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Thème

In-line inspection of Hydrocarbon Pipelines

(ILI Smart Pigs)

Jury de soutenance :

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APPRECIATION

THIS WORK IS SINCERELY DEDICATED TO MY MOTHER FOR THE GREAT SUPPORT WITHOUT HER WE WOULDN'T HAVE REACHED THIS LEVEL

JURY

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CHAPTER I

Background of Proposed Study

I.1 Introduction to Pipeline:

Pipelines are built for transporting liquids and gases such as oil and natural gas, which commonly used in offshore and onshore industries. However, pipelines have its own time limitation before its failure in operation which being affected because of increasing of aging infrastructure. The failure of the pipelines during operation may expose accidences to be occurred. Most of the accidents occurred in natural gases and liquids pipelines are internal and external defects .The geometry defect occurred from the corrosion and material properties will affect the limit load of the pipelines before it burst. In order to reduce any potential due to undue accident caused by a lack of unawareness of integrity of the line, regular inspection of pipelines is needed. However, a wide range of subjects that relate to the repair of pipelines using composite materials. Composite repair systems are going to continue to play an important role in rehabilitating the aging pipeline systems around the world. Prior research, as well as ongoing efforts, has focused on demonstrating how composite materials can restore the serviceability of pipelines using engineering analysis and testing methods. A significant body of knowledge has been accumulated over the past 20 years and is expected to continue in the future.

I.2 Pipeline Material:

Materials used in pipelines are influenced by the type of element that will be transported by the pipeline. Today, the **X70** pipeline steel is widely used in the world, the **X80** pipeline steel began to apply in some developed countries and the research and development of **X100/X120** pipeline steel is being studied in the recent years. In our country, the **X60** pipeline steel is widely used in the working pipelines. The **X70** pipeline steel is used in the West-East Gas Pipeline Project. Most of the researches are focus on the fatigue failure of the pipeline steel, especially the fatigue crack propagation of the pipeline steels. (Jiang, Y.& Chen, M. 2012).

Table I.1 API 5L Grade

API 5L Grade	Yield Strength min. (MPa)	Tensile Strength min.(MPa)	Yield to Tensile Ratio (max.)	Elongation min.%
A	207	331	0.93	28
B	241	414	0.93	23
X42	290	414	0.93	23
X46	317	434	0.93	22
X52	358	455	0.93	21
X56	386	490	0.93	19
X60	414	517	0.93	19
X65	448	530	0.93	18
X70	482	565	0.93	17
X80	551	620 ~ 827	0.93	16

I.3 API 5L Pipe Supply Range:

Grades: API 5L Grade B, X42, X52, X56, X60, X65, X70, X80

Product Specification Level: PSL1, PSL2, onshore and offshore sour services

Outer Diameter Range: 1/2" to 2", 3", 4", 6", 8", 10", 12", 16 inches, 18 inches, 20 inches, 24 inches up to 40 inches.

Thickness Schedule :SCH 10. SCH 20, SCH 40, SCH STD, SCH 80, SCH XS to SCH 160

Manufacturing Types: Seamless (Hot Rolled and Cold Rolled), Welded ERW (Electric resistance welded), SAW (Submerged Arc Welded) in LSAW, DSAW, SSAW, HSAW

Ends Type: Beveled ends, Plain ends

Length Range: SRL (Single Random Length), DRL (Double Random Length), 20 FT (6 meters), 40FT (12 meters) or, customized

Protection Caps in plastic or iron

Surface Treatment: Natural, Varnished, Black painting, FBE, 3PE (3LPE), 3PP, CWC (Concrete Weight Coated) CRA Clad or Lined

Table I.2 Tolerances for diameter and out-of-roundness

Specified outside diameter D mm (in)	Diameter tolerances [d] mm (in)				Out-of-roundness tolerances mm (in)	
	Pipe except the end [a]		Pipe end [a,b,c]		Pipe except the end [a]	Pipe end [a,b,c]
	SMLS pipe	Welded pipe	SMLS pipe	Welded pipe		
< 60,3 (2.375)	− 0,8 (0.031) to + 0,4 (0.016)		− 0,8 (0.031) to + 0,4 (0.016)		1,2 (0.048)	0,9 (0.036)
≥ 60,3 (2.375) to 168,3 (6.625)	± 0,007 5 D		− 0,4 (0.016) to + 1,6 (0.063)		0,020 D for $\frac{D}{t} \leq 75$; by agreement for $\frac{D}{t} > 75$	0,015 D for $\frac{D}{t} \leq 75$; by agreement for $\frac{D}{t} > 75$
> 168,3 (6.625) to 610 (24.000)	± 0,007 5 D	± 0,007 5 D, but maximum of ± 3,2 (0.125)	± 0,005 D, but maximum of ± 1,6 (0.063)		0,020 D	0,015 D
> 610 (24.000) to 1 422 (56.000)	± 0,01 D	± 0,005 D, but maximum of ± 4,0 (0.160)	± 2,0 (0.079)	± 1,6 (0.063)	0,015 D, but maximum of 15 (0.6) for $\frac{D}{t} \leq 75$; by agreement for $\frac{D}{t} > 75$	0,01 D, but maximum of 13 (0.5) for $\frac{D}{t} \leq 75$; by agreement for $\frac{D}{t} > 75$
> 1 422 (56.000)	as agreed					

[a] The pipe end includes a length of 100 mm (4.0 in) at each of the pipe extremities.

[b] For SMLS pipe, the tolerances apply for $t \leq 25,0$ mm (0.984 in), and the tolerances for thicker pipe shall be as agreed.

[c] For expanded pipe with D ≥ 219,1 mm (8.625 in) and for non-expanded pipe, the diameter tolerance and the out-of-roundness tolerance may be determined using the calculated inside diameter (the specified outside diameter minus two times the specified wall thickness) or measured inside diameter rather than the specified outside diameter (see 10.2.8.3).

[d] For determining compliance to diameter tolerances, the pipe diameter is defined as the circumference of the pipe in any circumferential plane divided by Pi.

Table I.3 Tolerances for wall thickness

Wall thickness *t* mm (in)	Tolerances [a] mm (in)
SMLS pipe [b]	
≤ 4,0 (0.157)	+ 0,6 (0.024) – 0,5 (0.020)
> 4,0 (0.157) to < 25,0 (0.984)	+ 0,150 *t* – 0,125 *t*
≥ 25,0 (0.984)	+ 3,7 (0.146) or + 0,1 *t*, whichever is the greater – 3,0 (0.120) or – 0,1 *t*, whichever is the greater
Welded pipe [c,d]	
≤ 5,0 (0.197)	± 0,5 (0.020)
> 5,0 (0.197) to < 15,0 (0.591)	± 0,1 *t*
≥ 15,0 (0.591)	± 1,5 (0.060)

a If the purchase order specifies a minus tolerance for wall thickness smaller than the applicable value given in this table, the plus tolerance for wall thickness shall be increased by an amount sufficient to maintain the applicable tolerance range.

b For pipe with D ≥ 355,6 mm (14.000 in) and t ≥ 25,0 mm (0.984 in), the wall-thickness tolerance locally may exceed the plus tolerance for wall thickness by an additional 0,05 t, provided that the plus tolerance for mass (see 9.14) is not exceeded.

c The plus tolerance for wall thickness does not apply to the weld area.

d See 9.13.2 for additional restrictions.

I.4 Pipeline Design :

I.4.1 Specified dimensions

Line pipe shall be furnished in the outside diameters and wall thicknesses specified on the purchase order; such dimensions shall be in accordance with one of the following:

a. As given in Table 4, 5, 6A, 6B, 6C, E-6A, E-68, or E-6C, Whichever is applicable

b. By agreement between the purchaser and the manufacturer, intermediate to the values given in Table 6A, 68, 6C, E-6A, E-68, or E-6C, whichever is applicable.

I.4.2 Diameter

The outside diameter shall be within the tolerances specified in Tables 7 and S. For threaded pipe, the outside diameter at the threaded ends shall be such that the thread length, L4, and the number of full-crest threads in that length are within the applicable dimensions and tolerances specified in API Standard 5B.

Pipe of sizes 20 and smaller shall permit the passage over theends, for a distance of4in. (101.6 mm),of a ring gage that has a bore diameter not larger than the pipe's specified outside diameter plus the applicable plus tolerance shown in Table 8. For submerged-arc welded pipe, ring gages may be slotted or notched to permit passage of the gage over the weld reinforcement.

Ring gage measurements shall be made at least once per 4 hours per operating shift. Diameter measurements of pipe larger than size 20 shall be made with a diameter tape. Diameter measurements of pipe sizes 20 and smaller shall be made with a snap gage, caliper, or other device that measures actual diameter across a single plane, except that the manufacturer shall have the option of using a diameter tape. Diameter measurements shall be made at least once per 4 hours per operating shift. Any pipe found to be out of tolerance is cause for individual diameter measurement of all pipe back to the last, and up to the next, two sequential pipes measured and found to be within tolerance.

By agreement between the purchaser and the manufacturer, the tolerances on the outside diameter at the pipe ends may be applied instead to the inside diameter at the pipe ends.

I.4.3 Wall thickness

Each length of pipe shall be measured for conformance to the specified wall thickness requirements. The wall thickness at any location shall be within the tolerances specified in Table 9, except that the weld area shall not be limited by the plus tolerance. Wall thickness measurements shall be made with a mechanical caliper or with a properly calibrated nondestructive inspection device of appropriate accuracy.

In case of dispute, the measurement determined by use of the mechanical caliper shall govern. The mechanical caliper shall be fitted with contact pins having circular cross sections of ¼ in. (6.4 mm) diameter. The end of the pin contacting the inside surface of the pipe shall be rounded to a maximum radius of *1112* in. (38.1 mm) for pipe of size *65/8* or larger, and to a maximum radius of *dl4* for pipe smaller than size *65/8,* with a minimum radius of *118* in. (3.2 mm). The end of the pin contacting the outside surface of the pipe shall be either fiat or rounded to a radius of not less than 1112 in. (38.1 mm).

I.4.4Weight

Each length of pipe of size *59/16* or larger shall be weighed separately; lengths of pipe smaller than size *59/16* shall be weighed either individually or in convenient groups, at the option of the manufacturer. For all pipe sizes, the order item weights and, where applicable, the carload weights shall be determined. Threaded-and-coupled pipe shall be weighed with the couplings screwed on but without thread protectors, except for carload determinations for which proper allowance shall be made for the weight of the thread protectors.

Threaded-and-coupled pipe may be weighed before the couplings are attached, provided that allowance is made for the weight of the couplings. For plain-end pipe, the weights determined as described above shall conform to the calculated weights, within the tolerances specified in Table 10. For threaded-and-coupled pipe, the weights determined as described above shall conform to the calculated weights or adjusted calculated weights, within the tolerances specified in Table 10. Full-length calculated weights shall be determined in accordance with the following equation:

$$W_L = (W_{pe} \times L) + e_w$$

W_L =calculated weight of a piece of pipe of length L, Ib (kg), $W_{pe} = plain - end\ weight\ per\ unit\ length\ rounded\ to\ the$

$nearest\ 0.0\ I\ Ib/ft\ (0.0\ I\ kg/m)$,

L =length of pipe, including end finish, as defined in 7.5, ft (m),

e_w =*weight gain or loss due to end finish, lb (kg). For plain-end pipe, e", equals 0.*

The plain-end weight per unit length,W_{pe} shall be calculated using the following equation and rounded to the nearest 0.01 *Ib / ft* (0.01 *kg/m):*

U.S. Customary unit equation *(tb/ft)* =W_{pe} = 10.69 *(D - t)t*

SI unit equation *(kg/m)* = W_{pe}= 0.02466 *(D - t)t*

where

D = specified outside diameter, in. (mm),
t = specified wall thickness, in. (mm).

I.5 Pipeline Deficiency and welding tolerances

I.5.1Jointers

When specified on the purchase order, jointers (two lengths of pipe coupled together by the manufacturer or two lengths of pipe welded together by the manufacturer in accordance with the requirements of Appendix A) may be furnished; however, no length used in making a jointer shall be less than 5.0 ft (1.52 m). For helical seam submerged-arc welded pipe, the junctions of skelp end welds and helical seam welds shall be permitted only at distances greater than 12 in. (304.8 mm) from jointer welds. By agreement between the purchaser and the manufacturer, skelp end welds in finished pipe shall be permitted at jointer welds, provided that there is a circumferential separation of at least 6 in. (152.4 mm) between the junction of the skelp end weld and the jointer weld and the junction of the helical seam and the jointer weld. Double joints are not within the purview of **API** Specification 5L. Double joints are defined as lengths of pipe welded together by parties other than the manufacturer or lengths welded together by the manufacturer in accordance with requirements other than those in Appendix A.

I.5.2 Workmanship And Defects

Imperfections of the types described in 7.8.1-7.8.14 that exceed the specified criteria shall be considered defects. The manufacturer shall take all reasonable precautions to minimize recurring imperfections, damage, and defects.

I.5.3 Offset of Plate Edges

For pipe with filler metal welds having specified wall thicknesses of 0.500 in. (12.7 mm) and less, the radial offset (misalignment) of plate edges in the weld seams shall not be greater than 1/16 in. (1.6 mm). For pipe with filler metal welds having specified wall thicknesses over *0.500* in. (12.7 mm), the radial offset shall not be greater than 0.125 *tor* 1/8 in. (3.2mm), whichever is smaller. For electric welded pipe, the radial offset of plate edges plus flash trim shall be no greater than 0.060 in. (1.5 mm). For laser welded pipe, the radial offset of plate edges plus weld reinforcement trim shall be no greater than 0.060 in. (1.5 mm).

I.5.4 Out-of-line Weld Bead for Pipe with Filler

Metal Welds Out-of-line weld bead (off-seam weld) shall not be cause for rejection, provided that complete penetration and complete fusion have been achieved, as indicated by nondestructive inspection.

I.5.5 Height of Outside and Inside Weld Beads Submerged-arc Welds

The weld bead shall not extend above the prolongation of the original surface of the pipe by more than the following:

Table I.4 Maximum Height of Weld Bead Based on Specified Wall Thickness

Specified Wall Thickness	Maximum Height of Weld Bead
$^1/_2$in. (12.7 mm) and under	$^1/_8\,in.$ (3.2 mm)
Over $^1/_2$ in. (12.7 mm)	$^3/_{16}\,in.$ (4.8 mm)

Weld beads higher than permitted by the requirements of this paragraph may be ground to acceptable limits at the option of the manufacturer.
The height of the weld bead shall in no case come below a prolongation of the surface of the pipe (outside or inside the weld bead) except that contouring by grinding, otherwise covered in this specification, shall be permitted.

I.5.6 Height of Flash of Electric Welded Pipe

The outside flash of electric welded pipe shall be trimmed to an essentially flush condition. The inside flash of electric welded pipe shall not extend above the prolongation of the original inside surface of the pipe more than 0.060 in. (1.5 mm).

I.5.7 Height of Weld Reinforcement of Laser Welded Pipe

The outside weld reinforcement of laser welded pipe shall be trimmed to an essentially flush condition. The inside weld reinforcement of laser welded pipe shall not extend above the prolongation of the original inside surface of the pipe more than 0.060 in. (1.5 mm). Laser welds may have underfills, which are acceptable within the limits of7.8.13.

I.5.8 Trim of Inside Flash of Electric Welded Pipe and Trim of Inside Weld Reinforcement of Laser Welded Pipe

The depth of groove resulting from removal of the intimal flash of electric welded pipe or removal of the internal weld reinforcement of laser welded pipe shall not be greater than that listed below for the various wall thicknesses. Depth of groove is defined as the difference between the wall thickness measured approximately I in. (25.4 mm) from the weld line and the remaining wall under the groove.

Table I.5 Trim of Inside Flash of Electric Welded Pipe

Specified Wall Thickness (t)	Maximum Depth of Trim
≤0.150 in.(3.8 mm)	0.10 t
>0.150 in.(3.8 mm) and <0.301 In.(7.6 mm)	0.015 in.(0.4 mm)
≥0.301 in.(7.6 mm) and greater	0.05 t

I.5.9 Hard Spots

Any hard spot having a minimum dimension greater than 2 in. (50.8 mm) in any direction and a hardness greater than or equal to 35 HRC (327 HB) shall be rejected. The section of pipe containing the hard spot shall be removed as a cylinder.

The surface of cold-formed welded pipe shall be examined visually to detect irregularities in the curvature of the pipe.

When this examination fails to disclose mechanical damage as the cause of the irregular surface but indicates that the irregular surface may be attributed to a hard spot, the hardness and dimensions of the area shall be determined. **If** hardness and dimensions exceed the aforementioned rejection criteria, the hard spot shall be removed.

I.5.10 Cracks, Sweats, and Leaks

All cracks, sweats, and leaks shall be considered as defects.

Any lamination or inclusion extending into the face or bevel of the pipe and having a visually determined transverse dimension exceeding 1/4 in. (6.4 mm) is considered a defect. Pipe containing such defects shall be cut back until no lamination or inclusion is

greater than 1/4 in. (6.4 mm). Any lamination in the body of the pipe exceeding both of the following is considered a defect:
a. Greater than or equal to 3/4 in. (19.0 mm) in the minor dimension.
b. Greater than or equal to 12 in.2 (7742 mm2) in area.
l I Disposition of such defects shall be in accordance with 9.9, Item c or d. No specific inspection by the manufacturer is required unless the purchaser specifies special nondestructive inspection on the purchase order.
Note: A lamination is an internal metal separation creating layers generally parallel to the surface.

I.5.11 Arc Burns
Arc bums are localized points of surface melting caused by arcing between electrode or ground and pipe surface and shall be considered defects (see note).
Disposition of pipe containing arc burns shall be in accordance with 9.7.6, except that removal of defects by grinding shall be subject to the following additional condition. Arc bums may be removed by grinding, chipping, or machining. The resultant cavity shall be thoroughly cleaned and checked for complete removal of damaged material by etching with a 10% solution of ammonium persulfate or a 5% solution of nital.
Note: Contact marks, defined as intermittent marks adjacent to the weld line, resulting from the electrical contact between the electrodes supplying the welding current and the pipe surface, are not defects.

I.5.12 Undercuts
Undercutting can best be located visually.
a. Minor undercutting on either the inside or the outside of the pipe is defined as follows and is acceptable without repair or grinding:
1. Maximum depth of 1/32 in. (0.8 mm) and not exceeding 12.5% of the specified wall thickness with a maximum length of one-half the specified wall thickness and not more than two such undercuts in any I ft (0.3 m) of the weld length.
2. Maximum depth of 1/64 in. (0.4 mm) any length.
b. Undercutting not classified as minor shall be considered a defect. Disposition shall be as follows:
1. Undercut defects not exceeding 1/32 in. (O.Smm) in depth and not exceeding 12.5% of the specified wall thickness shall be removed by grinding in accordance with 9.9, Item a.**I04**
2. Disposition of undercuts greater in depth than 1/32 in. (O.Smm) or 12.5% of the specified wall thickness shall be in accordance with 9.9, Item b, c, or d. **I 04**

I.5.13 Underfills
Underfill of laser welded pipe is a depression on the weld face or root surface extending below the adjacent surface of the base metal. Underfills can best be located visually.

a. Underfills on the inside of the pipe shall be considered a defect.
b. Minor underfills on the outside of the pipe are defined as follows and are acceptable without repair or grinding.
1. Maximum depth not exceeding 5% of the specified wall thickness with a maximum length of two times the specified wall thickness, with a remaining wall thickness of87.5% of

the specified wall thickness, and not more than two such underfills in any I ft (0.3 m) of weld length. Furthermore, the coincident combination of underfills, other imperfections, grinds, and weld trim on the outside and inside surfaces of laser welded pipe shall not reduce the remaining wall thickness to less than that pennitted in Table 9.
2. Maximum depth of '/64 in. (0.4 mm), any length.
c. Disposition of external underfills that are not classified as minor shall be in accordance with 9.9 except that the length of grind to remove underfills shall not exceed 6 in. (152.4 mm) in any I ft (0.30 m) of weld length or 12 in. (0.30 m) in any 5 ft (1.52 m) of weld length. Disposition of internal underfills shall be in accordance with 9.9, Items b, c, or d.

I.5.14 Other Defects

Any 00 or 10 suti'ace impeti'ection that has a depth greater than 12.5% of the specified wall thickness shall be considered A defect .

CHAPTER II

Pipeline Integrity: Corrosion & Defects

II.1 Types of Pipeline's Defects

Mechanical damage is the most common causes of pipeline accidents: the majority being external damages (49.6%). Manufacturing defects reach 16.5%, corrosion makes 15.3%, and ground displacement makes 7.3%, while other causes contribute 11.3% [12–15]. Because of the high level (49.6%) of accidents caused by mechanical damages, the companies maintaining the buried pipelines are often reluctant to apply expensive diagnostics, monitoring, and repairing techniques. As a rule, the buried pipelines are checked by using the intelligent pigging and inspection methods. The application of these technical solutions helped to detect many dangerous defects during the pipelines' operation [1–13] . Sometimes, the shape defects were so huge that the intelligent pigging robot could not move forward. The shape of defects, which are characterized by large plastic deformations with (or without) reduced wall thickness, are very dangerous because they can initiate (or can be combined with) various types of corrosion defects or cracks [20–23]. Therefore, these defects should also be examined to decide whether the pipelines of this age can be safely used further, or whether these defects must be removed.

For this reason, it is important to model the influence and evolution of local shape defects in order to assess the pipeline's reliability. The traditional analytical methods for evaluating the pipeline's failure pressure and probability of leaks are based on the determination of the defect's depth and length. Well-known mathematical methods, codes, and mathematical expressions can be used to predict the failure pressure of steel pipelines with various corrosion defects. The Finite Element Method allows for predicting failure pressure and evaluating complex defects for obtaining better results than the traditional methods can yield [23]

Oil and gas transmission pipelines basically have a good safety records. This is due to a combination of decent design, materials and operating observes; however, like any engineering structure, pipelines at times will fail. The most common causes of damage and failures in onshore and offshore transmission pipelines are mechanical damage which is cracks and corrosion. (Jiang, Y.& Chen, M. 2012) .

Figure 2.1below shows a schematic representation of the nonlinear behaviour of cracked steel structures under monotonic loading. It is noted that for similar structures the stiffness and ultimate strength of cracked structures is smaller than those of un-cracked structures.(Paik, J. K., *et al.*, 2004).

II.2 Corrosion

Accidents caused by corrosion defects have been one of the most concerned problems for security of pipeline structures. Defects in pipes are usually caused by oxidation and seawater corrosion and observed on **internal** and **external** surface (Fig II.1 A & B), which may lead to stiffness reduction of pipes. Hence, it is of great significance to take into consideration the corrosion defects on the dynamic behaviors of marine pipeline. To accurately simulate the influence of corrosion defects, here a new kind of finite element is developed

Corrosion defects and FE model. (a):different types of corrosion on the pipe (Kishawy H.A., 2010), (b):3-D figure of pipe with corrosion defects and (c):cross section of pipe with corrosion defects.

II.2.1 Types of Pipeline Corrosion

Pipelines suffer from a number of corrosion forms, some more common than others. They

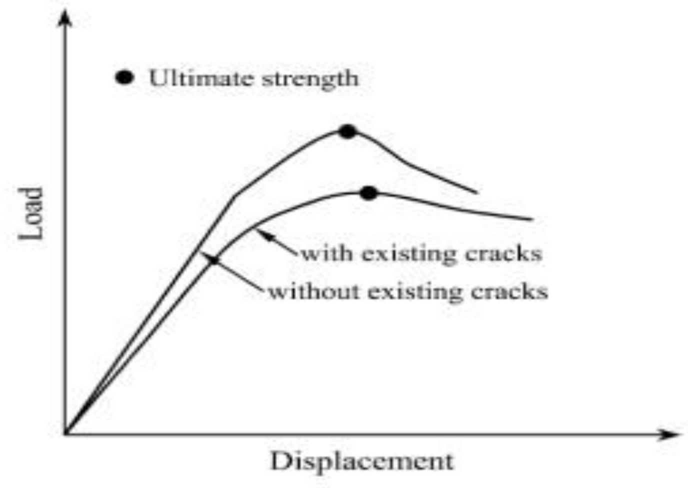


Fig II.1 A schematic representation of the cracking damage effect on the ultimate strength behaviour of steel structures

range from **pitting corrosion**, **uniform corrosion, galvanic corrosion**, **crevice corrosion** and **microbiologically influenced corrosion** to name a few. Corrosion can also develop in non-metallic pipes such as plastic or even carbon fibre.

- **External corrosion**: typically arising from external conditions of heat, water or pressure combined with contact with corrosive materials such as acidic soil.
- **Internal corrosion**: resulting from the transportation of a corrosive or pressurized product
- **Corrosion defects**: due to physical characteristics such as shape or form, or from issues resulting from handling or installation.

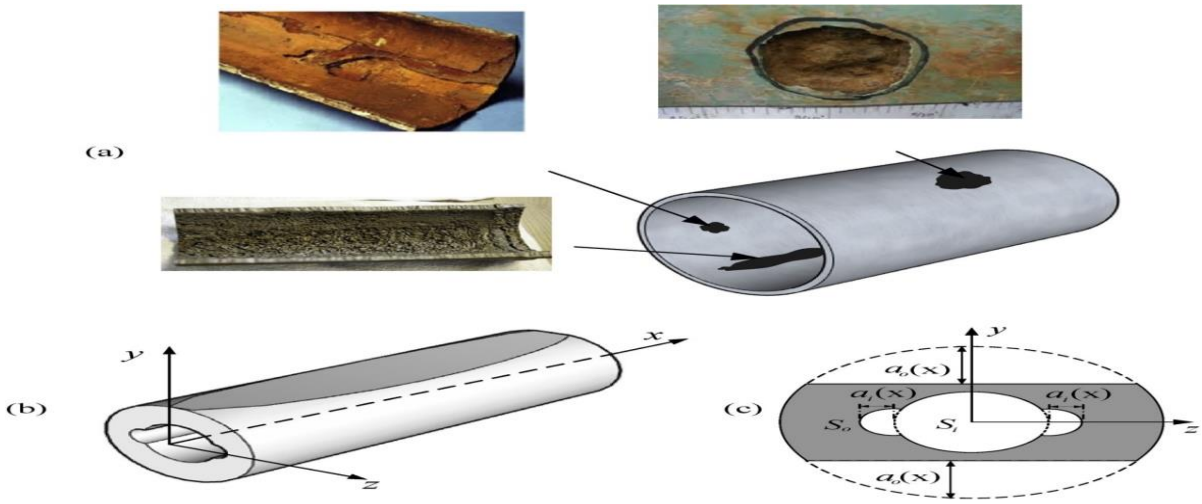


Fig II.1.B **Pipeline Corrosion**

II.2.2 Pipeline Corrosion Treatment

Chemical treatment is the main solution for many internal pipeline corrosion problems. Washing the pipe by chemical solutions pumping clears away any corrosion product. Coating and protection of the lining of the pipe by pumping chemicals is next in the process. For external treatment re-coating is the most common, tried and tested treatment. The same treatment applied to any corroded metal. The rust and corrosion is cleaned from the metal. The pipe is then coated with a specially designed coating to protect it.

Fig II.3 : internal corrosion defect

II.2.3 Metal loss

The parameters of anomalies are length "I", width "w" and depth "d". The starting point, S, and the dimension of an anomaly are defined as illustrated in Figure 2.1 looking in the ILI run direction. Start and end points are diagonally in a rectangle enclosing the anomaly. The depth represents the deepest point reported within the rectangle

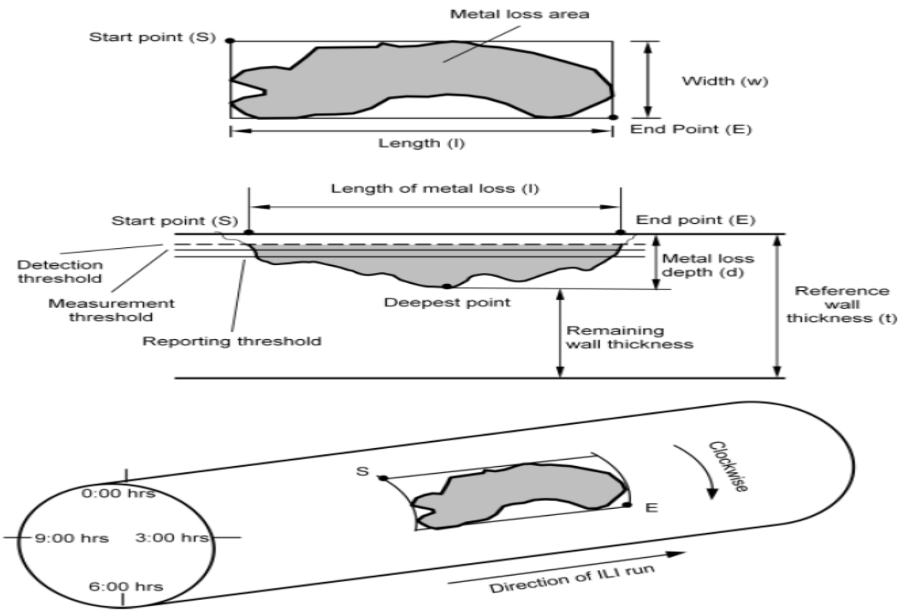


Fig.II.4: Illustration of parameters describing location and dimension of metal loss feature.

The start position of the anomaly has a lower clock position than the end position. Anomalies crossing the 0:00 o'clock position have a higher clock position at the start. Full circumferential anomalies are reported with S at 0:00 o'clock. Note: highest clock position shall be 11:59.

Metal loss anomaly classification

The measurement capabilities of non-destructive examination techniques, in particular the MFL technique, depend on the geometry of the metal loss anomalies. Metal loss anomaly classes have been defined as shown in Figure 2.2 for anomaly reporting purposes. In addition it allows for a proper specification of the measurement capabilities of MFL ILI tools.

Each anomaly class permits a large range of shapes. Within that shape a reference point/size is defined at which the POD for MFL tools is specified, see Table 2.1. An even distribution of length, width and depth shall be assumed for each anomaly dimension class to derive a statistical measurement performance on sizing accuracy.

Table II.1: Definition of anomaly dimension class and MFL POD reference point/size

Anomaly dimension class	Definition	Reference point/size for the POD in terms of l x w
General:	{[w ≥ 3A] and [l ≥ 3A]}	4A x 4A
Pitting:	{([1A ≤ w < 6A] and [1A ≤ l < 6A] and [0.5 < l/w < 2]) and not ([w ≥ 3A] and [l ≥ 3A])}	2A x 2A
Axial grooving:	{[1A ≤ w < 3A] and [l/w ≥ 2]}	4A x 2A
Circumferential grooving:	{[l/w ≤ 0.5] and [1A ≤ l < 3A]}	2A x 4A
Pinhole:	{[0 mm < w < 1A] and [0 mm < l < 1A}	Minimum dimensions to be further defined by Contractor, see table A3-2
Axial slotting*:	{[0 mm < w < 1A] and [l ≥ 1A]}	2A x ½A
Circumferential slotting*:	{[w ≥ 1A] and [0 mm < l < 1A]}	½A x 2A

* Anomalies with a width < 1mm are defined as crack of crack-like which might or might not be metal loss

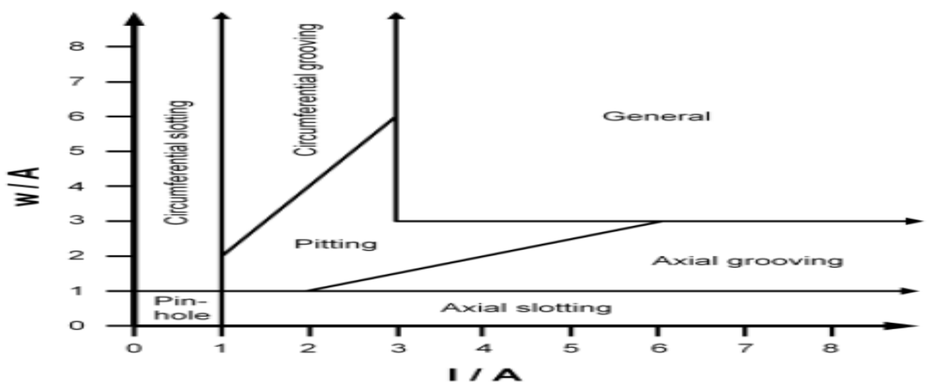


Figure II.5: Graphical presentation of surface dimensions

of metal loss anomalies per dimension class

The geometrical parameter A is linked to the NDE methods in the following manner:

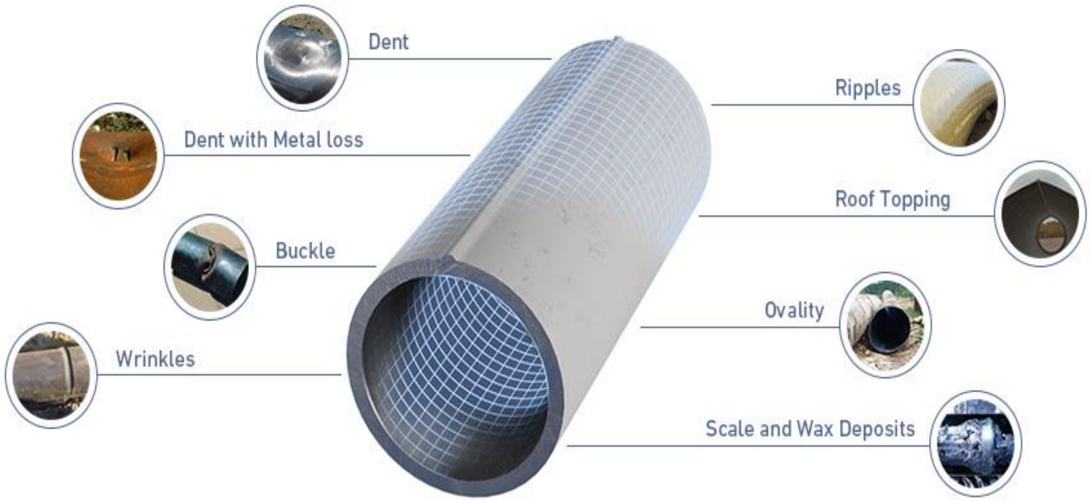
- **If t< 10 mm then A = 10 mm**
- **If t≥ 10 mm then A = t**

II.3 Dents

Among the different types of pipeline damage, **dents** are dangerous yet frequent forms of mechanical damage that are commonly associated with a loss of integrity. A dent is defined as a gross distortion of the pipe cross-section and may be caused by the impact of external elements such as construction equipment during the pipeline construction and operation, resulting in severe plastic deformation of the pipe wall. (ROSEN, 2022)

According to statistical results the Office of Pipeline Safety of the U.S. Department of Transportation (DOT), from 1985 until 2003, there are about 28% incidents had been reported most of the cases related to the failures of pipeline caused by dents

(Jacob et.al., 2010).There are several types of dents such as smooth dent, kinked dent, plain dent, unconstrained dent, and constrained dent. Smooth dent is caused by a smooth change in curvature of pipe wall. It contains a gouge is a very severe form



of mechanical damage.

Fig II.6 :Pipeline Dent defects

II.3.1 Types of Pipeline's Dents

II.3.1.1 Smooth dent:

A smooth dent which containing gouge is lower than a burst strength of equivalent plain dent and lower than equivalent gouge in un-dented pipe (Cosham and Hopkins, 2004). The dent depths include both the local indentation and any divergence from the nominal circular cross section.

II.3.1.2 Kinked dent :

Kinked dent is a dent cause by abrupt change in curvature of pipe wall of the sharpest part of dents is less than five times the wall thickness (Cosham and Hopkins, 2004).

II.3.1.3 Plain dent :

Plain dent is a smooth containing no wall thickness reductions suchas gouge or crack or some other imperfections such as girth or seam weld (Cosham and Hopkins, 2004). It is not significantly reducing the burst strength of the pipe (Macdonald et.al., 2007)

II.3.1.4 Unconstrained dent :

Unconstrained dent is a dent which elastically free rebound (spring back) when the indenter removed, and freely rebound as internal pressure changes (Cosham and Hopkins, 2004).

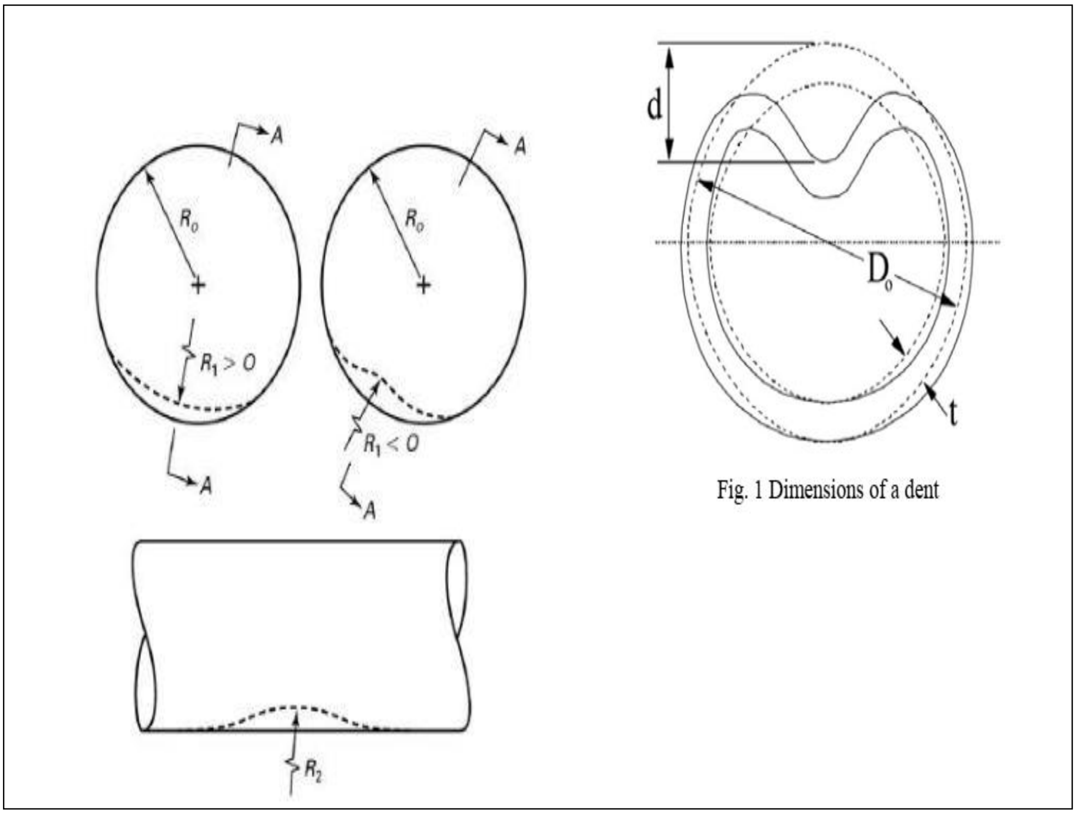


Fig.II.7 : Dimensions of dent

II.3.1.5 Constrained dent :

Constrained dent is a dent that not free to rebound or reround due to indenter is not removed. For example rock dent (Cosham and Hopkins, 2004).Constrained plain dents do not significantly reduce the burst strength of the pipe (Macdonald et.al., 2007).

II.3.2 Weld Cracking:

Welding defects occur in the welding process caused by defective welding techniques or welding patterns. The defect could be different from the weld bead’s appropriate shape, size, and quality.

Welding defects can appear on the surface as well as the inside of the weld metal. Some defects may be acceptable if they are within safety parameters, but some cracks are never fine.

II.3.3 Types of Welding Defects

Welding defects are divided into two categories : exterior and interior defects.

II.3.3.1 Exterior Welding Defects:

A- Porosity: Porosity is a cluster of little bubbles, whereas blowholes are comparatively large concealed holes or pores. They are caused mainly by trapped gases. Porosity is caused by weld metal deposition.

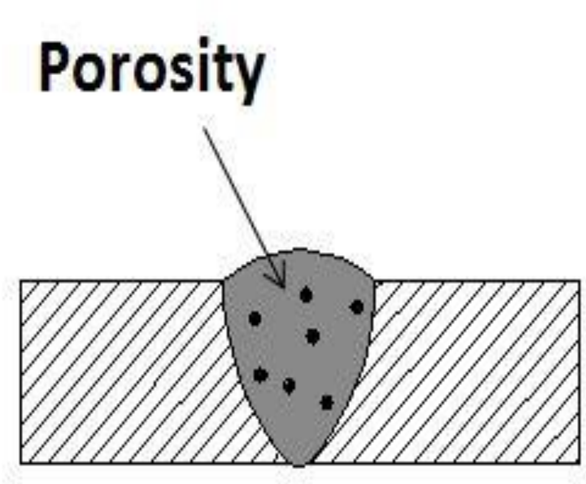


Fig.II.8 : porosity

B- Causes of Porosity:

- When the electrode isn't genuinely effective, this occurs.
- Using a longer arc may help you to improve.
- The amount of current used in welding has grown.
- The rusty or oily welding surface.

- **(I.2) Weld Crack :** These are the most hazardous types of welding defects. It is prohibited in operation by mostly all standards. It can appear on the surface, in the weld metal, or a place with a lot of heat.

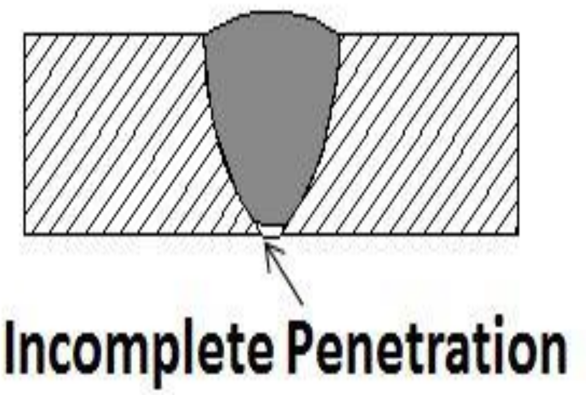
II.3.3.2 Cracks:

Depending on the temperature, different typzes of cracks may form during welding.

1. **Hot Cracks:**
   Hot cracks can arise during the welding process or the crystallization phase of the weld zone. At this time, temperatures can approach 10,000 degrees Celsius.
2. **Cold Cracks:**
   These cracks form after the weld is completed and the metal temperature has cooled. They can even be made after the steel has been welded, hours or days later. This is most typical when a steel frame develops cracks.
3. **Crater Cracks:**
   Such cracks emerge toward the end of the welding operation even before operators accomplish the weld joint. They're constantly made near the final step.

The weld volume must be large enough to compensate for metal shrinkage when the weld pool cooled down and froze. A crater crack will form eventually.

- **Causes of Weld Crack**
  - The flexibility of the supplied base metal is low.



  - A crack might form if there is residual stress on the weld metal.
  - The stiffness of the joint, which prevents the metals from expanding or contracting.
  - Cracks may emerge if there is a lot of sulfur and carbon in the mixing.

Fig.II.9: Incomplete Penetration

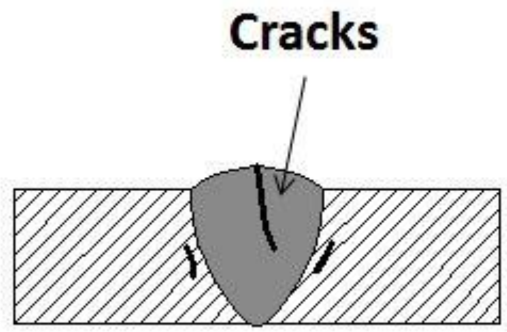


Fig.II.10: Cracks

  - Using hydrogen as a shielding gas while welding stainless steels

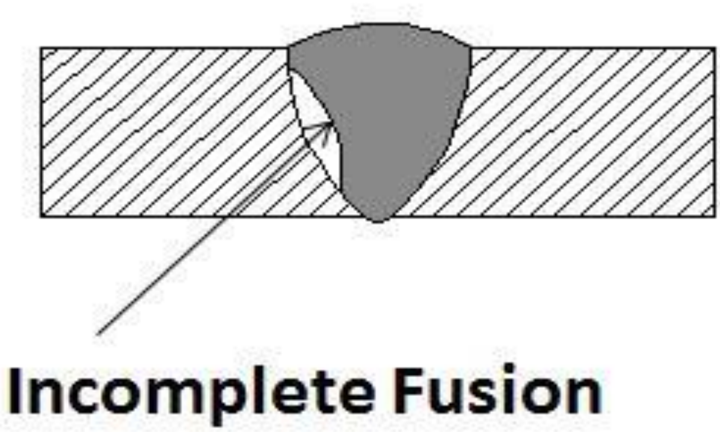
II 3.4 Interior Welding Defects

- **(II.1)Incomplete Penetration:** In these types of welding defects, the distance
- between the highest surface of the base plate and the maximum extent of the weld nugget is referred to as penetration.

The weld metal does not entirely extend over the joint thickness when the metal gap is not filled, resulting in incomplete penetration.

- **Causes of Incomplete Penetration:**
    - Metal deposition in the weld is decreased.
    - Using an incorrectly sized electrode.
    - Welding technique that is not really up to standard.
    - The electrode is placed incorrectly.

(II.9) Incomplete Fusion: Many types of welding defects arise when there is an insufficient fusion between the metal and the weld. As a result, there is a gap inside the joint that is not filled with molten material. It's also possible that it will appear between



adjacent weld beads.

Fig.II.11 Incomplete fusion

- **Causes of Incomplete Fusion:**
    - It occurs due to a lack of heat input.
    - When there is a big weld pool that goes beyond the arc.
    - When the angle of a joint is too small.
    - Incorrect electrode and torch angles might potentially result in incomplete fusion.
    - Incorrect bead placement.

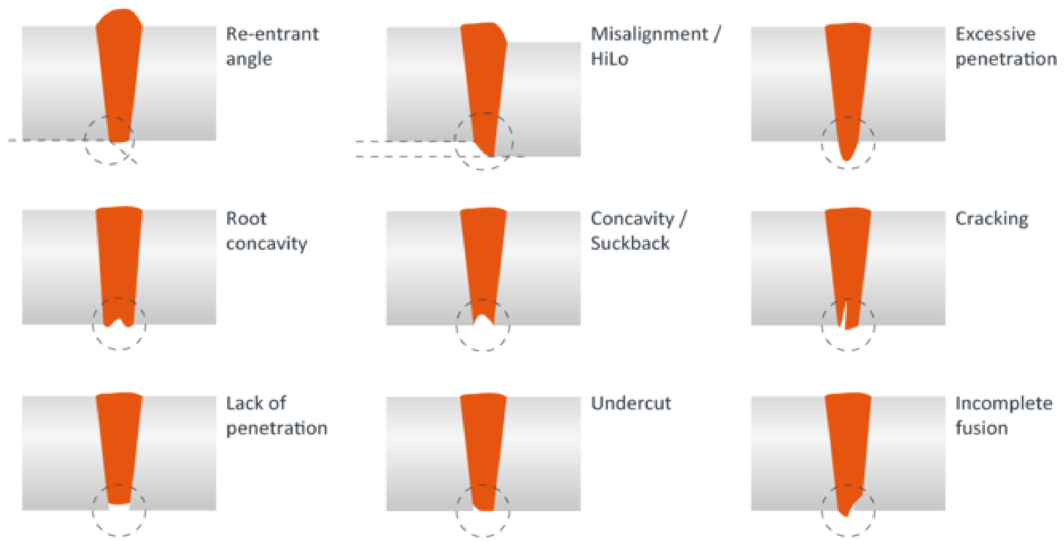
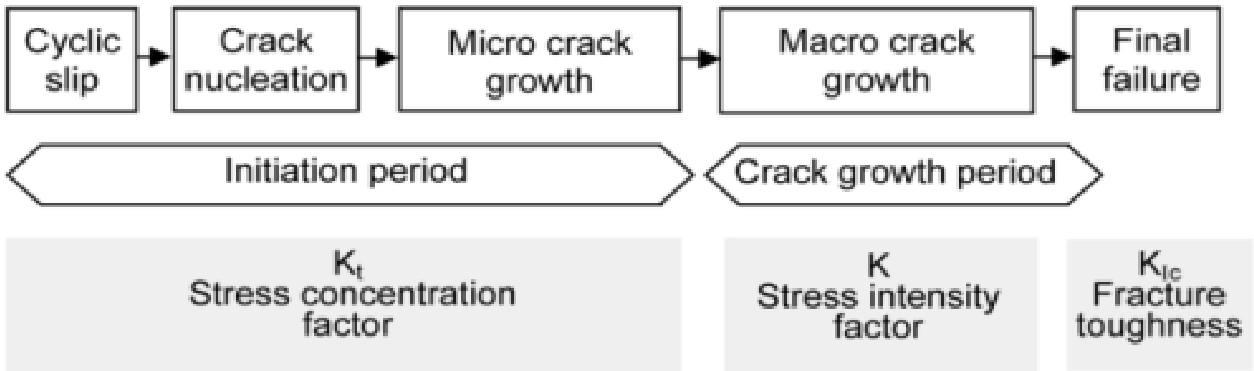


Fig.II.12 : Weld fails

II.4 Fatigue Cracks :

Fatigue cracking is a phenomenon that occurs in metals due to repeated load, which can lead to failure at loads considerably below the material's static strength [1, 48]. Welded structures such as offshore structures, pressure vessels and pipelines, are affected by fatigue



crack nuclei start as invisible micro cracks in slip bands. After more microscopic information on the growth of small cracks became available, it turned out that nucleation of micro cracks generally occurs very early in the fatigue life. Indications were obtained that it may take place almost immediately if a cyclic stress above the fatigue limit is applied. After a micro crack has been nucleated, crack growth can till be a slow and erratic process, due to effects of the microstructures, e.g. grain boundaries. However, after some micro crack growth has occurred away from the nucleation site, a more regular growth is observed. This is the beginning of the real crack growth period. Various steps in the fatigue life are indicated in Fig 4. The important point is that the fatigue life until failure consists of two periods: the crack initiation period and the crack growth period. Differentiating between the two periods is of great importance because several surface conditions do affect the initiation period, but have a negligible influence on the crack growth period [50].

II.4.1 Ovality:

Ovality is specified by IDmax and IDmin as shown in Figure 2.4

$$\frac{ID_{max} - ID_{min}}{\left[\frac{ID_{max}+ID_{min}}{2}\right]}$$

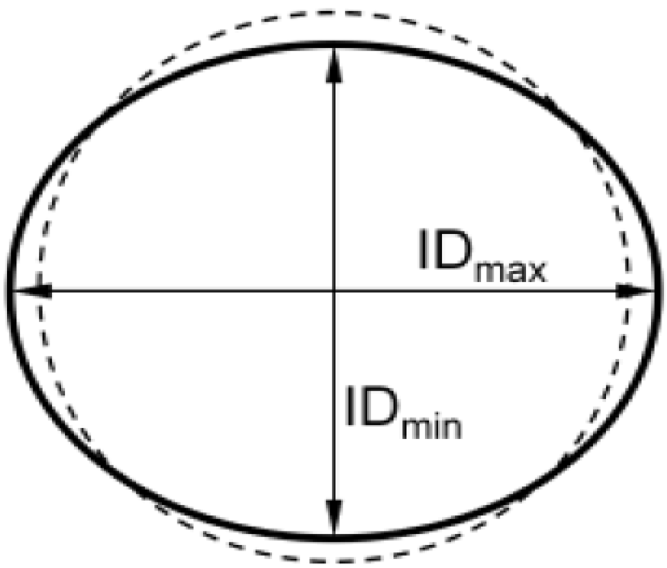


Figure II.14: Measurement of ovality at one point over distance.

The ovality is defined as the ratio given in the equation below:

The ovality reported at the joint is based on a statistical approach of the measurements along the joint. It can be the mean ovality or any percentile (90th is common) or the maximum measured, which is to be detailed by the Client in the contract. If not specified otherwise, the maximum shall be reported. *Note: Reporting of ovality dimensions depends on the used formula (code) and it is therefore required that the formula applied is stated in the report.*

II.4.2 Ripple/Wrinkle:

A ripple/wrinkle is specified by its height and length as shown in Figure 2.5Figure 2.5, Figure 2.6 and Figure 2.7. The maximum values shall be reported and, if requested, also the maximum strain based on a methodology agreed between Client and Contractor.

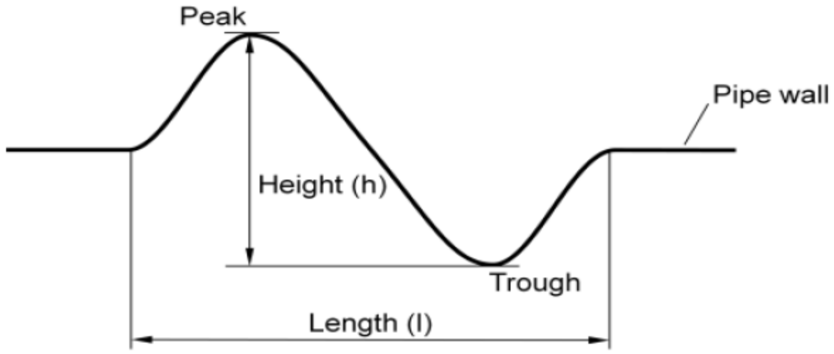


Figure 2.5: Measurement of ripple / wrinkle.

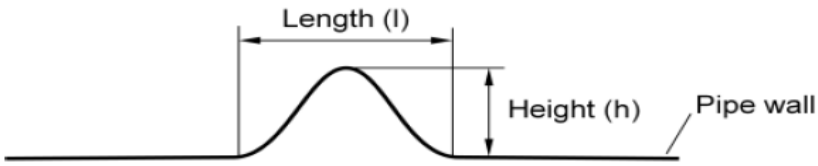


Figure 2.6: Measurement of single ripple/wrinkle.

A ripple/wrinkle is defined by its length (l) and maximum height (h).

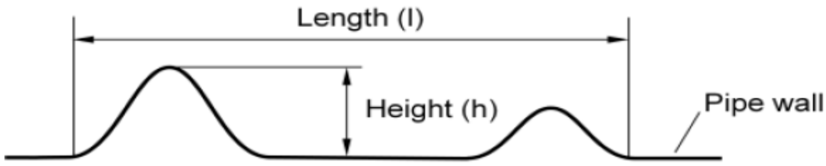


Fig II.15: Measurement of multiple ripple/wrinkles

Multiple ripples/wrinkles are defined by the total length (1) and maximum height (h).

II.4.3 Roof topping/peaking

Roof Topping/Peaking Is Specified By The Angle 2ɵ And Height (H), See Figure

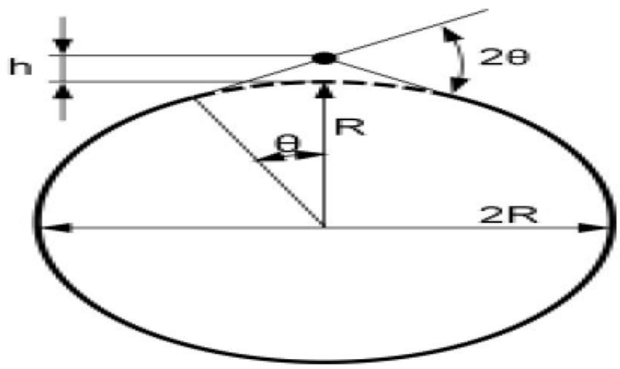


Fig II.16 : Measurement of Peaking /roof topping

Roof topping/peaking is defined by its height h in mm and angle 2Ɵ in degrees (°).

CHAPTER III

Inspection and repair

III.1 Pipeline Inspection:

III.1.1 Visual Inspection

Visual inspection shall be conducted by personnel who are trained to detect and evaluate surface imperfections, and have visual acuity that meets the applicable requirements of ASNT SNT-TC-l A, or equivalent.

a. Qualification of Personnel

As a minimum, ASNT SNT-TC-lA, or equivalent, shall be the basis of qualification for NDT personnel (excluding the SPECIFICATION FOR LINE PIPE 19 visual method). Personnel shall be requalified for any method previously qualified, if they have not performed NDT in that method for a period exceeding 12 months. NDT shall be conducted by Level T, II, or III personnel. Evaluation of indications shall be performed by Level I

personnel under the supervision of Level II or 1Il personnel, or by Level II or III personnel.

b. Standard Practices for Inspection

Except as allowed in Table 26, for other than surface inspection (see 9.6) and wall thickness verification, the required inspections shall be performed in accordance with the applicable ASTM standards, or equivalent, as follows:

- Electromagnetic (fl ux leakage) E570
- Electromagnetic (eddy-current) E309
- Ultrasonic E213
- Ultrasonic (weld seam) E273
- Magnetic Particle E 709
- Radiographic E 94
- Liquid Penetrant E 165

III.1.2 Inspection Methods in Pipelines:

Pipelines play an important role in the national/international transportation of natural gas, petroleum products, and other energy resources. Pipelines are set up in different environments and consequently suffer various damage challenges, such as environmental electrochemical reaction, welding defects, and external force damage, etc. Defects like metal loss, pitting, and cracks destroy the pipeline's integrity and cause serious safety issues. This should be prevented before it occurs to ensure the safe operation of the pipeline. In recent years, different non-destructive testing (**NDT**) methods have been developed for in-line pipeline inspection. These are magnetic flux leakage (**MFL**) testing, ultrasonic testing (**UT**), electromagnetic acoustic technology (**EMAT**), eddy current testing (**EC**). Single modality or different kinds of integrated **NDT** system named Pipeline Inspection Gauge (**PIG**) or un-piggable robotic inspection systems have been developed. Moreover, data management in conjunction with historic data for condition-based pipeline maintenance becomes important as well. In this study, various inspection methods in association with non-destructive testing are investigated. The state of the art of **PIG**s, un-piggable robots, as well as instrumental applications, are systematically compared. Furthermore, data models and management are utilized for defect quantification, classification, failure prediction and maintenance. Finally, the challenges, problems, and development trends of pipeline inspection as well as data management are derived and discussed.

Table III.1. Defects of steel pipelines produced during prefabrication and their Causes

Defects	Location	The Reason for the Formation
shrinkage cavity	near-surface	the last solidified of molten metal shrinks
casting hot crack	internal and external surfaces	stress due to different solidification rate
stoma	surface or near-surface	the gas is retained when the metal solidifies
inclusion	surface or near-surface	impurities were added into the casting process
cracks	surface	the surface depression is discontinuous and elongated during rolling
layered	surface or near-surface	inherent defects are elongated and flattened during the rolling
fold	surface	excess material covering and pressing into surfaces
heat treatment crack	surface	uneven heating or cooling
coating crack	surface	residual stress release

Table III.2. Defects of pipelines produced during operation and their causes

Defects	Location	The Reason for the Formation
fatigue crack	surface	periodic stress application below the ultimate tensile strength of the material
stress corrosion cracking	surface or near-surface	the combined action of tensile static load and corrosive medium
hydrogen-induced cracking	surface	tensile or residual stress interacts with the hydrogen-rich medium
corrosion	surface	interaction of corrosive medium and alternating stress

III.1.3 Non-Destructive Testing (NDT)

The scientific and engineering communities have presented various techniques to detect defects in an operational pipeline. These techniques can be grouped into three main categories for the maintenance of pipeline systems as shown in Figure 1 [29]. Technologies and defect detection and prevention include locating pipelines and underground facilities, determining excavation damage and encroachments to the right-of-way, leak detection, and damage mitigation. The pipeline and hazardous materials safety administration (**PHMSA**) of the U.S. Department of Transportation has recorded, excavation damage poses a leading threat to failure incidents of gas pipelines. However, leakage detection is usually an indicator of excavation damage and other threats. Thus, in order to reduce this damage and protect pipeline Right-of-Way (**ROW**), it is necessary to develop a locating equipment especially electromagnetic locators to identify the position of metallic pipelines. For instance, acoustic or ground-penetrating radar technologies are recent advancements. Among them, the damage mitigation and prevention technologies focus on minimizing the time and workload of taking measures to avoid the expansion of accidents. However, these technologies are hard to locate and protect inside the pipeline. Technologies for threats and integrity management contains inspecting existing defects (such as cracks, metal loss, rust and dents), making use of several devices in external corrosion direct assessment, internal inspection, pipeline detecting and monitoring, as well as stress analysis [30]. These technologies are the key points of threat identification and integrity management. Accordingly, plenty of in-line inspection (**ILI**) methods based on **NDT** have been developed to detect and quantify these defects or stress, and ILI is internationally considered as the most effective approach to detect and locate pipeline defects. As for risk assessment and information management, it covers various technologies for data visualization, asset tracking and traceability, geographical information system, risk assessment, awareness of response, as well as network and physical security. These technologies contain wide aspects of identifying high-risk pipelines for repair or replacement. Moreover, risk analysis using historical data depends heavily on the quantity and quality of the available data. Therefore, different NDT methods for ILI tools and data management-related defects quantification and health management are systematically reviewed and discussed in the paper.

III.1.4 NDT Methods for Testing Of Pipelines:

Radiography testing (RT) :

Radiography is the most commonly used non-destructive testing method for pipeline inspection. The principle is that a source of radiation is directed toward the inspected object. A sheet of radiographic film is placed behind the object. The setup usually takes a few minutes, the exposure 1-10 minutes and film processing about 10 minutes.
Advantage of this method is its reliability. Nowadays digital images can also be used and information saved and transported by computers. Disadvantage is the radiation danger.

Fig.III.1 Technologies categories and research areas.

Ultrasonic testing (UT):

Ultrasonic is used as an NDT-method to evaluate the integrity of automatic welded pipeline girth welds. The principle is to employ high frequency acoustic waves to probe the inspected sample. As the acoustic wave penetrates the sample, the wave is attenuated and/or reflected by any change in the density in the material. By observing the returned signal many of the characteristics of the material can be determined.
Setup takes less than an hour and scanning time varies from a few minutes to hours depending on the size of the sample and the desired resolution. Advantages are that there are no health risks for the environment, and it is possible to define very accurately where the defect is located and how big it is.

On the other hand the suitability for thin objects, like pipes, is restricted. Ultrasonic inspection also requires that the inspecting technicians must be very experienced in order to get reliable results.

Eddy Current (EC):

In eddy current testing, a time varying magnetic field in induced in the sample material by using a magnetic coil with alternating current. This magnetic field causes an electric current to be generated in conducting materials. These currents, in turn, produce small magnetic fields around the conducting materials. The smaller magnetic fields generally oppose the original field, which changes the impedance of the magnetic coil. Thus, by measuring the changes in impedance of the magnetic coil as it traverses the sample, different characteristics of the sample can be identified. The testing time is usually a few hours. Eddy current method has a limited depth of penetration, 4…8 mm only. In pipe industry it is however a widely applied inspection method. It is suitable for detecting for example porosity, cross and seam cracks and checking seams and butt welds. The testing method is relatively simple and costs moderate.

Fluorescent or Dye Penetrant (VT), (PT) :

This method is suitable for detection of cracking and porosity in welded joints. The principle is that the surface of the sample is coated with a penetrant in which a colorful or fluorescent dye is dissolved or suspended. The penetrant is pulled into surface defects by capillary action. After a waiting period to insure that the dye has penetrated into the cracks, the excess penetrant is cleaned from the surface of the inspected part. A developed, a white powder, is sprayed over the part. This lifts the penetrant out of the defect and the dye stains the developer. By visual inspection **(VT)** under white or ultraviolet light, the visible or fluorescent dye indications can be identified defining the defect. Less than one hour is usually required as an inspection time. The method is a lot cheaper compared to radiography or ultrasonics, but can only detect external defects.

Magnetic Particle testing (MT):

Magnetic particle method can be used for identification of surface or near-surface defects. The principle is that the sample is magnetized by dusting magnetic particles over it. A

surface defect will form a magnetic anomaly, attracting and holding magnetic particles and thus giving a visual indication of the defect. The evaluation time is typically few minutes. The sample must be ferromagnetic and therefore this technique can not be used on most stainless steels. This method also
is a lot cheaper compared to radiography or ultrasonics, but like the dye penetrant, it only can detect **external defects**.

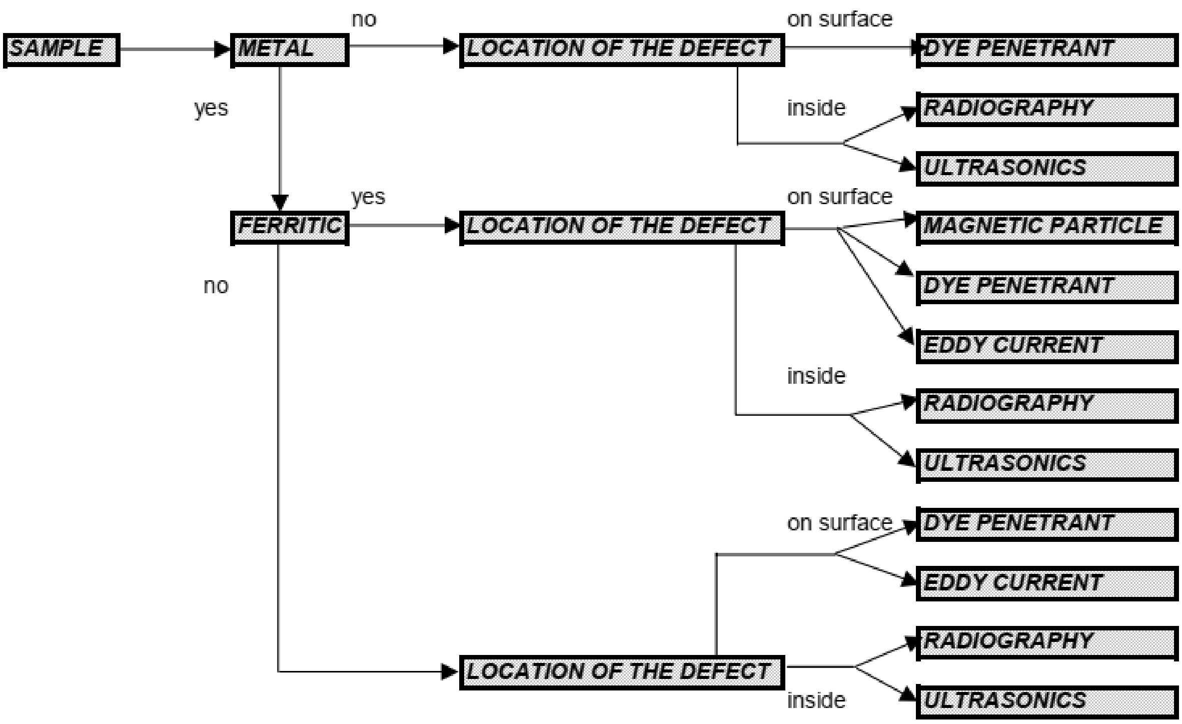


Fig.III.2. presents for what kind of testing the different NDT-methods are suitable.

Fig. 1: Suitability of different NDT-methods

III.1.5 Pipeline Inspection Gauge (PIG) : In this section, we provide a detail review of the application on state-of-the-art ILI techniques and instrumental systems for pipeline inspection. According to the type of pipeline, these can be divided into piggable pipelines and un-piggable pipelines. Therefore, the detection tools involved are inevitably different. For example, various widely used Geometry Pig (**GP**), **MFL** Pig, **UT** Pig, **EMAT** PIG, **EC** Pig, Integrated Function Pig and Specific Function Pig are contained for piggable pipelines.

The general ILI system fundamental structure and intelligent PIG ,The other one is represented by a closed-circuit television camera (CCTV) and smart ball for un-piggable pipelines. Thus, these two kinds of detection technologies will describe with two subsections, respectively.

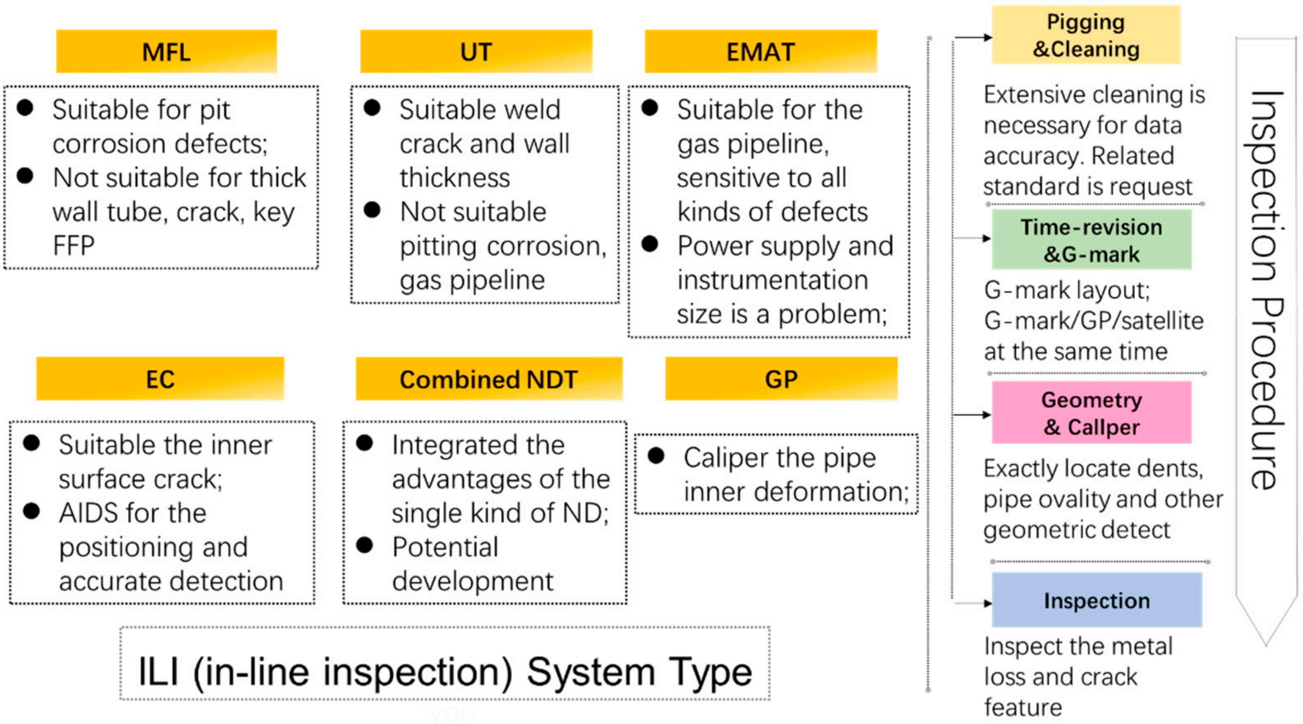


Fig.III.3 Structure schematic of internal inspection (ILI) system.

Table III.3. concludes some of the opinions and experiences of CERN piping specialists regarding the NDT methods presented in this paper.

	LHC	ST	TIS
RADIOGRAPHY	The most reliable	The most reliable	The most reliable
SAFERAD	Never used, no opinion	Never used, interesting	Never used, interesting
ULTRASONICS	Not used, may not detect all the possible defects	Used sometimes for measuring thickness	Complementary to radiography, for aluminium and carbon steel a very good method, particularly for detecting corrosion inside pipelines and vessels
EDDY CURRENT	Allowed for the required 10% testing of longitudinal welds in pipes	Used in testing heat exchangers	Not used
DYE PENETRANT	Not good enough for CERN pipes since only detects external cracks	Used in testing heat exchangers and if radiography is not possible	Used when any other technique is not suitable, f.ex. angle weld, fast and cheap
MAGNETIC PARTICLE	Not good enough for CERN pipes since only detects external cracks	Not used	Not used

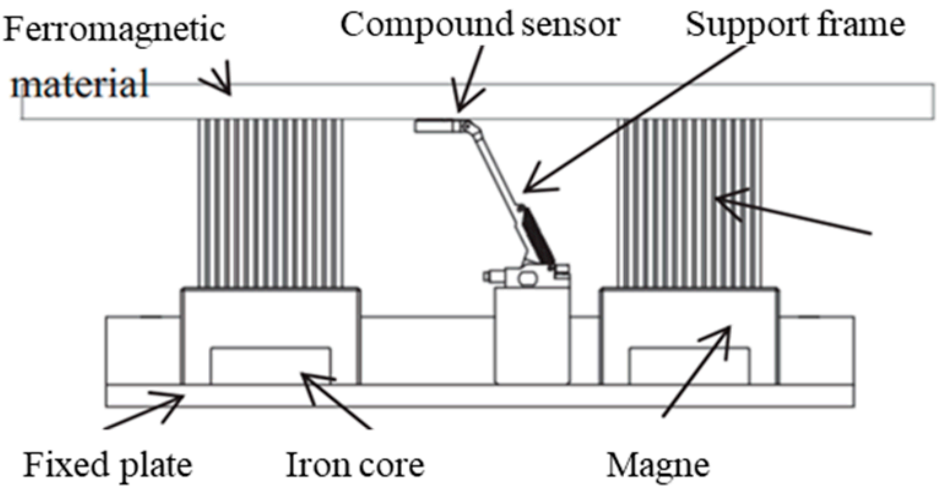
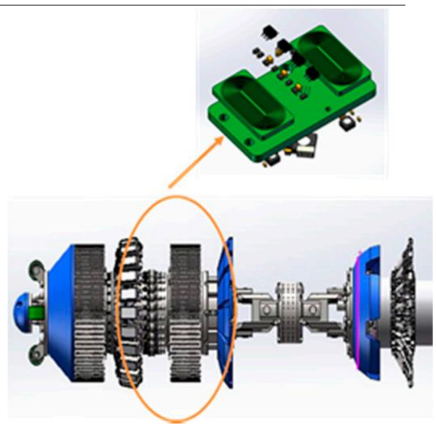


Fig.III.4 Magneto electric compound sensor detection device.

Table.III.4 : Advice for the choice of commercial Pipeline Inspection Gauge (PIG) technologies.

PIG	Type	Technical Function	Image
GP		To collect information relating to the physical shape or geometry of pipelines	 **ROGEO Untouched GP. Reprinted from ref. [110].**
MFL		Suitable for the pipe diameter range of 76–1422 mm and integrated for super high resolution to identify and size significant corrosion	 **GE PII MagneScan SHR MFL [4] (Reproduced with permission Elsevier**

UT	Special configuration unites metal loss and cracks detection, available for pipeline size 20” and above	 **NDT-GLOBAL LineExplorer UCM. Reprinted from ref. [110]**
EMAT	High reliability inspection and accurate continuous measurement of critical crack anomalies, coating disbandment	 **ROSEN RoDD EMAT [119,126]. Reprinted from ref.[119]**
EC	Integrated with deflection sensors that enable for simultaneous measurement of internal pipe profile and metal loss	 **ROSEN EC [110,127]. Reprinted from ref. [110]**
MEC	Inspection of compound pipelines with stainless steel and carbon steel in two layers	 **Shenyang Academy of Instrumentation Science MEC Tool**

III.2 Pipeline Repair Methods:

III.2.1 Pipe Grinding and Recoating:

Pipe grinding is used to produce smooth surface and remove the harmful stress concentration of defects and micro cracks. Repair of mechanical damage by grinding has historically been allowed by several standards [3].

The ASME B31.8 [4] permits repair by grinding to a depth of 10 percent of the pipe wall thickness during the installation of new pipes and provides certain criteria for grinding of dents with gouges for in-service pipelines. The ASME B31G [8] provides limits on the allowable extent of damage and the remaining strength of corroded pipelines. Certain restrictive conditions are.

also commonly applied for grinding, including [3]:

- The operating pressure should be reduced to 80 percent during the repair process.
- If the crack or the affected material near the defect is not entirely removed by grinding, an alternative repair technique must be applied.
- The removal of all cracks must be verified by non-destructive NDT testing after grinding.
- Removal by grinding of more than 40 percent of the wall thickness is not accepted

III.2.2 Metallic Sleeve Repair:

Mechanical sleeves mainly consist of the following two types:

- Steel Reinforcing Sleeves (Type **A**): This type consists of two halves of a steel cylinder which are placed around the pipe and welded to fully encircle the damaged section and restores the strength of the pipe. Type **A** sleeve is not welded directly onto the pipe and is not intended to contain pressure or a leak.
- The main advantage of type A is that it can be made of pre-fabricated units and do not require rigorous nondestructive inspection. It can be used for temporary and permanent repairs but it is not used to repair circumferentially oriented defects and leaking defects.
- Pressure Containing Sleeves (Type **B**): Type B sleeve is similar to type **A** sleeves, except that the ends of the sleeve are welded onto the pipe with full encirclement fillet welds as shown in Figure 1. Appropriate procedures for welding and inspection of the sleeve are required when the sleeve is installed while the pipe is in-service.

The thickness of the sleeve is designed to contain the Maximum Allowable Operating Pressure (**MAOP**) and the axial stresses imposed by secondary loads. Thus, type **B** sleeve can be used to repair leaks and to reinforce the circumferentially oriented defects.

Several research studies evaluated the characteristics of types **A** and **B** welded repairs [1-13] in addition to the deposition of weld metal directly into a defect [1-5]. In these projects, pipe samples were prepared with varying dents and gouges, and were pressurized to simulate conditions which a defect would develop in the field.

Fig.III.5- Steel Repair Sleeve (T.D. Williamson)

Several reports and publications on the evaluation of metallic sleeve repairs [1-13] further evaluated the repairs through weld analysis and field trials. The results of these studies enhanced understanding the characteristics of the steel repairs, as well as the defects and their corresponding effect on the repair.

Following the widespread testing and implementation of welded steel sleeves, a system was introduced in the late 1990s which incorporated the use of an epoxy underneath the traditional steel sleeve repair. The epoxy acts as a lubricant when first applied, allowing the sleeve to slide over the pipe when installed, and tightened around the pipe. Following the application, the epoxy then hardens, creating a solid material which can better distribute the load from the inner pipe to the repair when pressurized. Throughout the late 1990s, several experiments [1,13] investigated epoxy-filled steel reinforcements through burst and cyclical loading tests and field trials.

In addition to metal sleeves, several types of mechanical clamps are available in the market. Figure 2 shows a typical bolt-on clamp. These clamps are designed to contain full pipeline pressure, so they are generally thick-walled and heavy because of the large bolts used to provide the required clamping force [7]. The clamps normally have elastomeric seals to contain the pressure if the pipeline is leaking at the defect. They can be either installed like a Type A sleeve or can be fillet welded to the pipe like a Type B sleeve to contain a leak in case the seals fail [3].

Similar to other repair methods that involve welding on a live pipeline, appropriate procedures for welding and inspection of the sleeve are required.

Mechanical clamps were often favored over many methods due mainly to the availability of seemingly dependable leak clamps. Although the clamps were simple to install and sealed leaks initially, problems arose through time with corrosion of bolts, improper application methods, and poor seal retention

Fig.III.6 - Repair Clamp (T.D. Williamson)

In an effort to understand and improve the classical leak clamp design, the clamps underwent a series of evaluations and modifications to ensure that their use is accompanied by safe and proper working conditions. Several reports have provided technical insight into the use of leak clamps. One report [3] simulated various dents and leaks in non-linear finite element analysis to identify the limits of pipe damage to which leak repair clamps may be used.

In addition, another report [2] focused on safety while installing a leak clamp. The report outlined a procedure that includes: notification and confirmation of the leak, job site analysis and preparation for repairs, excavation, pipe and clamp preparation, clamp installation, line restoration to normal operation, and welding of the repair.

III.2.3 Composite Material Sleeve Repair (PATCH) :

Although steel sleeve repairs were widely used during the 1980s, research continued to advance with interest in new materials to aid in the repair. From the mid 1980s into the late 1990s, the Gas Research Institute (GRI) participated in a development program of a composite repair system: Clock Spring. Throughout a series of reports GRI conducted several testing programs for establishing the composite physical properties, long-term creep of the adhesives, and field performance in multiple-year monitoring program.

In addition to the work performed by GRI, development and testing of new composite repair materials have been conducted by composite manufacturers and other research agencies ,These reports addressed several performance tasks, including cyclical fatigue tests, lap shear testing, and long-term performance. A PHMSA report proposed recommended procedures for the certification of the composite repair materials. This work addressed cathodic disbondment testing, as well as an overview of the composite to metal interface characteristics.

In order to document commonly accepted techniques, a manual was created by the Pipeline Research Council International (PRCI) . The repair manual provides general understanding of the repair methods; thus assisting operators in selecting proper methods, developing repair procedures, and training staff on the use of repairs.

As composite repair system became increasingly popular, new standards were developed to identify the procedures for evaluating these material. Many of these standards are used in evaluating the entire composite systems as they were carried over from other materials' standards such as those initially developed for plastics and adhesives.

Currently, a wide variety of composite materials are used in pipeline repair systems. They are mainly proprietary manufactured products consisting of glass or carbon fiber reinforcement in a thermoset polymer matrix. The installation process results in a final composite which is shaped around the damaged part with the number of wraps designed according to the severity of the defect.

Composite wraps work by sharing the hoop stress in the pipe wall so that the MAOP pressure can be safely maintained. The repair, accordingly, offers the advantage of restoring the full strength of damaged pipeline, increasing its stiffness, and inhibiting the external corrosion since the composite acts like an external coating.

The ASME B31.8 currently limits the use of composites to corrosion repair of non-leaking pipes unless the repair is proven through reliable testing and analysis. The ASME standards provide the testing procedures and design requirements for using composite systems in the repair of leaking and non-leaking pipe sections.

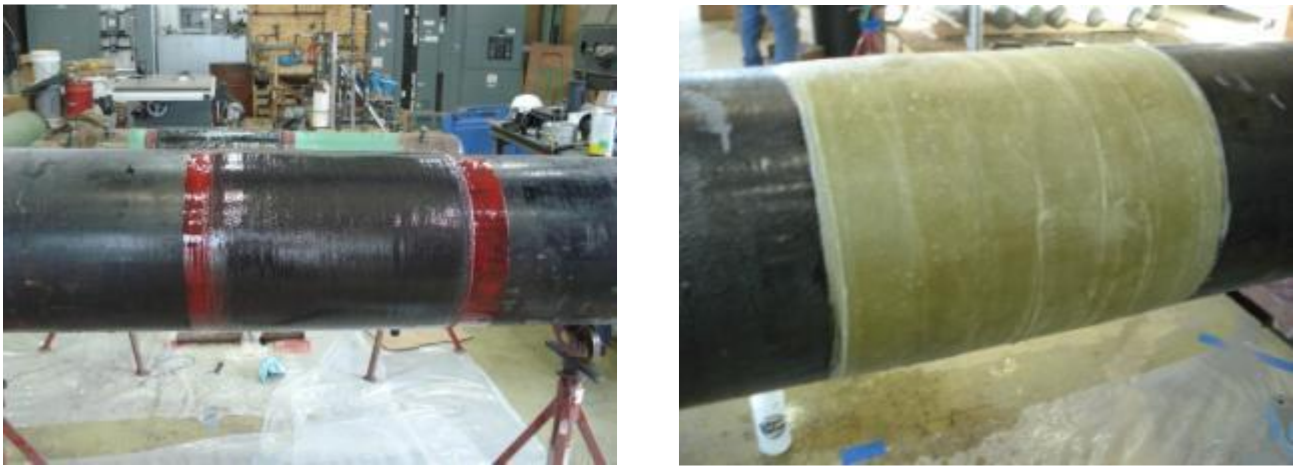


Fig.III.7 - (a) Carbon fiber, (b) Glass fiber composite repairs

III.2.4 Pipe Replacement:

A pipeline replacement project can be a significant construction operation. Typically, the new pipeline segment is installed adjacent to the existing pipeline, which allows the construction work to proceed without stopping the flow of natural gas through the original pipeline.

III.3 Analysis of pipeline Inspection:

III.3 .1 Case study: The case study is the 24’’ Algerian crude oil pipeline

According to the ageran regulation, a 24’’ Crude oil transpoaration piline (south region) have been ILI inspectd, and the following dat were collected

Table III.5 Case study (the 24’’ Algerian crude oil pipeline)

Commissioning Date	1960
Diameter / Length	24’’/775 km
Metal Grade / Thickness	API 5L X52 / 7,14 mm - 10,31 mm
Capacity / Max operating	7,8 MTA / 1000 Psi
Type of coating	Coal

The most recent inspection done by ILI (smart inline inspection) have given the results below:

Table III.6 smart in-line inspection data

Localization		Defects			
Point	PK (m)	length (mm)	width (mm)	Clock Position	Metal loss depth
01	28.084	27	20	05 :49	10%- 19%
02	31.840	21	18	05 :01	20%- 29%
03	31.895	30	27	06 :02	30%- 39%
04	39.646	38	26	01 :01	40%- 49%
05	41.628	29	33	09 :48	50%- 70%
06	41.697	49	60	09 :33	13%- 24%
07	44.601	24	36	06 :38	17%- 31%
08	44.665	19	21	04 :22	12%- 39%
09	74.735	40	24	02 :39	37%- 49%
10	81.297	27	28	10 :32	50%- 70%
11	96.862	21	21	05 :18	10%- 19%
12	101.697	49	60	09 :33	20%- 29%

III.3 .2 Barlow formulas:

The Barlow equation is given by:

t= DP/ (2YFL JT)

Where,

t=Pipe wall thickness, mm

P=design pressure, psig

D=outside diameter of pipe in mm

Y=minimum yield strength, psig

F=design factor (1)

L= Location factor based on class location (0.72)

J=welding joint factor (1)

T=Temperature derating factor (1)

Then, for this crude oil pipeline according to ASME, pipeline conditions, API 5L specifications and deserted location the factors are:

Table III.7 Related Factors

Factors	Values
F	1
L	0.72
J	1
T	1

The required thickness, using the above formula, for this pipeline is: t = 8.38 mm
From API 5L tables (nominal thickness), the design thickness is 9.52 mm.

III.3 .3 pipeline integrity verification:

The pipeline will resist to a pressure of 70 bars when thickness is 8.38 mm (9.52 mm design).

Using the inspection results, the thickness is reduced in severe zones by a 49%, which means that the pressure to be used in the pipeline commissioning must be reduced about 49%. Then using Barlow formula, the required pressure will be **35.7 bars.**

The pipeline will be used to carry crude oil in these new conditions until the affected points will repaired.

The methods of reparation to be used are described in chapter III.2

III.4 Compare results of Barlow's Formula and inline inspection:

Barlow's Formula is used to calculate the maximum allowable pressure that a pipe can withstand based on its dimensions and material strength. It does not directly provide information about finding a specific diameter under a given pressure.

On the other hand, inline inspection techniques, such as pipeline pigging or intelligent pigging, are used to assess the condition of pipelines and gather data about their internal diameter, wall thickness, and any defects or anomalies. This information can be useful in determining the suitability of the pipe for specific pressure requirements.

To find a pipe diameter that can withstand a pressure of 70 MPa, you would typically need to perform an engineering analysis considering factors such as the material properties, wall thickness, and safety factors. The analysis may involve using Barlow's Formula or other applicable equations to ensure that the selected pipe diameter can safely handle the specified pressure.

It's important to note that determining the suitable pipe diameter for a given pressure involves a comprehensive engineering evaluation and is not solely reliant on Barlow's Formula or inline inspection results. Professional expertise and adherence to applicable codes and standards are crucial in ensuring the integrity and safety of pipelines.

Conclusion

Conclusion

Pipelines are essential tools for the transport of fluids over long distances. They are the safest and most ecological mode of transporting hydrocarbons.

However, if their burial allows this discretion in performance, it is also problematic when it is necessary to consider ensuring the maintenance of these transport structures, when subjected to aggressive environment, damage by elements on the ground, fluid transported.

For this aim a several tools have therefore been developed to allow inspection of pipelines from the inside. These tools are called instrumented or intelligent Pigs (smart scrapers or pistons) due to their efficiency, low cost and safety several countries in the word use this method of inspection periodically.

In our study we have taken the Algerian 24’’ crude oil pipeline, that is subjected, according to the Algerian regulation, to an ILI inspection (smart-tool inspection).

The results demonstrate a several points affected by internal and external corrosion which need reparation.

This paper demonstrate that the commissioning parameters of the pipeline (especially pressure) must be reduced to a calculated value in order to maintain safely the crude oil transportation and also to allow the necessary and adequate reparation as described in chapter III.

it is important to note that if the affected zone by corrosion was discovered for long distance, the reparation will be done by installing new lines along the pipeline, these new lines must be hydraulically tested after welding and laying.

The Programs of the ILI inspection and reparation work need to go together so that all the corroded points must be fixed and then the parameters of pipeline will be returned to normal conditions.

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عنوان المذكرة: **In-line inspection of Hydrocarbon Pipelines (ILI Smart Pigs)**

اللقب: بعيليش/ حمدي **الاسم**: محمد العرابي / بدرالدين **المؤطر: بن عرفة علال**

ملخص: تتعرض انابيب نقل النفط والغاز كل عام لمشاكل ناتجة عن التشققات والتآكل والصدمات المسببة للتآكل مما يؤدي إلى خلق تحديات اقتصادية وإنتاجية بسبب عدم سلامة المعدات وفعالية الفحوصات المعقدة المطبقه على خطوط الأنابيب.

في دراستنا ، أخذنا خط أنابيب النفط الخام الجزائري مقاس 24 بوصة ، والذي يخضع ، وفقًا للوائح الجزائرية ، لتفتيش) ILI فحص الأداة الذكية.(

تظهر النتائج عدة نقاط متأثرة بالتآكل الداخلي والخارجي والتي تحتاج إلى إصلاح.

توضح هذه الورقة أنه يجب تقليل معايير التشغيل لخط الأنابيب (خاصة الضغط) إلى قيمة محسوبة من أجل الحفاظ على نقل النفط الخام بأمان وأيضًا للسماح بالتعويض اللازم .

كلمات مفتاحية: كلمة1، كلمة2، كلمة3، كلمة4، …

Memory title : n-line inspection of Hydrocarbon Pipelines (ILI Smart Pigs)

Name: BAILICHE/ HAMDI First name: MOHAMMED LARBI /BADEREDINE Directed by: BENARFA ALLAL

Abstract : The pipelines of oil and gas transportation are exposed every year to problems caused by cracks, corrosion and shocks causing erosion, which leads to the creation of economic and production challenges due to the safety lack of equipment, and the effectiveness of inspections applied to the damaged pipeline.

In our study we have taken the Algerian 24'' crude oil pipeline, that is subjected, according to the Algerian regulation, to an ILI inspection (smart-tool inspection).

The results demonstrate a several points affected by internal and external corrosion which need reparation.

This paper demonstrate that the commissioning parameters of the pipeline (especially pressure) must be reduced to a calculated value in order to maintain safely the crude oil transportation and also to allow the necessary and adequate reparation.

Key words: word1, word2, word3, word4, …

Titre du mémoire : In-line inspection of Hydrocarbon Pipelines (ILI Smart Pigs)

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Résumé : Les pipelines de transport de pétrole et de gaz sont exposés chaque année à des problèmes causés par des fissures, de la corrosion et des chocs provoquant l'érosion, ce qui entraîne la création de défis économiques et de production en raison du manque de sécurité des équipements et de l'efficacité des inspections appliquées aux endommagés. pipeline.Dans notre étude, nous avons pris le pipeline de pétrole brut algérien de 24 pouces, qui est soumis, conformément à la réglementation algérienne, à une inspection ILI (smart-tool inspection).

Les résultats montrent plusieurs points affectés par la corrosion interne et externe qui nécessitent une réparation.

Cet article démontre que les paramètres de mise en service du pipeline (en particulier la pression) doivent être réduits à une valeur calculée afin de maintenir en toute sécurité le transport du pétrole brut et aussi pour permettre la réparation nécessaire et adéquate des canalisations.

Mots clés : mot1, mot2, mot3, mot4, …