bauschinger effect in UOE pipe manufacturing operations. Consequently, higher compressive strengths than those normally expected have been achieved. By optimizing the various compression and expansion cycles, it has been possible to determine a set of manufacturing conditions that enable collapse performance to be enhanced, providing the potential for reducing pipe wall thickness for future deep water applications. During line pipe forming [9], inner surface compressive and outer surface tensile strains are produced at the U-ing and O-ing stage of UOE line pipe forming. The radius of the skelp after U-ing is smaller than that of the line pipe after the subsequent O-ing stages and this will produced some strain reversal at points in the lower half of the line pipe. In addition to these bending strains, small compressive strains are generally applied to the line pipe during O-ing. The line pipe forming and final expansion process will therefore involve work hardened together with the possibility of softening associated with bauschinger effect in region of strain reversal. The large-diameter pipes [10] used in offshore
applications is commonly manufactured by cold-forming plates through the UOE process. The plate is crimped along its edges, formed into a U-shape and then pressed into an O-shape between two semicircular dies. The pipe is welded closed and then circumferentially expanded to obtain a highly circular shape. Collapse experiments have demonstrated that these steps, especially the final expansion, degrade the mechanical properties of the pipe and result in a reduction in its collapse pressure upwards of 30 percent. Generally, increase in the O-strain and decrease in the expansion strain improve the collapse pressure. Substituting the expansion with compression can not only alleviate the UOE collapse pressure degradation but can result in significant increase in collapse performance. Crimping affects the shape of the upper part of a UOE pipe. In particular, it affects the shape (and ovality) of UO pipe. It was found that crimp radii that are smaller than the inner and outer radii of the final pipe give higher UO collapse pressures. Furthermore, reducing the length of the crimped part tends to increase the UO collapse pressures. It was also found that if the current practice of expanding the diameter of the pipe by about 1% is followed, both the negative and positive effects of crimping are usually erased. However, if alternate forming solutions such as under expansion are adopted, a more careful selection of the crimping dies can lead to improved collapse performance. The main crimp parameters affecting the pipe shape are the radii of the inner and outer radii, and the length of plate being crimped. Thus, a smaller inner die radius produces a rounder pipe. As the crimp radii are increased, the collapse pressures drop at first and then steadily rise again, if the pipe is expanded by 01 percent, the effect of the crimping is essentially erased. The first step [11] of the manufacturing process of line pipe is the edge press, during this process, the upper tool is fixed and the lower tool is moved in upward direction. Then the forming process continues with the ‘U’ press, where the plate is formed into a U-shape. Afterwards, the forming process continues in the ‘O’ press, where circumferential compression is applied to form an O-shape. To achieve this, two semi-cylindrical dies press the U-shape. At the point of maximum compression, the nodes of the pipe are fixed in the horizontal edge at the symmetrical axis. Finally, a radial expansion is applied in order to obtain the final shape of the line pipe. To achieve all these stages of line pipe forming, the required tooling has to be established to get the desired shape of the pipe.

6.1 Line Pipe Forming Tools Development

The forming of line pipe is nothing but giving the shape to the TMCP (Thermo mechanical controlled processing) and accelerated cooling processed plate into line pipe at various stages. The formation of line pipe from TMCP plate is mainly consist of trimming of the TMCP plate to the required width with the help of milling of the edges of the said plate for particular size and making of the weld joint geometry during trimming operation known as ‘edge milling’ as shown in figure # 6.01, the milled plate is formed by bending/forming of the edges of the said plate to required radius along the length of plate.
for particular size of line pipe is known as ‘edge crimping’ as shown in figure # 6.02, the edge crimped plate then formed to line pipe shape through JCO process with incremental pressing to the required radius of the line pipe by making first ‘J-shape’ then ‘C-shape’ and finally O-shape is known as ‘JCO-forming’ as shown in Figure # 6.03, and after long seam welding then welded line pipe is mechanically expanded from inside to the required diameter of particular size of line pipe to achieve the final dimensions as shown in figure # 6.04.
The forming tools can be divided into four categories on the basis of nature of process for line pipe manufacturing at different stages namely edge milling, crimping press, JCO Press and mechanical expander tools.

6.1.1 Plate Edge Milling

For making weld joint geometry the standard line pipe 600 mm diameter cutter used with 40° cartridge for milling insert as shown in figure # 5.05 and # 5.06 respectively. The body of the milling cutter is made out of En-31 material to have a sufficient load bearing capacity 180-200 rpm and sufficient hardenability to get the desired hardness to prevent the deformation during the cyclic cutting load and wear resistance. The milling inserts used for the said operation made of tungsten carbide (WC) as a basic material with alloying element through powder metallurgy rout with special thermal resistance ceramic coating to withstand the temperature produced during the milling operation. The WC is alloyed with elements like aluminum, cobalt etc. to get the toughness to absorb the impact load of the milling operation without breaking as the tungsten carbide (WC) is a very brittle material without the alloying elements.
Figure # 6.05 Milling Diameter Cutter

Figure # 6.06 Milling cartridge 40°

Figure # 6.07 - Weld Joint Geometry for Line Pipe
The weld joint geometry used in the line pipe manufacturing is double Y joint which has three dimensions namely upper bevel, lower bevel and root face as shown in figure # 6.07. The cartridges for insert has been designed to produce the 40° bevel angle at lower, upper bevel and 2° angle at root face with a flexibility to get desired dimensions at the above places for high speed milling operation of ultra high strength TMCP steel. The 2° angle is given at root face is to get zero gape at the time of tack welding of line pipe as shown in figure # 6.08. The gape at the root face is not desirable during tack
welding fit up, as this end up with defects like porosity and slag inclusion during the final submerged arc welding. The design aspects are beyond the scope of the thesis.

6.1.2 Plate Edge Crimping

The plate edge crimping operation in line pipe manufacturing is very critical as far as final dimensions after mechanical expansion of line pipe around weld of long seam are concerned. The final dimensions of the line pipe around weld of long seam are controlled through crimping of the plate edges along the length by getting required radius in the crimped edges of the plate. The improper plate edge crimping is end up with peaking (positive or negative) at weld and localized flatness in the crimped area after mechanical expansion. The under edge crimping will produce positive peaking and over edge crimping will produce negative peaking. These dimensional defects are not acceptable as per line pipe manufacturing specifications. As per API-5L the limit for these defects is 1.59 mm maximum after mechanical expansion or even these dimensions may be limited to 0.5 mm depending upon the end use of the line pipe. From the manufacturing point of view peaking beyond certain limit cannot be rectified at mechanical expander and there are chances of fracture of line pipe from the toe of long seam weld, if the peaking generated at the crimping stage is more than the standard operating practice. The as-weld is the cast structure and no treatment has been given in standard line pipe manufacturing operation and direct expansion of the weld is not acceptable as the line pipe manufacturing specifications. During mechanical expansion operation if the peaking is more, then the positive peaking generate crack at inside weld toe (fusion line) and vice versa. The standard operating procedure in line pipe manufacturing is to control the peaking at the plate edge stage itself by designing the plate edge crimping tools/dies accordingly.

The designing of the plate edge crimping dies has two aspects, first is material and its treatment and second is the dimensions (radii). The material and the treatment of the dies are equally important as the dimensions. These dies are made out of EN-19 and induction hardened to 45-48 HRC to have the wear resistance of the working area of dies as shown in figure # 6.09.

![Crimping Tools for Line Pipe](image)

Figure # 6.09 Crimping Tools for Line Pipe
The radius of the plate edge crimping dies is decided with respect to the diameter, thickness and grade of line pipe. The diameter is the deciding factor of outer die radius, diameter and thickness is deciding factor for the radius of inside die of plate edge crimping. The grade/strength is equally important as it shows the spring back behavior of the TMCP steel which has to be taken into account while deciding the radii of inside as well outside plate edge crimping dies. The diameter of line pipe is fixed at the width milling (trimming) stage by fixing the width of the plate. The width of the plate is nothing but the circumference of the pipe minus percentage expansion of line pipe diameter. The milling width of the plate for line pipe manufacturing can be expressed as

\[ M_w = (D-t-\Delta D)\pi \]

Where

- 'M_w' is the milled width of the plate for line pipe,
- 'D' is Nominal outside diameter of the final line pipe,
- 't' is Actual thickness of the TMCP plate and
- '\Delta D' is the percentage of expansion in diameter to achieve the nominal diameter.

The line pipe diameter before expansion can be expressed in terms of the width/ circumference of the plate.

\[ C_{BE} = \pi \times d_{BE} \]

\[ M_w = \pi \times d_{BE} \]

\[ d_{BE} = \frac{M_w}{\pi} \]

Where

- 'C_{BE}' is the circumference before forming of line pipe and
- 'd_{BE}' is outside diameter before forming or 'd_{BE}' is equal to \((D-t-\Delta D)\pi\).

On the basis of diameter of the line pipe before forming the inside plate edge crimping die and plate edge crimping outside die diameter can be expressed as

\[ d_{CIN} = d_{BE} - 2t \]

\[ d_{COUT} = d_{BE}. \]

Where,

- 'd_{CIN}' is the inside crimping die diameter and
- 'd_{COUT}' is outside crimping die diameter. Ideally this will be the diameters of the crimping dies for plate edge crimping of the line pipe. But there is one unknown factor which is known as spring back. So the spring back has to be considered while deciding the dies radii of plate edge crimping. Therefore the dies Radii is nothing but the percentage of the shape deviation from the ideal shape (respective pipe radius), so by including the said parameter the radius of the inside as well outside crimping dies can be expressed as below.
\[ r_{\text{CIN}} = \frac{d_{\text{CIN}}}{2} - \psi \]
\[ r_{\text{COUT}} = \frac{d_{\text{COUT}}}{2} - \psi \]

Where 'r_{\text{CIN}}' is the inside crimping die radius, 'r_{\text{COUT}}' is outside crimping die radius and 'ψ' is the percentage spring back factor for line pipe steel. For grade X-70, the ψ is approximately 10% of the line pipe radius before forming and for X-80; the ψ is typically 15-20% of the radius of the line pipe before forming. For X-120, 'ψ' is taken as 30% to the respective radius of the line pipe before forming.

The diameter of plate edge crimping template is nothing but the nominal diameter minus thickness and minus percentage of the expansion. The diameter of the template for outside diameter and inside diameter plate edge crimping is

\[ d_{\text{OUT}} = (D-t) - AD \]
\[ d_{\text{IN}} = (D-t) - AD - 2t \]

Therefore the respective radii for plate edge crimping are

\[ r_{\text{IN}} = \frac{(d_{\text{IN}})}{2} \]
\[ r_{\text{OUT}} = \frac{(d_{\text{OUT}})}{2} \]

Where 'd_{\text{IN}}' is the inside crimping template diameter, 'd_{\text{OUT}}' is outside crimping template diameter, 'r_{\text{IN}}' is the inside crimping template radius and 'r_{\text{OUT}}' is outside crimping template radius. These templates are used to verify the correctness of the plate edge crimping profile to ensure the proper function of the operation.

6.1.3 J-C-O Forming

The JCO line pipe forming operation in line pipe manufacturing is very critical as far as the final dimensions after mechanical expansion of the line pipe around circumference are concerned. The final dimensions of the line pipe around the circumference are controlled through the forming of the plate by getting the required radius in the line pipe of formed plate. The improper forming is end up with oval and localized flatness in the formed area after mechanical expansion. These dimensional defects are not acceptable as per line pipe manufacturing specifications. As per API-5L, the limit for these defects is 1.59 mm maximum for localized flatness and 1 percent for ovality (deviation from the circularity) after mechanical expansion or even these dimensions may be limited to ±0.5 mm for localized flatness and 1.0 mm for ovality depending upon the end use of the line pipe. From the manufacturing point of view localized flatness and ovality beyond certain limit cannot be rectified at mechanical expander. The oval
shape of the line pipe and localized flatness in circumference along the length of line pipe also affect the line pipe very badly at continuous tack weld stage. With these defects, there may be chances of line pipe getting damaged due to heavy dents and deep marks of the edges of the continuous tack welding rollers, as the continuous tack weld rollers are aligned in a circular cage of roller to have the uniform gap free set up of the joint at continuous tack weld station as shown in the figure # 6.10. The standard operating procedure in line pipe manufacturing is to control the localized flatness and ovality at the JCO forming stage itself by designing the JCO line pipe forming dies accordingly.

![Figure # 6.10 Continuous Tack welding set up for Line Pipe](image)

The designing of the J-C-O line pipe forming dies has two aspects, first is material and its treatment and second is the dimensions (radii). The material and the treatment of the dies are equally important as the dimensions. These dies are made out of EN-19 and induction hardened to 45-48 HRC to have the wear resistance of the working area of dies as shown in figure # 6.11. The radius of the JCO line pipe forming dies is critical for achieving the desired shape and quality of the finished product.

![Figure # 6.11 J-C-O Tools for Line Pipe](image)
pipe forming dies is decided with respect to the diameter, thickness and grade of the line pipe. The diameter and thickness is deciding factor for the radius of the JCO line pipe forming die. The grade/strength is equally important as it shows the spring back behavior of the TMCP steel which has to be taken into account while deciding the radius of the JCO line pipe forming dies. The diameter of line pipe is fixed at the width milling (trimming) stage by fixing the width of the plate. The radius of the JCO line pipe forming die and the verification template can design on the same hypothesis as for inside plate edge crimping die as stated above in section 6.1.2.

6.1.4 Mechanical Expansion

The mechanical expansion operation in line pipe manufacturing is very critical as for as the final dimensions after the seam weld of the long seam line pipe are concerned. The final dimensions of the line pipe around the weld of the long seam and along the circumference. The weld is cast structure and no treatment has been given in standard line pipe manufacturing operation and direct expansion of the weld is not acceptable as the line pipe manufacturing specifications. During mechanical the seam weld of inside of the line pipe should not be in contact with the expander die. In one of the expander die there is a slot of 5 mm deep and 50 mm wide for locating the position of inside weld so that it should never be in contact with the expander die during the expansion operation as shown in the figure # 6.12, as the expansion mark on the weld bead is not acceptable in line pipe manufacturing specifications.

Figure # 6.12 Rectangular Slotted Expander Die

The final dimensions of the line pipe which are controlled at expander are peaking at weld, flatness, ovality, straightness, and diameter. These dimensions are again depends up the tool design and the percentage of expansion of the line pipe. The tooling are playing important role during the expansion of the line pipe, first is expansion segment, second is wedge (in conical shape) on which the expansion dies
are fitted and third one is line pipe sport roll through/on which line pipe is moving reverse and forward during the expansion. The designing of the expander tooling has two aspects, (1) material and its treatment and (2) the dimensions of the respective tool (radii). The material and the treatment of the dies are equally important as the dimensions. These expansion dies are made out of D-2 and volume hardened and tempered to 55-88 HRC to have the wear resistance of the working area of dies as shown in figure # 6.09. The wedge is playing a very important role as the expansion segment is moving under expansion load on it and surface finish and its self lubricating properties should be properly designed. The material and its heat treatment are very critical. The material of the wedge in use was SG 600 with poor nodularity count 82/mm², matrix of the structure is mostly ferritic in nature and ultimate tensile strength is 482 MPa at hardness 22 HRC. The requirement of the hardness is minimum 45-48 HRC and in SG-600, it is not possible without carburizing or any other equivalent heat treating process. Therefore the new wedge of Austempered ductile iron (ADI) material has been redesigned to have proper strength and wear resistance with self lubricating properties. The new wedge ADI material with modularity count 103-120/mm², matrix of the structure is pearlitic in nature and ultimate tensile strength is 790 MPa at hardness 32 HRC. The wedge material ADI is volume hardened and tempered to 45-48 HRC satisfactorily. The developmental detail is beyond the scope of the thesis.

The radii of the expansion segments of the expander are decided with respect to the diameter, thickness and grade of the line pipe. The diameter and thickness are the deciding factor for the radii of the expansion segment of the expander. The grade/ strength is equally important as it shows the spring back behavior of the TMCP steel which has to be taken into account while deciding the radii of the expansion segment of the expander. The diameter of line pipe is fixed at the width milling (trimming) stage by fixing width of plate. The radii of the expansion segments can design on the same hypothesis as for inside plate edge crimping die as stated above in section 6.1.2. The radius of the verification template is the final nominal radius of the line pipe.

6.2 Line Pipe Forming

On the basis of above hypothesis (Plate Edge Milling, Plate Edge Crimping, J-C-O Formation and Mechanical Expansion) for tools/dies design for line pipe formation, one set of complete tools/dies has been designed and manufactured for line pipe of 18" (457.2 mm) of diameter and thickness is 14.3 mm of API-5L grade X-120M. The plate width and radius of the dies of plate crimping press, forming and expansion are shown in table # 6.01. The same radius templates were also made to check the profile of the formed pipe at all stages as per the table # 6.01.
Die Radius Calculations

<table>
<thead>
<tr>
<th>Item</th>
<th>Formula</th>
<th>Value (mm)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate Milled Width</td>
<td>$M_w = \frac{(D-t)-D}{\pi}$</td>
<td>1377.0</td>
<td>$\pi = 3.14159$</td>
</tr>
<tr>
<td>Unexpanded Diameter</td>
<td>$d_{BE} = \frac{M_w}{\pi}$</td>
<td>438.3</td>
<td></td>
</tr>
<tr>
<td>Inside Die Diameter</td>
<td>$d_{CN} = d_{BE} - 2t$</td>
<td>409.7</td>
<td></td>
</tr>
<tr>
<td>Outside Die Diameter</td>
<td>$d_{OUT} = d_{BE}$</td>
<td>438.3</td>
<td></td>
</tr>
<tr>
<td>Inside Die Radius</td>
<td>$r_{CN} = \frac{(d_{CN})}{2} - t$</td>
<td>143.4</td>
<td>$\psi = 30%$</td>
</tr>
<tr>
<td>Outside Die Radius</td>
<td>$r_{OUT} = \frac{(d_{OUT})}{2} - t$</td>
<td>153.4</td>
<td></td>
</tr>
<tr>
<td>Outside Templet Diameter</td>
<td>$d_{OUT} = \frac{(D-t)-D}{\pi}$</td>
<td>438.3</td>
<td></td>
</tr>
<tr>
<td>Inside Templet Diameter</td>
<td>$d_{IN} = \frac{(D-t)-D}{2t}$</td>
<td>409.7</td>
<td></td>
</tr>
<tr>
<td>Inside Templet Radius</td>
<td>$r_{IN} = \frac{(d_{IN})}{2}$</td>
<td>204.9</td>
<td></td>
</tr>
<tr>
<td>Outside Templet Radius</td>
<td>$r_{OUT} = \frac{(d_{OUT})}{2}$</td>
<td>219.2</td>
<td></td>
</tr>
<tr>
<td>Forming Tool Radius</td>
<td>Same as Plate Crimping</td>
<td>143.4</td>
<td></td>
</tr>
<tr>
<td>Inside Templet Radius</td>
<td>Same as Plate Crimping</td>
<td>204.9</td>
<td></td>
</tr>
<tr>
<td>Outside Templet Radius</td>
<td>Same as Plate Crimping</td>
<td>219.2</td>
<td></td>
</tr>
</tbody>
</table>

Table # 6.01 Calculation for Forming Tools.

One pipe was formed dually covered all activities like tab joining, plate ultrasonic testing, milling, washing, continuous tack welding, cleaning and submerged arc welding. The submerged arc welding has been carried out as per procedure established in Chapter # IV and V. All the above activities will be discussed in welding section of pipe manufacturing chapter # VII. The shape of the line pipe comes out like egg shape, the ovality at F-end was 26 mm and at T-end is 30 mm, peaking at F and T-end was 6 and 7 mm respectively and the straightness was 20 mm. The dimensions of the line pipe after forming and submerged weld were on very higher side and the profile was also not matching with the profile template. During the mechanical expansion the line pipe fails because the dimensional defects which were cannot be rectified with expander as discussed in section 6.1.2 and due to these dimensional defects the compressive strength which is more than the strength of the line pipe [9]. The crack initiate at the inside weld toe i.e. fusion line due to the very high positive peaking and poor profile as shown in figure # 6.13.
The tools/dies design was revisited and found the radius of the tools was not as per the profile required for line pipe. The tools are redesigned with the spring back of 40% of the diameter of the pipe. The plate width and radius of the dies of plate crimping press, forming and expansion are shown in table # 6.02. The same radius templates were also made to check the profile of the formed line pipe. Again one line pipe of 18” x 14.3 mm of X-120M is made through all the stations as mentioned above. The shape of the line pipe looks good as shown in the figure # 6.14, the ovality at F-end is 10 mm and at T-end is 12 mm, peaking at F and T-end are 2 and 2.5 mm respectively and the straightness is 16 mm.

### Die Radius Calculations

<table>
<thead>
<tr>
<th>Pipe Size</th>
<th>18&quot;X14.3 mm</th>
<th>API-5L, X-120M</th>
<th>Expansion Percent = 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Formula</td>
<td>Values (mm)</td>
<td>Remarks</td>
</tr>
<tr>
<td>Plate Milled Width</td>
<td>$M_w = \frac{(D-t)-D}{2}\pi$</td>
<td>1377.0</td>
<td>II=3.14159</td>
</tr>
<tr>
<td>Unexpanded Diameter</td>
<td>$d_{BE}=M_w/\pi$</td>
<td>438.3</td>
<td></td>
</tr>
<tr>
<td>Inside Die Diameter</td>
<td>$d_{CIN}=d_{BE}-2t$</td>
<td>409.7</td>
<td></td>
</tr>
<tr>
<td>Outside Die Diameter</td>
<td>$d_{COUR}=d_{BE}$</td>
<td>438.3</td>
<td></td>
</tr>
<tr>
<td>Inside Die Radius</td>
<td>$r_{CIN}=(\frac{d_{CIN}}{2})-\psi$</td>
<td>122.9</td>
<td>$\psi=40%$</td>
</tr>
<tr>
<td>Outside Die Radius</td>
<td>$r_{COUR}=(\frac{d_{COUR}}{2})-\psi$</td>
<td>131.5</td>
<td></td>
</tr>
<tr>
<td>Outside Templet Diameter</td>
<td>$d_{TOUT}=\frac{(D-t)-D}{2}$</td>
<td>438.3</td>
<td></td>
</tr>
<tr>
<td>Inside Templet Diameter</td>
<td>$d_{ Tin}=(D-t)-2t$</td>
<td>409.7</td>
<td></td>
</tr>
<tr>
<td>Inside Templet Radius</td>
<td>$r_{ Tin}=(\frac{d_{ Tin}}{2})$</td>
<td>204.9</td>
<td></td>
</tr>
<tr>
<td>Outside Templet Radius</td>
<td>$r_{ TOUT}=(\frac{d_{TOUT}}{2})$</td>
<td>219.2</td>
<td></td>
</tr>
<tr>
<td>Forming Tool Radius</td>
<td>Same as Plate Crimping</td>
<td>122.9</td>
<td></td>
</tr>
<tr>
<td>Inside Templet Radius</td>
<td>Same as Plate Crimping</td>
<td>204.9</td>
<td></td>
</tr>
<tr>
<td>Outside Templet Radius</td>
<td>Same as Plate Crimping</td>
<td>219.2</td>
<td></td>
</tr>
</tbody>
</table>

Table # 6.02 Calculation for Forming Tools.
The dimensions of the line pipe after forming and submerged weld were satisfactory as per the standard line pipe manufacturing procedure and the profile was also matching with the profile template. Therefore all the parameters like profile, peaking, and ovality within the limit and line pipe expansion is successful with ovality 3-4 mm, peaking 0.8 mm, and straightness 7 mm at 1.0 percentage of expansion. The details of the forming, welding, and finishing operations along with mechanical and physical properties will be discussed in the chapter # VII of line pipe manufacturing.

6.3 Results and Discussion

The line pipe of size 18” X 14.3 mm has been formed from the plate produced through TMCP (Thermo mechanical controlled processing) and accelerated cooling process. The springback behavior again varies from plate mill to plate mill in the same grade of steel plate as discussed. The line pipe has been formed by the tools developed in this chapter through various stages like plate edge miller, plate crimping, and J-C-O formation with one percent of expansion and springback consideration of 30 percent. The line pipe has been welded as procedures established in chapter # IV and V and expanded as per the tooling developed in this chapter. The outcomes in terms of shape of the line pipe like egg shape, the ovality at F-end was 26 mm and at T-end was 30 mm, peaking at F and T-end 6 and 7 mm respectively and the straightness was 20 mm. The dimensions of line pipe after forming and submerged weld were on very higher side and the profile was also not matching with the profile template. During the mechanical expansion the line pipe fails because the dimensional defects which were not rectified with expander as discussed in section 6.1.2 and due to these dimensional defects the compressive strength which is more than the strength of the line pipe [9]. The crack initiate at the inside weld toe i.e. fusion line due to the very high positive peaking and poor profile.
The tools/dies design was revisited and found the radius of the tools was not as per the profile required for X-120M line pipe. The tools are redesigned with the spring back of 40 percent of the diameter of the pipe. The line pipe of 18" x 14.3 mm of X-120M was again made with new tooling through all the stations as mentioned above. The ovality at F-end was 10 mm and at T-end was 12 mm, peaking at F and T-end as 2 and 2.5 mm respectively and the straightness was 16 mm before mechanical expansion. The dimensions of the line pipe after forming and submerged weld were satisfactory as per the standard line pipe manufacturing procedure and the profile was also matching with the profile template. Therefore all the parameter likes profile, peaking and ovality within the limit and line pipe expansion is successful with ovality 3-4 mm, peaking 0.8 mm and straightness 7 mm at 0.8-1.0 percentage of the expansion.

Therefore spring back during the formation is unpredictable before actual formation is happening. The spring back is a vital factor which needs to access correctly to decide the radius of tools/dies used at various stages of the line pipe forming. The radius of the tools/dies at every station of line pipe forming except the plate edge milling operation is playing a critical role in forming a line pipe with acceptable final dimensions and profile/curvature.

6.4 References


2. Hans-Georg Hillenbrand, Andreas Liessem, Karin Biermann, Carl Justus Heckmann, Volker Schwinn; Development and Production of Linepipe Steels in Grade X100 and X120. - Seminar of X120 grade High Performance Pipe Steels, Technical Conference Beijing, China 2005.


