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To obtain Master degrees

in ***Mechanical Engineering***

Field : **Mechanical and production manufacturing**

Title:

Damaged Pipeline repairs by GRINDING

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- Engineer ZEDI M. (ALTUMET)

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Dedicates 1

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May this work be the fulfillment of your wishes so much alleged, and the leak of your support

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To all the people who love me

Thank you for always being there for me.

GUERFI Aya

Dedicates 2

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Who surrounded me with her tenderness and never stopped praying for me.

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Abstract

The international demand for gas is increasing day by day. It is then necessary to increase the supply rate by increasing the working pressure which leads to a risk on the fatigue behavior of a crack,

Cracks are present in all structures; they can exist as a fundamental defect in the material or be induced during construction or during operation.

these cracks are responsible for the majority of failures that occur in structures and machine parts in service, subjected to static or dynamic forces. The presence of a crack in a pressurized pipeline requires, for obvious safety reasons, a precise knowledge of its degree of harmfulness. The gas transport pipeline containing a longitudinal crack (mode I of the rupture) is solicited with an internal pressure. The numerical modeling of a cracked medium by the commercial code ANSYS allows on the one hand to characterize the singularity of the stress field at the crack front. Crack repair with grinding has confirmed its effectiveness in reducing the stress intensity at the crack points.

The dimensional geometry of the grinding plays a necessary role in the distribution of stress concentrations in the vicinity and at the crack front.

Keywords: **Crack, Pipelines, numerical simulation, ANSYS, APDL, Grinding**

Résumé

La demande internationale de gaz augmente de jour en jour. Il est alors nécessaire d'augmenter le débit d'approvisionnement en augmentant la pression de service ce qui entraîne un risque sur le comportement en fatigue d'une fissure,

Les fissures sont présentes dans toutes les structures, elles peuvent exister en tant que défaut fondamental du matériau ou être induites lors de la construction ou de l'exploitation.

Les fissures sont responsables de la majorité des défaillances qui se produisent dans les structures et les pièces de machines en service, soumises à des forces statiques ou dynamiques.

La présence d'une fissure dans une canalisation sous pression nécessite, pour des raisons évidentes de sécurité, une connaissance précise de son degré de nocivité. La canalisation de transport de gaz contenant une fissure longitudinale (mode I de la rupture) est sollicitée par une pression interne. La modélisation numérique d'un milieu fissuré par le code commercial ANSYS permet d'une part de caractériser la singularité du champ de contraintes au front de la fissure. En effet, La réparation des fissures par meulage a confirmé son efficacité pour réduire l'intensité des contraintes aux points de fissures. La géométrie dimensionnelle du meulage joue un rôle nécessaire dans la distribution des concentrations de contraintes au voisinage et au front de la fissure.

Mots clés : **fissure, pipeline, simulation numérique, ANSYS, APDL, meulage.**

ملخص

الطلب الدولي على الغاز يتزايد يوما بعد يوم. من الضروري بعد ذلك زيادة تدفق الإمداد عن طريق زيادة ضغط الخدمة مما ينطوي على خطر على سلوك التعب الناتج عن الشق. .

الشقوق موجودة في جميع الهياكل ، ويمكن أن توجد كعيب أساسي في المادة أو تحدث أثناء البناء أو التشغيل.

الشقوق مسؤولة عن معظم حالات الفشل التي تحدث في الهياكل وأجزاء الماكينة في الخدمة ، والتي تخضع لقوى ثابتة أو ديناميكية. يتطلب وجود صدع في أنبوب مضغوط ، لأسباب تتعلق بالسلامة الواضحة ، معرفة دقيقة بدرجة ضرره. يتم التأكيد على خط أنابيب نقل الغاز الذي يحتوي على صدع طولي (الوضع الأول للتمزق) بواسطة ضغط داخلي. النمذجة العددية لوسط متصدع بواسطة الكود التجاري ANSYS تجعل من الممكن ، من ناحية ، وصف تفرد مجال الضغط في مقدمة الشق.

وبالفعل ، فإن إصلاح الشقوق عن طريق الطحن قد أكد فعاليته في تقليل شدة الضغوط عند نقاط التصدع. تلعب هندسة أبعاد الطحن دورًا ضروريًا في توزيع تركيزات الإجهاد بالقرب من طرف الشق وعنده.

الكلمات المفتاحية: **الشق، خط الأنابيب، المحاكاة العددية , ANSYS ، APDL, الطحن.**

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Abbreviations list

API : American Petroleum Institute

F.E.M : Finite Element Method

FIC : Stress Intensity Invoice

ASME : American Society of Mechanical Engineers

SMAW : Shielded Metal Arc welding

List of nominators

d : Depth of the crack

c : Longitudinal long axis of the crack

σ : Stress

E : Young's modulus

P : Pressure

K_{IC} : Critical stress intensity factor

θ : Angle in polar coordinates

W :Width of the defect

GENERAL INTRODUCTION

1. Introduction

Over the last 50 years, pipelines have become the least expensive and safest means of transporting large quantities of energy over long distances (several hundred or even several thousand kilometre's).

Many examples mark the history of industrial development in Algeria. Among the latest accidents, we cite the disaster that occurred in the industrial zone of Skikda on January 21, 2004, which was due to the rupture of a natural gas storage back.

A pipeline is a structure whose integrity must be guaranteed. In particular, to avoid any rupture initiation. The structure is designed to work in the elastic domain with an adequate safety factor, which allows for a critical defect size. In addition, the brittle ductile transition temperature of the steel is chosen to prevent brittle failure of the pipe. The safety of the installations requires a good toughness to avoid the ruin of the structure by rapid crack propagation. Gas pipelines are composed of about ten different grades (Grade A, Grade B, X42, X46, X52, X56, X60, X65, X70, X80…, X120) **[1].** Grade B, X52 and X60 represent about **70%** of the diversity of these networks. However, these pipes are often subject to various kinds of aggressions. Recent studies done by **[2],** show that more than **50%** of the ruptures are caused by external aggressions. For many years, the only possible solutions for damaged pipes were to replace them with others or to weld a new section to them. These procedures usually require production downtime. In addition, hot work is sometimes not allowed in hazardous areas. Finally, metallurgical problems caused by welding add to the disadvantages of this complicated and costly solution. In order to avoid the replacement of the damaged structure, for economical and technical reasons, a simple solution explained by **ASME B31.8** standard **[24],** allows the repair of tubes and the elimination of defects by mechanical grinding, including cracks, is allowed by the **ASME B31.8** standard up to depths of **40%** of the nominal thickness.

1.1 Scope:

The principal scope of this work is to understand the physical phenomena of rupture, during service or accidental stresses and study the reparation of the cracks using grinding method.

1.2 Objectives:

The objective planned of my Master thesis is to take an overview about the physical phenomena of rupture as well as the Non-destructive testing and propose a complete study, on the pipe containing emergency repair by grinding for which we search about the optimal width that the Standard ASME B31-08 didn't talk about.

1.3 General context of the project:

Our end-of-study project was carried out in first part within ALTUMET (Rghaia) which aim to make known about pipelines process manufacturing and methods of control and maintenance during manufacturing

In other hand, to make known the different defects in pipes and suggest a research study about repair methods in order to propose an optimal repair for crack during production.

This work is divided into six chapters and general conclusion:

Chapter I: in the first chapter we present our internship company ALTUMET spa ... discussing on the implementation of a pipeline system from its planning …

Chapter II: presents a state of the art on linear fracture mechanics in the behavior of a ductile material, the different failure modes and the application of the finite element method in linear

Chapter III: We talk about manufacturing process of pipelines used in ALTUMET Company

Chapter IV: Non-destructive testing

Chapter V : Damage and repair technology of pipelines

Chapter VI: Modeling and Numerical Simulation

General Conclusion and Perspective

CHAPTER I:
Internship Report

CHAPTER I: Internship Report

1. Introduction

The mechanical industry is a very important factor in the economy of a country that contributes to progress. It represents the level of evolution of the modernity of a country. Mechanical engineering has a great importance in the economic field, it contributes to the improvement and development of a country and to the local production. The new global industrial strategy is based on the modern high technology acquired by large international manufacturers. In order to improve the quality of the product, productivity, cost price and execution time the use of new production methods is necessary otherwise the transport of hydrocarbons that is very important in a vast country like Algeria, because the demand for it increases with time, it is therefore necessary to develop the means of transport.

Algeria as the other countries of the world, tries to build a sufficient industrial base to catch up the delay in this field which counts each day of extraordinary advances, especially in the field of manufacture of pipelines.

ALTUMET (spa) is one of the Algerian companies specialized in manufacturing and providing pipes coating services in accordance with international standards.

2. Presentation of ALTUMET Company Reghaia- Algiers-

History:

The creation of the company goes back to the 50's and more precisely to 1959, when the French group **"VALLOUREC"** created the company under the name and after the independence, with the nationalization of the wealth and goods of the country the same fate as all the other companies, and this on the date of **13/06/1968**, under the of 13/06/1968, under the name of the unit "GROS TUBES" within the company SNS , the company "SNS" - national company of steel industry- , created by the decree n° 627/1983.

During the years 1988, with the promulgation of the law on the autonomy of companies and the companies and the restructuring of SNS, the company received a new name namely ENTTPP **ANABIB** «National Company of Tubes and Transformation of Flat Products".

At the beginning of the years 2000, and in order to be able to face the difficulties and the competition born from the opening of the national market, ALTUMET gave birth to several subsidiaries including: PIPEGAZ, IRRAGRIS, TUBPROFIL and ANABIB, the Big Pipe Unit and Became what it is today, namely ANABIB.

The EPE ANABIB issued, in January 2016, from the organic restructuring of the ANABIB Group, is a Public Economic Enterprise named "National Company of Tubes and Processing of Flat Products" belongs to the IMETAL Group.

Initially conceived to integrate harmoniously downstream of the steel industrial potential constituted by the complex of El-Hadjar, ANABIB was to ensure the national needs in steel products of second transformation.

The change in the economic environment has been the determining factor in ANABIB's adaptation to the market through the development of its fields of activity by opting for state-of-the-art technologies.

3. ALTUMET Company:

ALTUMET is a public company with an economic character, its status is a joint-stock company with a share capital of **1 739 560 000 DA**, registered in the trade register of the wilaya of Algiers under n° RC N° 0015196, it is located in the industrial zone of Reghaia, on the road axis of the national road n°, distance of 25 km from Algiers.

Before being fixed on the name **ALTUMET**, this company knew several of its status, and it is thanks to this that it could survive, develop its activities and to gradate shares of the market which became more and more difficult to keep.

Figure 1:ALTUMET (Spa)

3.1 Area of Activity:

- Manufacturing of spiral welded tubes from steel strips.
- Research and development of other manufacturing processes.
- Import and export of spiral welded tubes.
- Provision of coating.
- Distribution of products and derivatives such as welded tubes intended for the transport of hydrocarbons, water and other various uses:

  (Supports of construction, piles beaten for drilling...).

3.2 Share capital:

The share capital of the company is 1 739 560 000 DA, 1 739 560 shares of 10 000 DA each.

3.3 Registered office:

The head office of the company is located at the level of the industrial zone of Reghaia, route national n° 5 Réghaia, Algiers. It is endowed with a surface of 50 063 m^2

3.4 Range of products:

The manufacture concerns a range of steel tubes with a diameter ranging from " 8 to 32" (219 to 914), delivered bare or coated. They are intended for:

- Hydrocarbon transport.

- Hydraulic pipes.

3.5 Production capacity:

The plant has an annual production capacity, which breaks down as follows

- Tubes: 40 000 tons.

- Coating: 40 000 tons.

3.6 Market share:

The products manufactured by the company are intended to satisfy the needs in for the energy and hydraulic sectors.

The potential customers are made up of:

- Energy sector:

■ Cameg Filiale Sonalg

■ Kanagaz

- Hydraulic sector:

■ Directorate of hydraulics of the wilayas

■ (DHW).

■ National hydraulic company.

■ Hydro-aménagement.

■ Hydro-treatment.

■ GTH.

■ Hydro-transfer.

As well as other companies in the sector both public and private.

3.7 Field of Application:

The pipe thus obtained are intended for the:

- The transfer of fluids:

■ Water.

■ Oil.

■ Gas.

- For construction use:

■ Construction supports (poles).

■ Driven piles for foundations or drilling.

■ Lighting supports (lighting masts).

3.8 Detail of the organization chart:

The organization chart of ALTUMET is composed as follows:

- General management.
- Plant management.
- Direction of accounting and finance.
- Human resources management.
- Commercial management.

3.9 Quality:

The quality approach of **EPE ANABIB SPA (ALTUMET)**is based on a quality management system **ISO 9001/2015, API Q1 and ISO/TS 291001**.

As well as the **API 5L** license, allowing it to affix the **API** monogram on its products.

Certificate of Authority to use the Official API Monogram

License Number: 5L-0557 ORIGINAL

The American Petroleum Institute hereby grants to

ALTUMET-ALGERIENNE DES TUBES METALLIQUES
BP 11 Zi-Reghaia Wilaya d'alger
Reghaia, Algiers
Algeria

the right to use the Official API Monogram® on manufactured products under the conditions in the official publications of the American Petroleum Institute entitled API Spec Q1® and API-5L and in accordance with the provisions of the License Agreement.

In all cases where the Official API Monogram is applied, the API Monogram shall be used in conjunction with this certificate number: 5L-0557

The American Petroleum Institute reserves the right to revoke this authorization to use the Official API Monogram for any reason satisfactory to the Board of Directors of the American Petroleum Institute.

The scope of this license includes the following: Manufacturer of Line Pipe Plain End at PSL 1 - Type of Pipe: SAWH / Delivery Condition: N / Max. Grade: X70; Manufacturer of Line Pipe Plain End at PSL 2 - Type of Pipe: SAWH / Delivery Condition: M / Max. Grade: X70 and / Delivery Condition: N / Max. Grade: X60

QMS Exclusions: Design and Development; Servicing

Effective Date: SEPTEMBER 15, 2020
Expiration Date: SEPTEMBER 15, 2023

To verify the authenticity of this license, go to www.api.org/compositelist.

Vice President of Global Industry Services

American Petroleum Institute

Figure 2 : API-5L, AMERICAIN PETROLEUM INSTITUTE

REGISTRATION NO. Q1-0393

Certificate of Registration

The American Petroleum Institute certifies that the quality management system of

ALTUMET-ALGERIENNE DES TUBES METALLIQUES
BP 11 Zi-Reghaia Wilaya d'alger
Reghaia, Algiers
Algeria

has been assessed by the American Petroleum Institute and found to be in conformance with the following:

API Specification Q1

The scope of this registration and the approved quality management system applies to the:

Manufacture and Coating of Line Pipe

API approves the organization's justification for excluding:
Design and Development; Servicing

Effective Date: SEPTEMBER 15, 2020
Expiration Date: SEPTEMBER 15, 2023
Registered Since: JANUARY 8, 2007

Vice President of Global Industry Services

API Spec Q1 Registered

QMS REGISTERED

Certificate of Registration

APIQR® REGISTRATION NUMBER
0650

This certifies that the quality management system of

ALTUMET-ALGERIENNE DES TUBES METALLIQUES
BP 11 Zi-Reghaia Wilaya d'alger
Reghaia, Algiers
Algeria

has been assessed by the American Petroleum Institute Quality Registrar (APIQR®) and found it to be in conformance with the following standard:

ISO 9001:2015

The scope of this registration and the approved quality management system applies to the
Manufacture and Coating of Line Pipe

APIQR® approves the organization's justification for excluding:
8.3 Design and Development of Products and Services; 8.5.5 Post-delivery Activities

Effective Date: SEPTEMBER 30, 2020
Expiration Date: SEPTEMBER 15, 2023
Registered Since: SEPTEMBER 15, 2017

Vice President of Global Industry Services

QUALITY REGISTRAR

Figure 3 : API spécification Q1Certificats ISO 9001 : 2015

4. Organization of the company ALTUMET s.p.a:

Within the framework of the establishment of the central structures of the General Management the organization and structuring of the company "ALTUMET S.P.A.", is defined

As follows:

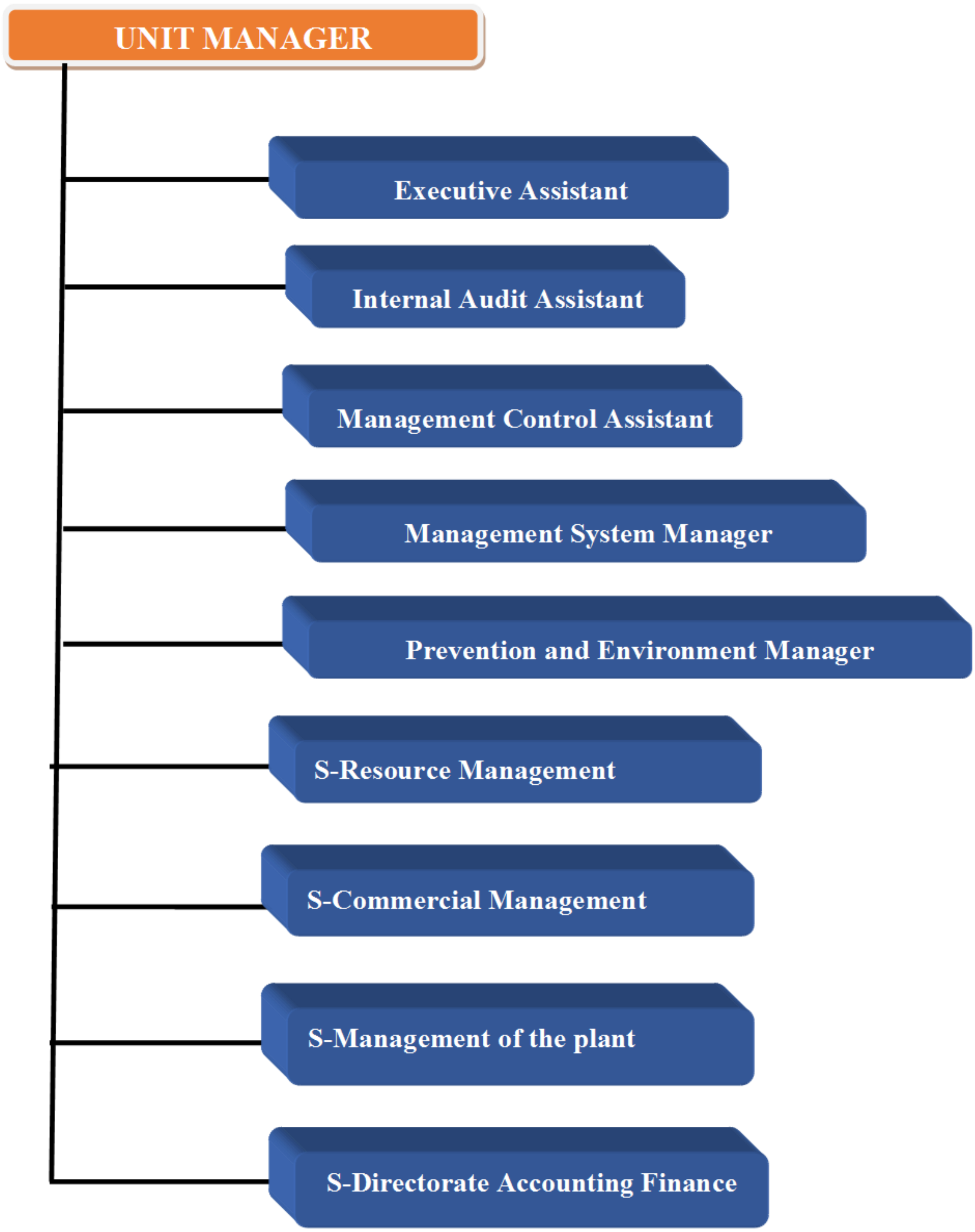


Figure 4 : organizational chart of the company

5. General Organization System:

5.1 Product range :

We manufacture a range of steel pipes with diameters between 8" and 36" **(219.1- 914 mm)** steel grade **(S235JR-X70M)** with coil width between **(820 mm to 1200mm)** depending on the diameter of the pipe to be processed next

20" and 48" **(508- 1219.2 mm)** steel grade **(S235JR-X80M)** with coil width between **(1000 mm to1800 mm)** depending on the diameter of the tube to be processed are delivered bare or coated.

The coils are unwound flat, formed into a helix and then submerged arc welded in two successive passes on a spiral welding machine.

The quality of the spiral welded tubes **(SAWH)** processed by ALTUMET is based on the control from the reception of the raw material (coil - Wire-Flow) to the finished product (tube) following the American standard **API 5L**, passing several states of destructive and non-destructive control.

5.2 Manufacturing standards:

5.2.1 Hydrocarbon tube range:

- API 5L (American Petroleum Institute).
- Customer requirements (SONATRACH, SONELGAZ....).

5.2.2 Hydraulic tubes range:

- NF EN 10224.

At each stage of their manufacture, the pipes under control tests in order to obtain a reliable pipe by the:

- Aspect and dimensional control with calibrated means.
- Non-destructive control.
- Destructive control.
- Final control before reception.

5.3 Coating standards (PE):

The coatings applied for the tubes are in accordance with the standards:

5.3.1 Hydrocarbon pipe range :

- ISO/FDIS 21809-1 for the external coating in three-layer polyethylene.
- EN ISO 15741 for the inner coating in epoxy gas.

5.3.2 Hydraulic pipe range:

- NF A49-710 for the outer coating in three-layer polyethylene.
- NFA49-709 and VERITAL certificate for the internal coating in food epoxy.

Chapter II:

State of the art

(Mechanics of fracture)

Chapter II: State of the art (Mechanics of fracture)

1. Introduction

Fracture mechanics seeks to specify a material property that can be characterized by its resistance to brittle failure. Structures are designed so that the maximum stresses do not exceed the elastic limit of the material. They are not automatically safe from failure by brittle fracture, either from a crack at commissioning or from fatigue.

This chapter gives an overview of the different concepts of **fracture mechanics** and the application of **finite element** method necessary for this study.

2. Linear and non-linear fracture mechanics

The brittle type failure occurs when the solicitations exist in actions at high speeds of stresses and damage pre-existing or created during service. The brittle failure corresponds to the lack of ductility of the material under a thermal loading. The accidental ductile failure, for a very low plastic deformation, there is no direct relationship between the toughness and the temperature. The maximum rupture is related to the imminent propagation of a crack.

2.1 Fracture criteria

In linear fracture mechanics two main criteria are used; the first one proposed by Griffith **[3]** is based on an energetic approach, the second one proposed by Irwin **[4]** is defined from the stress field at the crack tip.

2.1.1 Energy approach: During his work on the theory of brittle fracture, Griffith introduced the rate of energy restitution, noted G corresponding to the energy released during the propagation of a crack in a perfectly elastic solid. According to Griffith, failure occurs when sufficient energy is released for the creation of new fracture surfaces. This energy comes from the elastic energy stored in the material and the potential energy of the loading system. Griffith **[3]** considers a solid of thickness h, subjected to a loading P, with a crack of length 2a. The total free energy of the cracked body is equal to:

$$U = U_0 + U_S + U_E - W \qquad \text{(Eq 1)}$$

Where:

U_0 : is the strain energy of the uncracked body.

U_S : is the surface energy due to the formation of the crack.

U_E: is the elastic strain energy change due to the introduction of the crack.

W: is the variation of the external work.

In the original Griffith theory applying to brittle fracture, the energy ΔU is the energy required to create new surfaces in the material.

The Griffith energy G is related to the unit area; it is defined from ΔU by:

$$G = \lim \frac{\Delta U}{\Delta a} = \frac{\partial U}{\partial a} \qquad \text{(Eq 2)}$$

$$G = \frac{\partial U}{\partial a} = 2\gamma_s \qquad \text{(Eq 3)}$$

Griffith expressed the total energy in the fracture criterion as:

G < **0:** the crack is unstable (brittle fracture).

G = **0** : the crack is in equilibrium.

G> **0**: the crack is stable (ductile failure).

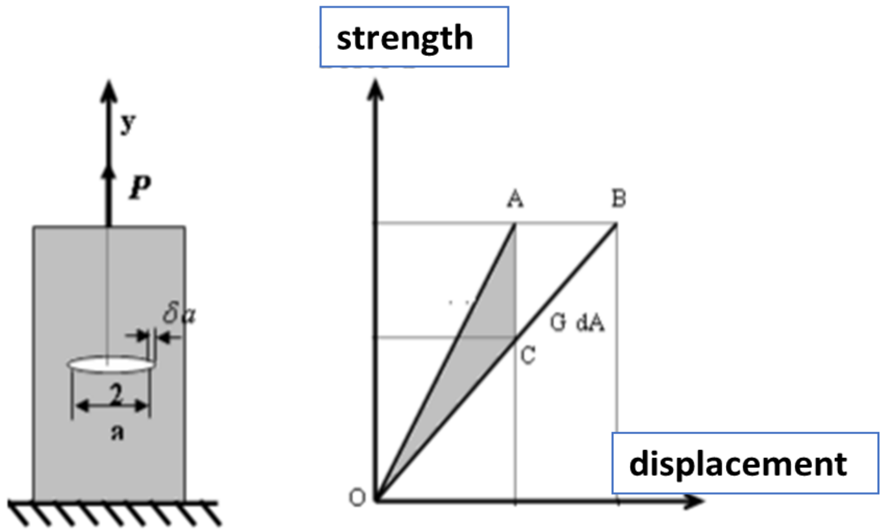


Figure 5 : Relationship between G and the complacency of the structure [3].

On the Force/Displacement curve above, OA corresponds to a crack of length a, and OB to a crack of length a+δa. G represents the area located in the triangle OAB for a test performed under imposed load or in the triangle OAC for a driving under imposed displacement. Using the stress field in the singular zone and the linear elastic behavior law, it is possible to relate the rate of energy restitution to the stress intensity factors.

3. Different modes of failure

A crack is defined as the surface separating locally a solid into two parts. The displacement field is then discontinuous across this surface and the three vector components of this discontinuity form the three modes of rupture (figure 6): mode I for an opening, mode II for a planar slip and mode III for an anti-planar slip. The real case is a superposition of these three (3) modes, one speaks then of mixed mode **[5].**

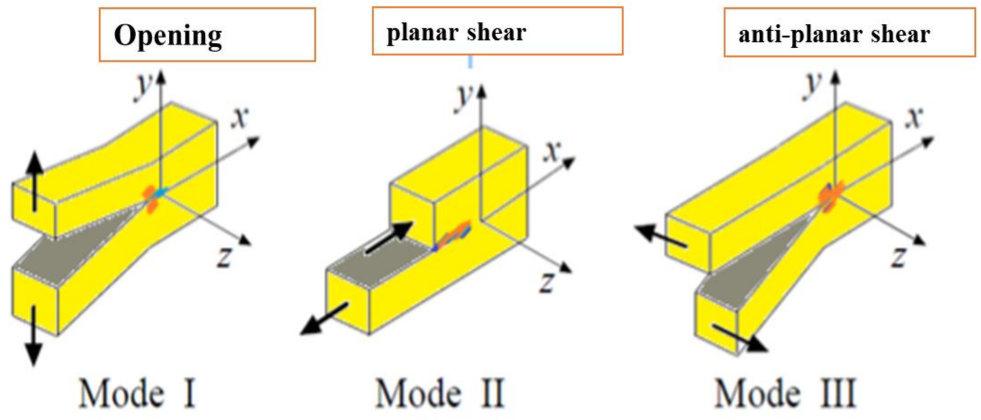


Figure 6: Different failure modes [5].

-Mode I (opening mode): the lips of the crack move in opposite directions and perpendicular to the crack plane.

-Mode II (planar shear): the lips of the crack move in the same plane and in a direction perpendicular to the crack front.

-Mode III (anti-planar shear): the lips of the crack move in the same plane and in a direction parallel to the crack front.

4. Stress intensity factor

Irwin **[4],** considers a solid of linear elastic behavior and includes a crack. He shows that the stress field in the vicinity of the crack can be defined only by a parameter K called stress intensity factor. Failure can occur when K reaches a critical value Kc. Using the Westergaad functions **[6],** it is possible to describe the stress field at a distance r from the crack tip (Figure 7). The general expression for this field is of the form:

$$\sigma_{ij} = \frac{K}{\sqrt{2\pi \ r}} f_{ij}(\theta)$$
(Eq 4)

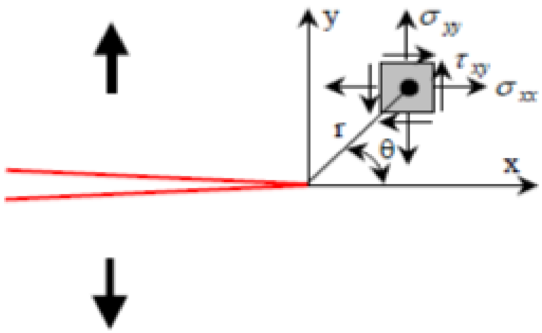


Figure 7: Stresses near the end of a crack [7].

Where: **r, θ** are the polar coordinates of the point under consideration**, K** is the stress intensity factor, which is here: σπ a and contains both the information about the loading level and the crack size. Since the stress intensity factor K defines the stress field in the vicinity of the crack, Irwin **[13]** postulated that the condition K ≥ Kc represents a failure criterion. K is given by the following relationship:

$$K = Y.\sigma \sqrt{\pi \ a}$$
(Eq 5)

σ: is the value reached by the applied stress,

Y: is a geometric factor (Correction Coefficient) takes into account the dimensions and geometry of the specimen. This parameter is given for each type of specimen as a polynomial function of (a/w), where w is the specimen width and a is the crack length.

The factors KI KII and KIII are defined respectively for modes I, II and III described above. The stress fields are expressed using the stress intensity factors In Mode I:

$$\begin{cases} \sigma_{xx} = \dfrac{K_1}{\sqrt{2\pi r}} \cos\dfrac{\theta}{2}\left(1 - \sin\dfrac{\theta}{2}\sin\dfrac{3\theta}{2}\right) \\ \sigma_{yy} = \dfrac{K_1}{\sqrt{2\pi r}} \cos\dfrac{\theta}{2}\left(1 + \sin\dfrac{\theta}{2}\sin\dfrac{3\theta}{2}\right) \\ \tau_{xy} = \dfrac{K_1}{\sqrt{2\pi r}} \cos\dfrac{\theta}{2}\sin\dfrac{\theta}{2}\cos\dfrac{3\theta}{2} \end{cases}$$

En mode II :

$$\begin{cases} \sigma_{xx} = -\dfrac{K_{II}}{\sqrt{2\pi r}} \sin\dfrac{\theta}{2}\left(2 + \cos\dfrac{\theta}{2}\cos\dfrac{3\theta}{2}\right) \\ \sigma_{yy} = \dfrac{K_{II}}{\sqrt{2\pi r}} \sin\dfrac{\theta}{2}\cos\dfrac{\theta}{2}\cos\dfrac{3\theta}{2} \\ \tau_{xy} = \dfrac{K_{II}}{\sqrt{2\pi r}} \cos\dfrac{\theta}{2}\left(1 - \sin\dfrac{\theta}{2}\sin\dfrac{3\theta}{2}\right) \end{cases}$$

En mode III :

$$\begin{cases} \tau_{xz} = -\dfrac{K_{III}}{\sqrt{2\pi r}} \sin\dfrac{\theta}{2} \\ \tau_{yz} = \dfrac{K_{III}}{\sqrt{2\pi r}} \cos\dfrac{\theta}{2} \end{cases}$$

(Eq 6), (Eq 7), (Eq 8)

In a pipe, stresses are exerted in two directions, (Figure 8), circumferentially (so-called circumferential stress) and longitudinally (so-called longitudinal or axial stress).

The different sources of circumferential and longitudinal stresses are:

- Internal operating pressure is the most important stress component,
- Pipe fabrication induces residual stresses,
- Internal pressure, acting on an ovalized pipe, gives a bending stress,
- Settlement and landslides induce secondary stresses,
- Temperature changes along the pipeline axis

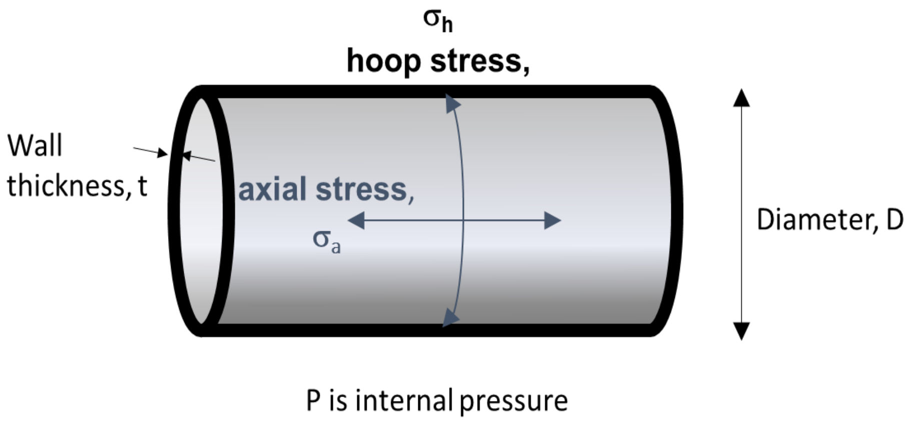


Figure 8: Stresses on a pipeline [8].

In addition to longitudinal cracks, circumferential cracks can also be encountered in pipes. These cracks can propagate over the entire thickness of the pipe and under the various stresses. They lead to sudden ruptures.

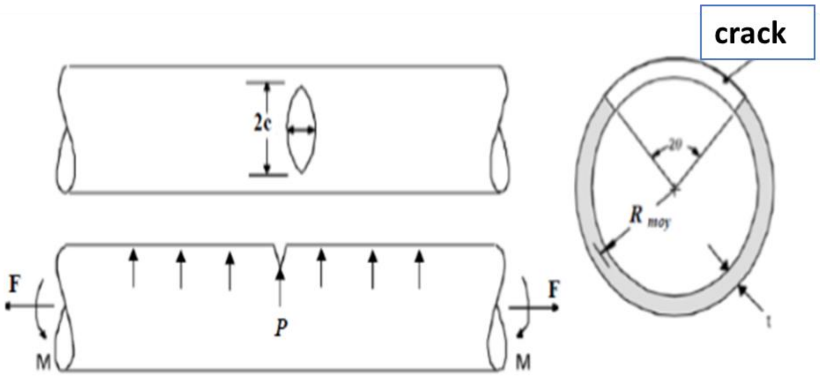


Figure 9 : Geometry of a tube with a circumferential crack

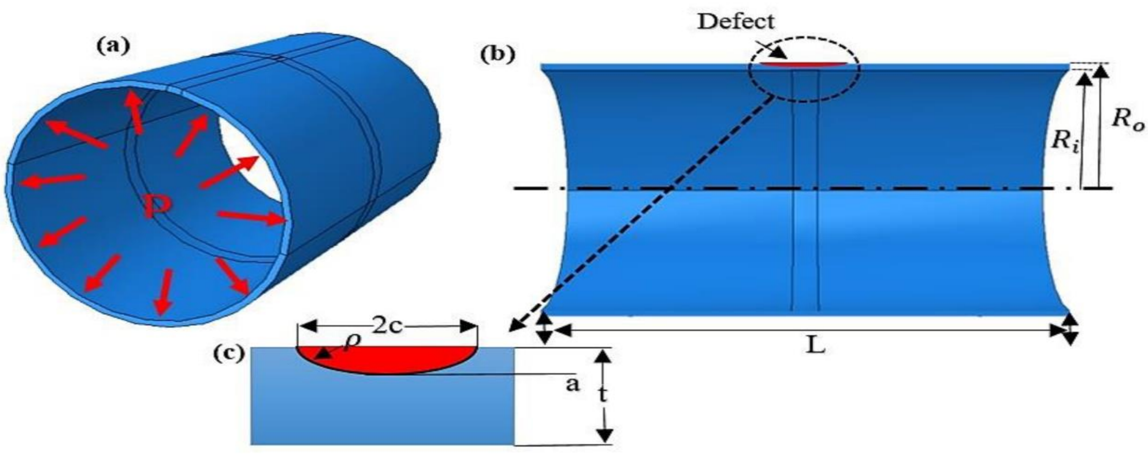


Figure 10 : Schéma du modèle dimensionnel : (a) modèle 3D de la canalisation, (b) dimensions du modèle géométrique avec défaut, (c) caractéristiques du défaut.

5.Finite element method in linear elasticity

The use of the finite element method on a given domain to determine an unknown function (stress, displacement...) requires the description of the considered domain in a finite number of subdomains called finite elements. The continuous system will be replaced by an equivalent discretized system.

The elements used for the discretization can be one-dimensional, two-dimensional, and three-dimensional. These elements are related to each other at a finite number of points called nodes that are located at the corners and along the boundary of these elements.

The objective of the finite element method is to obtain the relationship linking displacements

$$\{F\} = [K]\{u\} \qquad \text{(Eq 6)}$$

Where**:** **K** represents the stiffness matrix.

6. Singularity modeling

Often in a cracked structure to have good accuracy in conventional finite element analysis, a more refined mesh is required in the crack front region, but the convergence rate becomes very low. Therefore, to avoid a refined mesh discretization of cracked structures, it is preferable to use special crack tip elements with shape functions compatible with the singularity of the displacement field.

7. Conclusion

This chapter allows us to set the framework of our subject. From a theoretical point of view, the asymptotic analysis in linear fracture mechanics has defined the parameters describing the fracture. We have recalled the main works related to the determination of the stress field in the vicinity of a notch and the stress concentration factor in the elastic case.

Chapter III:

Pipe Manufacturing Process

Chapter III: Pipe Manufacturing Process

1- Introduction

Gas pipelines are made of butt-welded steel pipes, covered with an insulating material (polyethylene, polypropylene, ..) contributing to their protection against corrosion. They can also be internally coated to improve the flow of the transported fluid or to prevent internal corrosion if the transported gas is corrosive.

Depending on the type of use, pipelines are operated by exploration, production, transportation or distribution companies. The operation of a pipeline consists of maintaining the structure in good working order under optimal conditions of safety and cost. Today, there are millions of kilometres of pipelines that are widely used to transport water, gas and oil either overhead, underground or under the sea, from the original sources to the product processing plants (filtration, refining, liquefaction.) (Figure 11).

Pipelines are susceptible to internal and external corrosion phenomena resulting from defects such as cracking, mainly leading to leaks and ruptures. Accidents, sometimes resulting in catastrophic damage (human injury, pollution of the natural environment, additional repair costs, prolonged shutdown of production units) occur sporadically during their operation.

Figure 11: The pipelines

2. General information on oil and natural gas pipelines

2.1 Definition of a pipeline:

A pipeline is a pipe designed to carry gaseous, liquid, solid or polyphase materials from one place to another. The nominal diameter of a pipeline can range from about thirty millimeters (1.25") for special fluids to more than three meters twenty (68") for water conveyance.

When a pipe has a very small diameter (less than about thirty millimeters), it is referred to as piping.

The characteristics of the pipes (diameter, thickness, type of steel) are defined by calculation according to several parameters such as: the desired flow rate, the choice of the ground profile, the environmental zones crossed, while respecting the regulations in force.

2.2 The characteristics of the pipeline:

The characteristics of the pipeline thus defined, diameter and thickness allowing to fix the operating pressure and the pressure drop, leading to the determination of the pressure energy to be supplied to the fluid by pumping or compression, the simple problem for incompressible fluids, for which the pressure drop is proportional to the distance, becomes obviously more complex for gases, for which the pressure drop depends on the average pressure in the section of the pipeline, thus the spacing of the power injection points, i.e. of the compression stations

2.3 Manufacturing process of pipeline pipes :

The multiplicity of diameters and thicknesses of pipes and the development over time of their manufacturing techniques **[12],** are the reasons for the diversity of the Algerian gas transport network. We find :

- Spiral welded pipes
- Longitudinal welded pipes
- Seamless pipes.

2.3.1 Spiral welded pipes

The procedures for manufacturing spiral welded pipes are made by bending strips of steel sheets in the shape of a pipe and welding them together. This production technique goes through stages, as shown in Figure 12. The welding occurs here on the production of spiral tubes that are usually supplied.

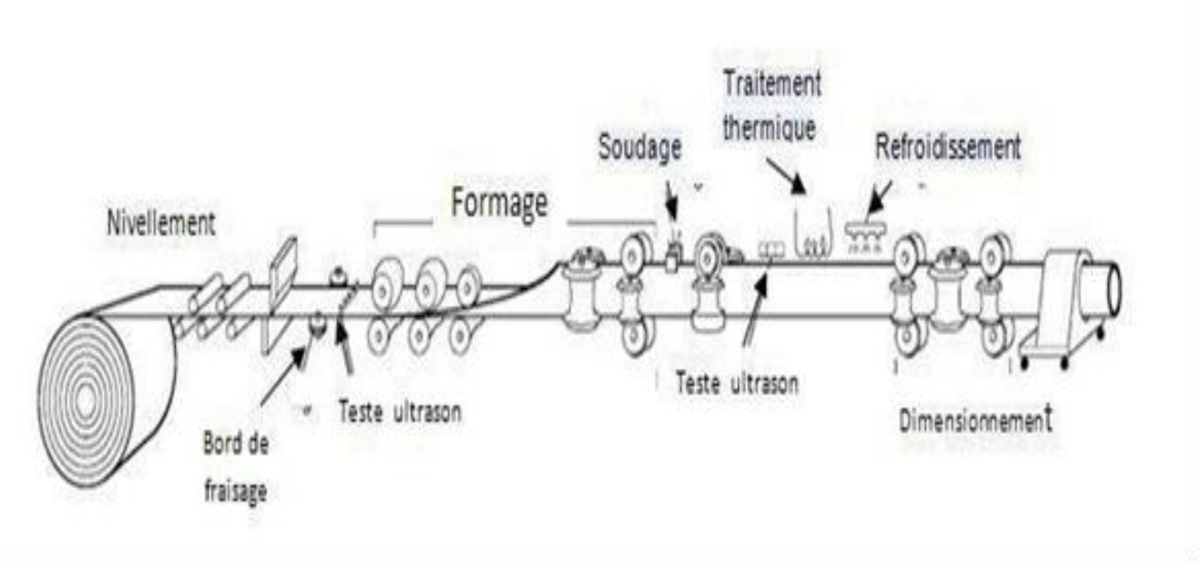


Figure 12: Manufacturing technique for spiral welded tubes

The production of spiral tubes can be divided into the following main operations:

- Preparation of the strip
- The splicing strip
- Bending
- Welding
- Finishing
- Receiving and inspection

The preparation of the strip and the edges of the strip as well as the butt welds have a direct influence on the quality of the pipe. Because of the importance, we pay special attention to the latter in this presentation.

The following operations are carried out at the entrance of the spiral tube machine:

- Unwinding of the band
- Straightening of the shearing strip
- Chamfering the edges of the strip
- Cambering of the edges to eliminate the roof effect

At the entrance to the forming cage, the inner pass of the weld is made, while the outer pass is made on the formed tube. The usual processes for cutting are :

- Oxycutting
- Plasma cutting

3. Procedure For acceptance of a casting for production :

For each pour to be accepted, the purchaser shall perform the analyses and tests mentioned in this specific in the present specific on 02 tubes in accordance with table N°18 of API 5L.

Figure 13: Galvanised steel

- ✓ If the two (02) tubes tested have compliant results.

NB: all the coils of the casting will be accepted.

- ✓ If one of the two (02) tubes is the subject of non-conforming results.

NB: a counter test will be carried out on two (02) new tubes of the same casting.

- ✓ If the results are in conformity.

NB: all the coils of the casting will be accepted except the one which gave results (-).

- ✓ If the results are not in conformity.

NB: the buyer reserves the right to reject the whole run.

- ✓ If one of the two tubes is the subject of results (-).

NB: the rest of the casting will be tested reel by reel and the tubes from the non-compliant reels will be scrapped.

- ✓ The coils whose results (-) are confirmed.

NB: the coils will be replaced.

4. Technique for processing welded pipes in spiral (SAWH):

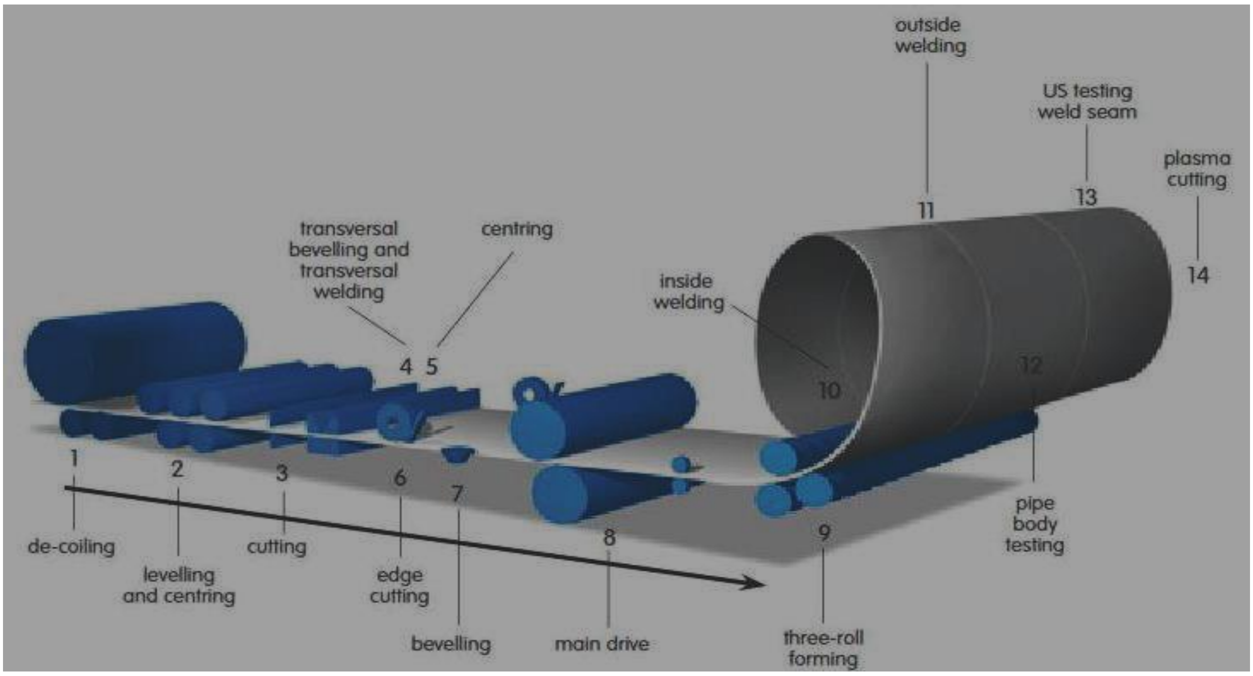


Figure 14 :pipe process

4.1 Introduction submerged arc welding (SAW) process:

The welding process used submerged arc welding with the welding wire in the principle is as follows:

- Submerged arc welding uses one or more wires of an electric current between the wire and the workpiece.
- Through a medium consisting of a slag resulting from melting of a powder flux cover the end of the wire arc and the melting property this process is used only in automatic.

4.2 Adjust the forming angles according to the adjustment sheet:

		FICHE DE REGLAGE N.L.A.T				
		SERVICE METHODES ET OUTILLAGES				
		FICHE DE REGLAGE N.L.A.T N° :				
		PRODUIT :	Bobine d'acier Fournisseur			
EPE ANABIB SPA		DEBUT FAB :	2021		FIN FAB :	2021
UNITE ALTUMET						
COMMANDE G R T G /SPA N° :	2545	Etabli par :				
QUANTITE COMMANDÈE (ML) :	10000,00	date :				
QUANTITÉ à FABRIQUÉ(ML):		VISA:				
			U.M			
NUANCE	X70M	485	N/mm²	DIAMÉTRE =	711,2	mm
LONGEUR TUBE	L_T=	07,00 à 12,30	ml	EPAISSEUR =	9,50	mm
LARGEUR BRUTE	L_B	1210	mm	SPÈCIFICATIONS TECHNIQUES :		
LARGEUR CISAILLÉE	L_C =	1200	mm	API 5 L Qualité PSL2		
ANGLE MACHINE	B_m =	57,02	°	CIRCONFÈRENCE EXTREMITÈ:		
ANGLE ROULEAU DE FORMAGE AVANT	RF AV =	57,02	°	MAXI=	2239	mm
ANGLE ROULEAU DE FORMAGE ARRIÉRE	RF AR =	57,02	°	MINI=	2229	mm
ANGLE ROULEAU DE FORMAGE INTERIEUR	RF INT =	57,02	°			
HAUTEUR SUPPORT INTERIEUR	H =	700	mm	CIRCONFÈRENCE CORPS:		
	C =	5	mm	MAXI=	2245	mm
distance entre les deux axes RF "AV" et RF "AR"	L =	225,45	mm	MINI=	2223	mm
	ANGLE (æ) =	14,69	°	EPREUVES HYDROSTATIQUES (bars):		117
	ANGLE (ß) =	22,36	°	TEMPS DE MAINTIENS (seconde) :		15
distance entre l'axes table de formage et l'axe RF"AV"	L_1 =	90,18	mm	REVETEMENT TYPE:		
distance entre l'axes table de formage et l'axe RF"AR"	L_2 =	135,27	mm	EXTERIEUR:	PE	ISO 21809
PRESSION COMMANDE PRINCIPALE	P =	90 - 100	bars	INTERIEUR:	Epoxy gaz	API 5L2
distance entre centre galet de formage'AV" et lARIVE		80	mm	OBSERVATIONS:		
60 à 80 mm	on prend=			JOINTS PREPARATION:		
distance entre centre galet de formage'AR" et lARIVE		120	mm		en (X)	
120 à 150 mm	on prend =					
PARAMÈTRE DE SOUDAGE RABOUTAGE				CADENCES		
					70%	100%
Vitesse de soudage = 0,7m/min	570A	28V		CADENCE POSTE(ML):	210,34	300,48
PARAMÈTRE DE SOUDAGE				CADENCE HEURE(ML):	26,29	37,56
	INTERIEUR	EXTERIEUR				
une seule téte	650±20	830±20	A	MACROGRAPHIE:	01 TUBE MACHINE	
	30±1	31±1	V	FIL SOUDURE	S2moΦ3,2mm	S2moΦ4,0mm
VITESSE DE SOUDAGE=	1,15		m/min	FLUX :GEKA	ELIFLUX BFPP	

4.3 Mode of operation for pipe transformation (SAWH) :

-Placement of the coil on the "chair" carriage.

-Engage the "chair" carriage forward to the level of the walls.

-Holding the coil with the walls.

-Opening the coil with the coil opener.

-Unwinding of the coil by the carriage roller up to the auxiliary drive.

-Holding of the coil with the auxiliary drive roller "two position".

-Engage the coil by the auxiliary drive to the leveler.

-Put the levelers in the upper position.

-Launch the coil by the auxiliary drive up to the mobile clamp.

-Move the levelers to the lower position.

-Cutting of end and start of coil.

-Milling of end and start of coil.

-Move the new sheet to the welding position.

-Move the cutter rail to the upper position.

4.3.1 Welding and rubbing (see adjustment sheet):

-Grind both ends of the weld beads to facilitate splicing engagement.

- Measuring the strip with encoder 01.

- Milling of the strip edges.

-Main control if to start the sheet and the machine with the sheet guiding arms.

Pre-bending of the left strip edges "up / down - in / out".

4.3.2 Front forming roller:

- Machine angle.
- Angle α.
- Front forming roller.

4.3.3 Fear forming roller:

- Machine angle
- Angle β
- Rear forming roller

4.3.4 Top forming roller "inner forming trains" :

- Machine angle.

4.3.5 Adjustment of :

- Calibration arm up/down.
- Calibration arm in / out.
- Calibration roller 45° in / out.
- Calibration rollers up / down.

-Calibration rollers in/out.

4.3.6 Internal welding:

-Internal head "left/right".

-Nozzle 3,2 mm

4.3.7 Check circumference extremity :

- Maximum end circumference (mm).

- Minimum end circumference (mm).

4.3.8 External welding:

-Inside head "left/right

- Nozzle 4,0 mm

NB: Three tube guide rollers after the forming cage other tube guide rollers.

4.3.9 Plasma pipe cutting :

The cutting carriage is a steel construction which is fixed on the tube outlet frame.

It consists of (03) linear units.

- 01 plasma cutting system
- 02 limit switches
- 01 US sensor
- 01 servomotor with absolute value indicator
- 01 three-phase motor and an auxiliary axis for the middle of the tube.

NB : Plasma tube cut according to the length.

5. Introduction processing procedure:

The tubes are obtained from a strip wound cold in spiral and welded with the immersed arc (SAWH) has (01) welding machine which allows the realization of several operations to manufacture the tube.

Figure 15:strip wound cold in spiral

Figure 16 : welding machine

5.1 Web dressing :

A set of straightening rollers ensures a perfect and helpful guidance of the raw web.

Figure 17 : part of guidance for the raw band

5.2 The jointing (assembly the two bands):

It is an operation that consists in cutting, with the oxycutter, to the thin strip on the machine and to join.

- The end of the previous coil to the new one by an automatic welding under flux.
- The duration of the operation lasts about 30min.

Figure 18 : assembly the two bands

5.3 Milling:

Milling blocks on both edges allow the final width of the strip to be set

Figure 19 : final adjustment of the bandwidth

5.4 Forming of the band

The strip is driven by cylindrical rollers, it undergoes a preforming by cambering rollers, guide arms maintain the strip this one is introduced into the cage of forming made up of several trains of rollers, adjusted according to the diameter to be carried out.

Figure 20 : the forming band part

5.5 Interior welding: -Interior head (left/right)

-Nuzzle 3.2 mm

Figure 21 : interior welding of the pipe

5.6 External welding: Interior head (left/right)

-Nuzzle 4.0mm

Figure 22 :External welding

5.7 Tube cutting device with plasma cutting :

Figure 23 :plasma cutting machine

- Tube cleaning:

The tube thus put in ongeur is cleaned inside (system of air) which rids it of all the waste (flux. Laitier...etc).

- Controls of the tubes:

These controls concern the base metal and the welding bead. They have for

Purpose of highlighting defects either directly (visual) or indirectly by their effects (visual, magnetic particle, ultrasound, radiography ...). These defects are of types:

- Admissible defects (elongated spherical blows, arc cut...).
- Inadmissible defects (lack of penetration, cracks, gutters...).

The conformity of the tubes is checked at the end of the manufacturing operation and before their routing to the park by different means of control.

5.8 Tube inspection procedures:

These checks are for the base metal and the weld bead.

The control steps are as follows:

Figure 24 :inspection procedures

5.8.1 Visual control :

The visual inspection is the simplest and the first of the controls that is implemented. It allows the detection of shape defects and other defects on the surface of the welded joints. The inspection is done at the following level

The inspection is done under a light level of at least 350lux. Metrological evaluation of arc welded tubes

The metrological evaluation of powder arc welded pipes consists of the following parameters:

At this level, the following operations are performed:

- Control of the visual aspect of the sheet and the bead.
- Dimensional control (length - diameter - thickness).
- Elimination by grinding of certain types of defects.
- Transcription of this information on the tube tracking card.

Table 1:represent visual checks with measuring methods

Parameter	Unit	Measuring methods
Diameter	(mm)	Micrometer (tape measure)
Thickness		DM2 (micrometer)
Length		Double decameter
Straightness		Plumb line and ruler
End squaring		Square
Roof effect		Comparator
Leveling (offset)		Comparator
Cord height		Elevation gauge
Bead Width		Ruler
Chamfer angle		Compas de chanfreins
Chamfer heel		Ruler
Beveling		Ruler
Tube weight	(kg)	Scale

5.8.2 Repair of the defects of weld bead:

Equiped with two (02) manual welding station to carry out all operations of detrimental defects of the weld, reported upstream by the visual inspection.

- Only qualified welders are allowed to carry out the repair of the pipes:

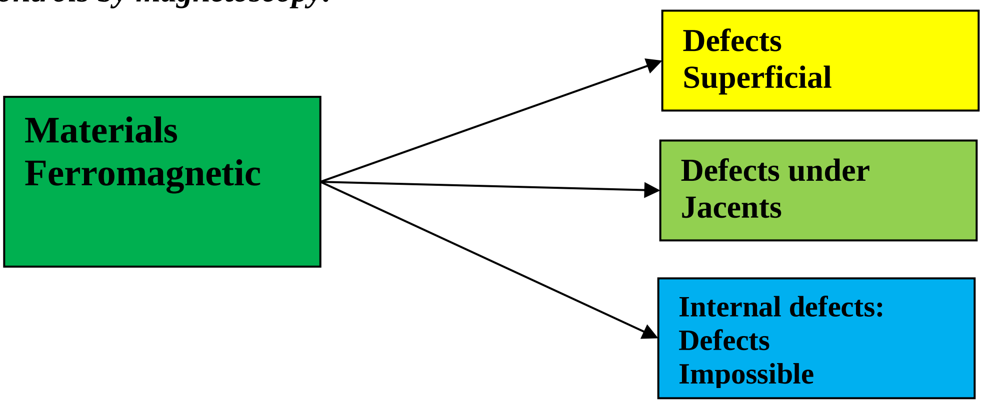
- The repair of tubes is carried out with coated electrodes.
- No repair is allowed within 150mm of the ends.
- Single pass welding repair is not allowed.

- No more than three (03) repair welds per tube are allowed, the distance between repair ≥ ½ Ø tube. A second repair of the same defect is not allowed.
- The total length repaired by welding shall not exceed the nominal tube diameter.
- Any tube repaired by welding shall be hydraulically tested after repair

Welded repairs shall be subject to manual ultrasonic testing or perform a combined automatic and manual US test.

Figure 25 : the defects of weld bead

5.8.3 Controls by magnetoscopy:



Also called "magnetization examination" this process is only applicable to Ferromagnetic materials: steel (except Austenitic), cast iron, nickel, cobalt.

Magnetocoscopy is used to detect defects on the surface of the weld seam, or even slightly underneath it, and is particularly useful for separating the weld seam from the weld after each gouging and grinding operation.

A magnetic contrast inspection is carried out to ensure that the defects indicated by the chamber have been completely eliminated.

The area to be repaired is checked by X-ray.

5.9 Bruching of the tube interior:

- The inner and outer weld shall be flush for a distance of 101.6 mm from each end in the direction of the tube Special care shall be taken to ensure that minimum thickness tolerances are met.
- The minimum thickness of the tube must be guaranteed after grinding.

Figure 26 :bruching of the interior of the pipes

5.10 Chamfering of the tube ends:

The tube ends are chamfered by machining sequentially with a :

1- 30° angle (+5. -0)

- 1.6 mm ± 0.80

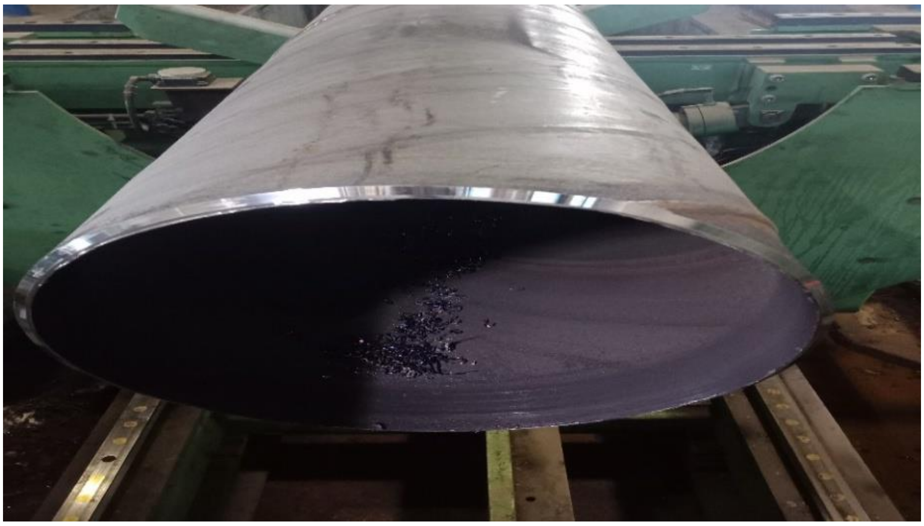


Figure 27 : chamfering the pipe

5.11 Hydrostatic test (pressure + holding time)

Each tube will undergo the hydrostatic test at the level of the installation related to this test. The results are automatically recorded and a graph is printed with the results for each test. The pressure holding time is at least 15 seconds.

Figure 28 :Hydrostatic test

5.12 Non-Destructive testing in manufacturing :

5.12.1 Ultrasound test

- ***Automatic ultrasonic inspection of the base metal:***

The body of the tube will be subject to an automatic ultrasonic inspection of 100% of the tube surface

- ***Automatic ultrasonic inspection of the tube ends:***

The base metal of both ends of each tube shall be automatically ultrasonically inspected over an area 30 mm wide from the ends

- ***Automatic* ultrasonic weld seam inspection:**

All tubes after hydrostatic testing shall be 100% checked.

The reference defect of the weld seam shall be in accordance with the customer's pipe specification and API 5L 46th edition.

- ***Manual ultrasonic weld seam inspection***

Each tube under repair must pass a manual US inspection in accordance with **API 5L** and customer specification.

Figure 29 : Ultrasonic test

5.12.2 Radiographic and radioscopic inspection:

Each welding defect detected by automatic ultrasound on the welding machine is subject to an initial X-ray radiography.

A second device serves as an x-ray of the end welds. Fluoroscopy uses a fluorescent screen to visualize the defects, while radiography uses x-ray films. These installations are isolated by a lead screen to protect personnel against X-rays…

- **X-ray inspection of tube ends, manual weld repairs and automatic US indications:**

This control is performed in accordance with **API 5L** for the following three cases:

- On the ends of all tubes over a length of 200 mm

- After each manual weld repair

On the part of the weld seam that has been subject to defect detection by the automatic ultrasonic machine

- **Requirements:**

The X-ray inspection of tube ends, manual weld repairs and automatic US indications.

Figure 30 :X-Ray inspection

5.13 Final control area:

At this stand, the following operations are carried out:

- Visual and dimensional control.
- Verification of the follower card of the tube, two cases can arise:
- The tube does not have any faults and the operations mentioned on the tracking card are carried out; in this case the tube receives a dispatch number and follows its way to the stockyard.

5.14 Pipe coating plant

This plant makes the coating of tubes externally by polyethylene and internally by paint.

Process of the exterior coating line:

- Drying
- External shot blasting
- Induction heating
- Epoxy resin coating
- PE coatin
- PE supply and adhesive agent
- Pipe cooling section
- Water removal
- Brushing of pipe ends
- Coating control by internal receiving table

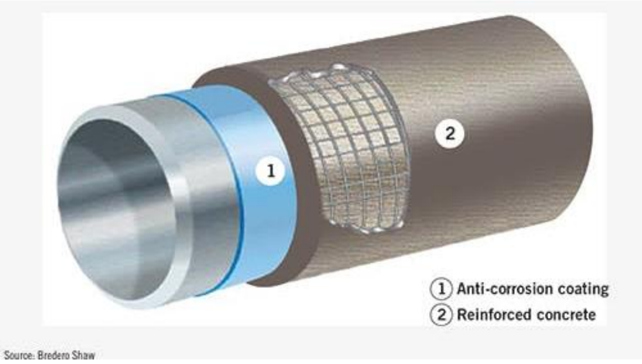


Figure 31 :Pipe coating

Interior Coating Line Process:

- Cleaning by karcher
- Drying by gas burner
- Tube shot blasting
- Interior painting
- Final inspection

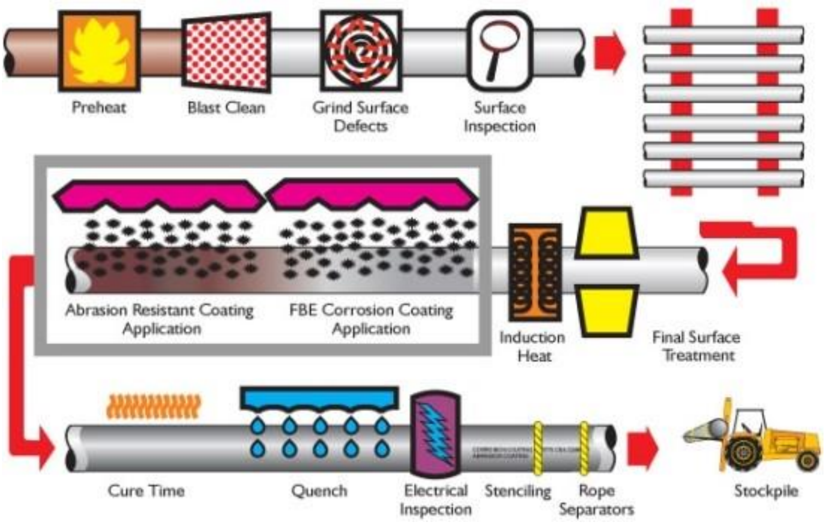


Figure 32 :pipe coating process

Chapter IV:

Non-destructive testing NDT

Chapter IV: Non-destructive testing NDT

1. Generality on NDT

1.1 Introduction:

Non-Destructive Testing (NDT) is a set of methods that allow to characterize the state of integrity of structures or materials, without degrading them, either during production, or during use, or during maintenance. The content of this course presents the techniques of non-destructive testing (NDT) most commonly used in industry. For each of the techniques, a presentation of the principles and methods of use is made at first. Then a more detailed approach (physical principles and basic equations) will be proposed. The presentation is also based on graphical illustrations often translating the equivalent of several pages of description and comments. This course also proposes test and evaluation activities allowing the learner to self-evaluate the mastery of the proposed content. Learning activities are also offered to learners. During these activities, the learner is called upon to deal with problems that will lead him/her to deepen the subject matter through research, analysis and synthesis. For some of these techniques, an overview is also given on the control equipment and its operation through a document of introduction to the TP. The objective of this course is to make students aware of the concept of non-destructive testing. This field is part of the general concept of quality assurance, it plays a key role in all applications requiring a minimum of safety and reliability (pipe, nuclear, aeronautics, automotive,). This course is an initiation that aims to show in a concrete way (based on practical work done on real parts) how and why these techniques are implemented.

The name Non-Destructive Testing naturally brings to mind the diagnosis that a doctor makes when examining his patient: the same principle applied to mechanical parts consists of implementing investigative methods that make it possible to judge "without destruction" the state of health of the parts and to formulate an opinion on their ability to perform the function for which they are intended.

Considered under this aspect of fitness for use, the definition supposes a good knowledge of all the phenomena involved, in particular the harmfulness of the defects, their evolution in time and the general laws of the mechanics of rupture.

In practice, the non-destructive testing specialists in charge of inspection are more confronted with problems of interpretation of the test results in relation to criteria established in conjunction with the designer of the part. In this spirit, the following definition of Non-Destructive Testing appears closer to the industrial reality: it is "to qualify, without necessarily quantifying, the state of a product, without altering its characteristics in relation to recipe standards".

In this sense, non-destructive testing (NDT) appears to be a major element of product quality control. It differs from laboratory and industrial instrumentation because the purpose is to detect heterogeneities and anomalies rather than to measure physical parameters such as the weight or dimensions of a part.

1.2 History:

Non-destructive testing (NDT) is a privileged field of application of the discoveries of physics. The history of non-destructive testing (NDT) began with the discovery of modern physics at the end of the 19th century: discovery of X-rays, eddy currents, piezoelectricity, etc. However, it was not until the Second World War that NDT techniques took their place in industry, particularly in metallurgy: control of steels, radiography of welds. A great development of NDT occurred in the 1960s/1970s with the rapid development of application sectors such as nuclear power plant engineering, civil aeronautics, gas and oil pipelines and off-shore platforms. The last decade has seen the emergence of NDT techniques that could not be implemented without the contribution of integrated electronics and powerful computing; we are then witnessing the rapid development of fully automated controls and the rise of techniques requiring computer processing, such as optical controls. At the same time, we find this same evolution in certain medical control techniques such as ultrasound, radiography... the basic physical principles are often similar to industrial techniques. The principle of the detection of a defect is to excite it and to collect its response. In all the methods used, we can distinguish the following steps:

- Implementation of a physical energy process,

- Modulation or alteration of this process by the defects,

- Detection of these modifications by an appropriate sensor,

- Signal processing and interpretation of the information provided.

NDT methods: the NDT methods used are:

1- Visual

2- Radiography (first applications of X-ray control in 1900)

3- Ultrasound (discovered in 1883 by Galton)

4- Dye penetration (practiced in 1930)

5- Magnetoscopy (principle attributed to Major W H Hoke in 1922)

6- Thermography

7- Acoustic emission

8- Eddy current

9- Oil analysis

10- Vibration analysis

1.3 Principe:

Two groups of detection methods can be distinguished schematically:

- The methods of flow, with an excitation and a detection of the same nature and for which the defect introduces a disturbance of flow which can be noted either directly in the transmitted flow (radiography) or the rediffused flow (ultrasounds), or by an effect of proximity (coil of probe with eddy currents, magnetic leakage flow), the great majority of the processes of the nondestructive control refer to this group of methods.

- The methods for which the excitation and detection are of different natures, each one putting in play an original and specific process; the most employed excitation is the mechanical solicitation; it leads to the techniques of analysis of mechanical vibrations or micro deformations (holographic interferometry) or to a technique of provoked emission of which the most known is the acoustic emission.

- The application of each method involves three distinct elements:
- The exciter element: often characterized by electromagnetic radiation, or a vibration and a magnetic field.
- The disturbing element: defined by the part and possibly by the defect it contains.
- The revealing element: provided either by the eye or by a system of sensors translating the reaction of the part into electrical signal

EXCITATION

(Wave, Vibration, Magnetic field, Penetrating ...)

⇩

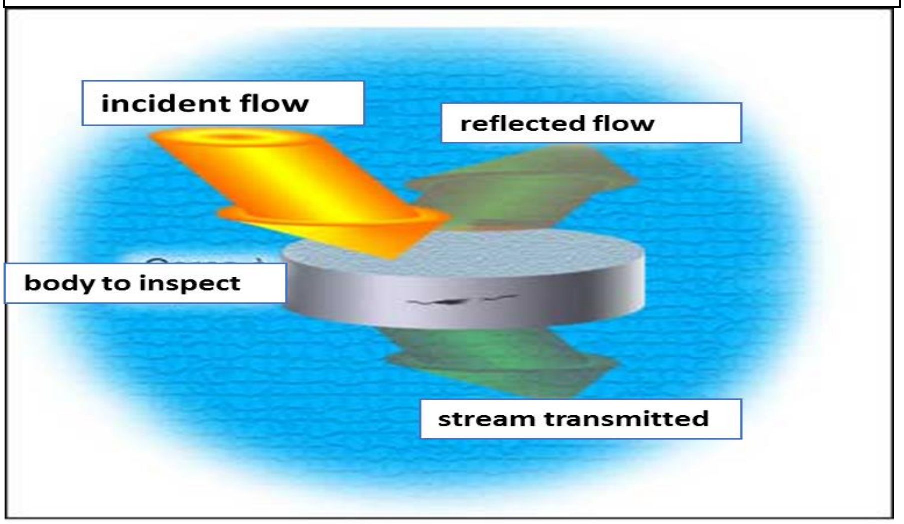
PERTURBATION

(Defect, Anomaly ...)

⇩

REVELATION

(Eye, imagery...)



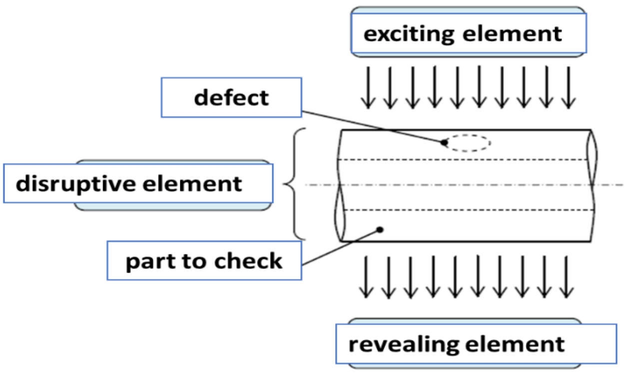


Figure 33:Principle of NDT

For each method and in accordance with the rules of quality assurance, a procedure must be put in place to ensure the reliability and reproducibility of the examination, as well as the location, identification and characterization in size and nature of the defects, their classification and presentation, and finally the decision as to the allocation of the product with archiving of the results and the conditions under which the examination was performed. This requires, in each case, the development of a procedure specifying the operations of calibration, acquisition and data processing.

1.4 Fields of application:

Non-destructive testing is essential for manufacturing industries that implement or use different materials, products and structures of all kinds. Today, the field of application of NDT continues to expand; these techniques are even becoming essential tools in the quality approach of:

- the automotive industry (engine block control);
- the oil industry (pipelines, welds, tanks)
- the naval industry (control of hulls)
- aeronautics (aircraft wings);
- the energy industry (reactors, boilers, turbines)
- the railway industry (axles, wheels);

The nature of the defects to be detected is very variable. We are looking for specific technological defects, such as those inherent to the manufacture and use of metals (fatigue cracks), but also appearance defects (stains on a clean surface) and harmful foreign bodies (glass fragments in a food package). For a given product, we can consider that the non-destructive testing intervenes at three different stages of the life of the product:

- The control during the manufacturing process. The system used in this case is often automated this requires an equipment installed and operating in manufacturing line. In this case, we try to satisfy both the criteria of robustness, with the speed of the reaction and a low operating cost. The defects are generally well identified, the operation is automatic, leading to a detection or a sorting of the defective products. When the defect detector cannot be installed on the production line, inspection benches are used in the industry, often corresponding to large equipment in terms of size and cost.

- The control at the reception of a batch of parts, an installation or a work, allows to verify the respect of conformity with the specifications of quality defined beforehand. At this stage, it is a question of detecting defects but also very often of defining their nature and dimensions.

- The in-service inspection is performed on parts or structures during maintenance operations or following the detection of anomalies in the behavior of the material. For this type of inspection, it is necessary to be able to estimate the nature and dimensions of the defects as well as possible in order to be able to assess their seriousness; it is also necessary to have a good reproducibility of the non-destructive examinations, in order to be able to follow the evolution of the damage over time. NDT techniques will certainly continue to expand their field of application to new sectors of economic activity. It is no longer enough to detect a defect; it is also necessary to characterize and dimension it. It is also necessary to imagine non-destructive techniques and processes capable of revealing complex physical heterogeneities or irregularities in properties such as, for example, variations in the microstructure of a metal, variations in the texture or roughness of a surface, or variations in the electromagnetic properties of a strip. These objectives are often difficult to achieve, and progress is slow. The same is not true for the automation of NDT, which benefits fully from advances in information technology. The result is that, year after year, more efficient, more reliable and, above all, easier-to-use equipment is being put on the market in compliance with very strict control procedures. However, the development of NDT must take into account the cost aspect, which can slow down the development of new high-performance techniques, as is currently the case for X-ray tomography for example

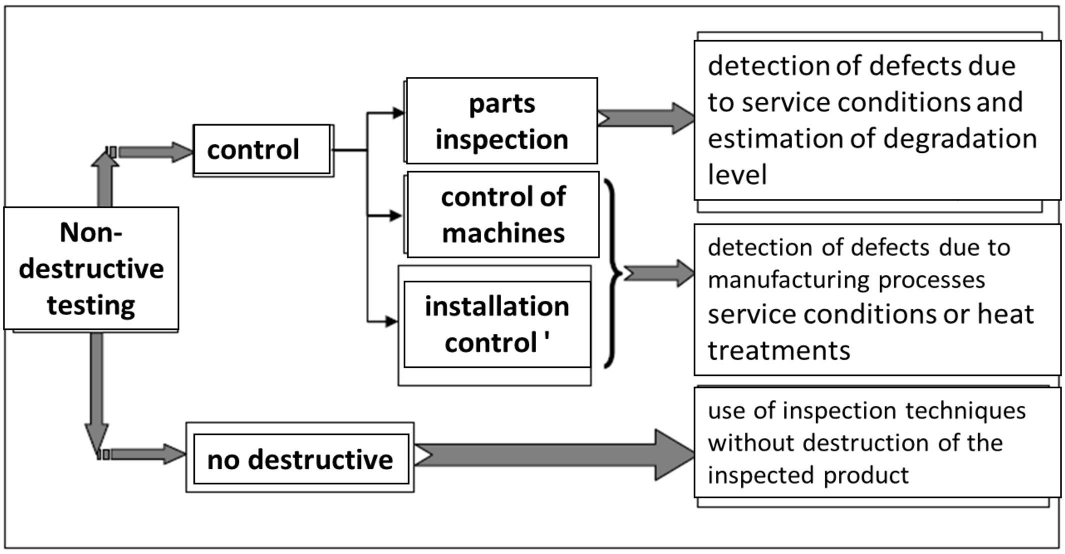


Figure 34: Scope of the NDT

1.5 Classification of NDTs:

- External defects: Apart from the visual examination or the search for defects with a magnifying glass, we have other simple and effective methods at our disposal, such as the penetrant liquid test (dye penetrant test) or the magnetic test (magnetic particle test).

- Internal defects: The non-destructive examination of internal defects is mainly performed with X-rays and ultrasonic waves.

Basic types of non-destructive testing methods include contact and non-contact methods. Applications for testing and evaluating composites. Most NDT techniques require good contact between the sensor and the composite surface under test to obtain reliable data. Contact methods include traditional ultrasonic testing, vortex testing, magnetic testing, electromagnetic testing and dye penetrant testing. Another approach to speed up the data collection process is to eliminate the need for physical contact between the sensor and the structure under test. Non-contact methods include: transmission ultrasonics, radiographic testing, visual inspection, optical methods (thermography, holography or shearography, for example).

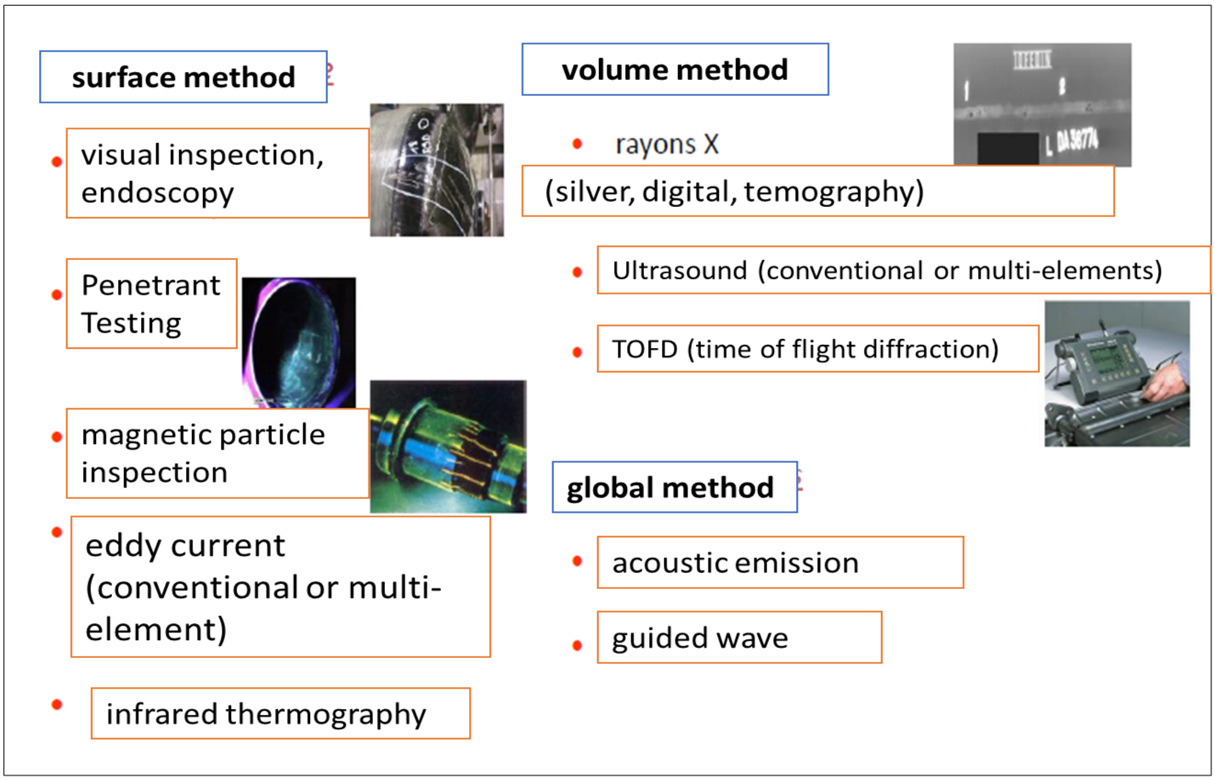


Figure 35:Classification of CND methods

The most commonly used NDT techniques can be classified into two main families, closely related to the location of the defect on the part under examination:

- Surface methods: for which the defect is located on the external surface and among them: visual examination, penetrant testing, magnetic particle inspection or eddy current.
- Volumetric methods: for which the defect is located in the volume of the part and among them: ultrasound, ionizing radiation, thermography or acoustic emission.

1.6 The main defects in materials

When a metal or metal alloy is deformed, it first goes through a plastic deformation regime and then through a ductile damage regime. The ductility of a metallic material is characterized by its ability to deform plastically without damage or failure.

The damage represents surface or volume discontinuities. The initial causes of damage are the accumulation of dislocations in metals that modify intermolecular bonds or cause micro-decohesion's, resulting in micro-cavities or cracks.

Among the most frequent causes of failure in parts are progressive cracks caused by forces that induce significant stresses in the part. The presence of a defect that locally reduces the resolution of the part to these fatigue stresses is particularly harmful by promoting the birth of the crack.

1.6.1 Manufacturing defects

1.6.1.1 Defect due to the chemical composition of the molten metal

These are essentially micro-inclusions with dimensions less than 100 µm. These inclusions generally result from reactions of the elements constituting the alloy in the liquid state with impurities such as oxygen, sulfur, and nitrogen to form:

- Oxides,
- Sulfides,
- Nitrides.

1.6.1.2 Defects related to the solidification process

a/ Segregation

This phenomenon has already been mentioned in the chapter "General metallurgy". It takes place during solidification and leads to an enrichment in impurities (sulfur in particular) of the liquid metal as the less "fusible" elements solidify. Segregation can occur at two scales:

- at the grain or dendrite scale: this is minor segregation. This can lead to hot cracking or to liquation phenomena.
- on the scale of the ingot or the piece: it is the major segregation. The last solidified parts of a piece are then made of a metal more impure than the average composition of the piece.

b/ Reversals

The shrinkage that occurs during solidification is the cause of shrinkage. Indeed, the passage from the liquid state to the solid-state results in a decrease in volume (about 3% for a steel with 0.35% carbon).

The design of a casting must therefore take into account this phenomenon in order to :

- to supply the shrinkage of the metal constituting the future part,
- to localize the shrinkage in the areas that will be dropped.

Feeder weights allow a better control of the solidification of a casting. However, local variations in the mass of the part (thickness variation) can lead to the formation of inter-dendritic micro-shrinkage.

c/ The creeks

These are intergranular cracks that develop under the action of shrinkage stresses after solidification of a part of the part. These defects, generally superficial and not very deep, appear:

- In particularly stressed areas (connection radii, interior corners),
- In segregation bands with basaltic solidification.

Some central parts are also the seat of inter-dendritic micro-cracks due to shrinkage stresses hindered by the rigidity of the solidified outer layers and possibly amplified by allotropic transformations.

1.6.1.3 Defects related to the production process (CASTING, MOLDING)

a/ Blows and stings

These are gas bubbles trapped in the metal during solidification. The gas can come from :

- From the "effervescent" character of the steel (CO),
- From the mold or a foundry core (H2, H2O, N2),
- Variation in the solubility of gases dissolved in the metal.

Blowholes are internal defects and are of endogenous nature (related to the quality of steel).

Pitting is a surface defect and is exogenous (from the mold or the atmosphere).

These defects can have three main configurations:

- Spheroidal, small diameter (about 1 mm), quite numerous and localized in the vicinity of the skin.

A heat treatment and sandblasting can make them unlockable.

- Ovoid and sometimes a few centimeters long, oriented perpendicular to the surface,
- Of any shape (rounded), sometimes associated with slag or pits.

b/ Macro-inclusions

They are differentiated from micro-inclusions by their exogenous nature and size. They are generally oxides coming from:

- oxidation of the liquid metal during its production (furnace, ladle, casting, mold),
- the possible entrainment of refractory lining (furnace, ladle, mold), slag or sand,
- elements added for calming.

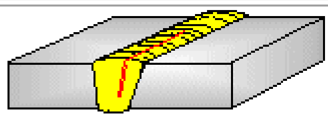
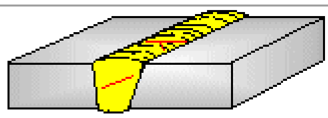
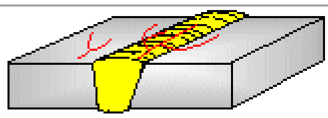
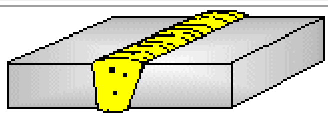
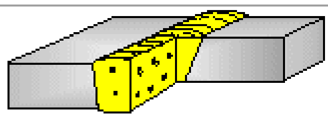
Composition: FeO, MnO, SiO2, Al2O3, CaO. Their dimensions are generally superior to the millimeter. Macro-inclusions detectable by classical CND methods...

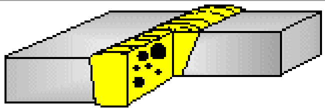
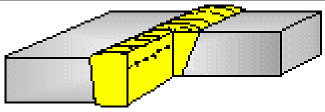
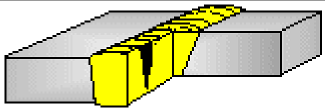
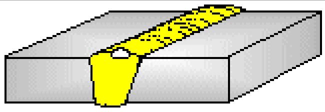
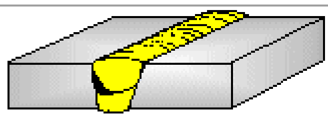
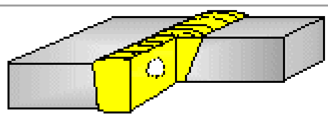
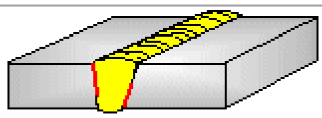
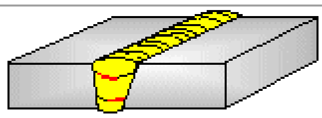
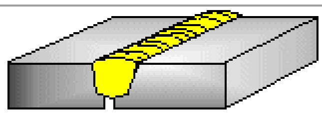
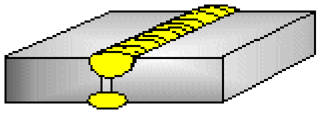
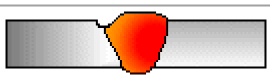
c/ The flakes

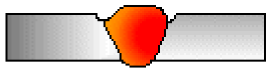
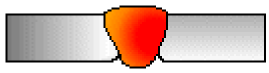
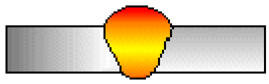
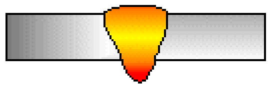
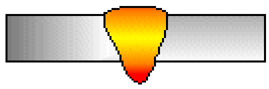
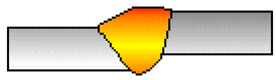
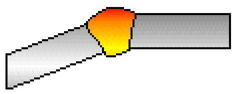
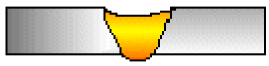
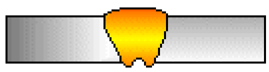
These are cracks that appear during cooling, in the solid state, as a result of local stresses due to shrinkage during the allotropic transformation $\gamma \rightarrow \alpha$. Segregations, as well as hydrogen, promote the appearance of these defects by locally weakening the material. These defects are called flakes because of their characteristic appearance in the form of circular spots of 1 to 3 mm in diameter, radiating around a crack

1.6.2 Defects in welded constructions:

Table 2 : table of welding defects

Number	Designation	Illustration	
GROUP N° 1 - Cracks			
101	Longitudinal cracks		
102	TRANSVERSE CRACK		
103	RADIANT CRACKS		
GROUP N° 2 - CAVITIES			
2011	SPHEROIDAL BLAST		
2012	EVENLY DISTRIBUTED BLOWINGS		

2013	NEST OF PUFFS		
2014	ALIGNED BLAST		
2016	VERMICULAR BUFFER		
2017	STING		
GROUP N° 3 - SOLID INCLUSIONS			
301	SLAB INCLUSION		
304	METAL INCLUSION		
GROUP N° 4 - LACK OF FUSION			
4011	LACK OF EDGE BLENDING		
4012	LACK OF BLENDING BETWEEN PASSES		
GROUP N° 5- LACK OF PENETRATION			
402	LACK OF PENETRATION		
402	LACK OF INTERPENETRATION		
GROUP N° 5 - SHAPE DEFECTS			
5011	GUTTER		

5012	BITE		
5013	ROOT CHANNEL		
502	EXCESSIVE EXTRA THICKNESS		
504	EXCESS PENETRATION		
5041	DROP OR LOCAL EXCESS PENETRATION		
507	ALIGNMENT DEFECT		
508	ANGULAR DEFORMATION		
511	LACK OF THICKNESS		
515	ROOT REASSURANCE		

1.6.3 Faults occurring during operation

1.6.3.1 Fatigue defects

In case of accumulation of a certain number of cycles associated with a stress "σ" of a certain amplitude, a micro-cracking starts in one or more points of the test specimen or the part (in particular from the notches or pre-existing defects). This small crack(s) gives rise to a fatigue crack that propagates. If the cyclic loading is interrupted, the crack propagation also stops and starts again, when the loading is again applied away from the point of origin. Thus, a fatigue crack occurring in service usually presents, on the fracture face, a series of stop lines whose concavity is mostly turned towards the point of origin. The origin of the fracture and its subsequent propagation can thus be identified. The final failure does not always occur in service because it is sometimes possible to take remedial measures before this stage is reached. The important characteristic of fatigue cracking is that, when the load is maintained, it progresses with little or no deformation and may not be easily detected by visual examination.

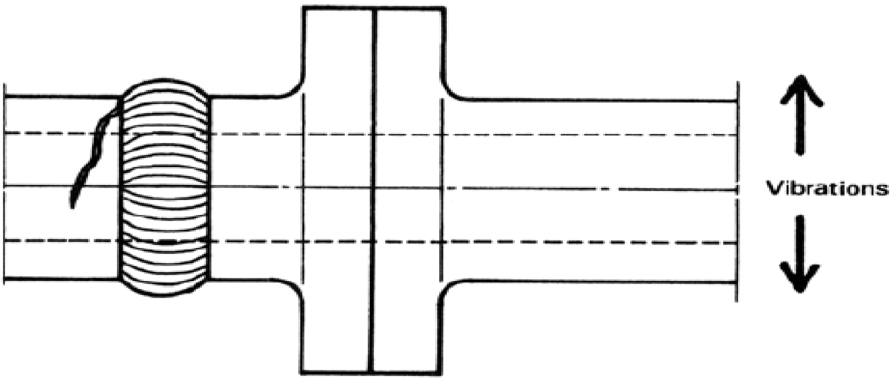


Figure 36:Crack at the right of a notch effect under the effect of vibrations

1.6.3.2 Corrosion phenomena

- Stress corrosion cracking

Generally, these branched cracks are oriented perpendicular to the direction of the tensile stresses. In welded assemblies, they develop on the corrosive side and generally under stress concentration due to sheet forming, residual welding stresses or service stresses. This phenomenon appears only for certain couples of materials/corrosive media. The temperature of the corrosive environment also plays a very important role.

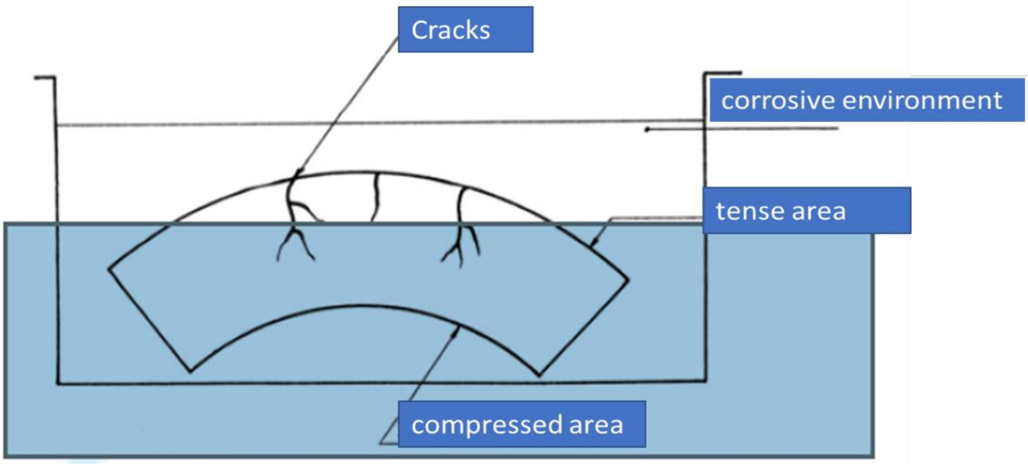


Figure 37: Development of cracks in the tensioned zone of a bent part in a corrosive environment

1.6.4 Heterogeneities and defects

The term defect is ambiguous, relative and not very precise, but its negative connotation evokes well the role that non-destructive testing plays in the search for quality. In fact, to detect a defect in a part is physically to highlight a heterogeneity of material, a local variation of physical or chemical property detrimental to the good use of it. That said, we usually classify defects into two main categories related to their location: surface defects, internal defects.

1.6.4.1 Surface defects

Surface defects, accessible to direct observation but not always visible to the naked eye, can be classified into two distinct categories: point defects and appearance defects.

a- Punctual defects: which correspond to the most harmful defects from a technological point of view, since they are cracks, pits, fissures, cracks, generally capable of causing the failure of the part in the long term, by initiating fatigue cracks for example. In metal parts, the thickness of these cracks is often very small and they can be harmful as soon as their depth exceeds a few tenths of a millimeter, which implies the use of sensitive non-destructive methods for their detection, such as dye penetrant testing, magnetic particle inspection, eddy currents, ultrasound.

b- The defects of aspect: which correspond to areas in which a variation of geometric or physical parameters (roughness, excess thickness, various stains) attracts the eye and makes the product unusable. Here, visual control is possible, but we are trying to replace it by automatic optical controls.

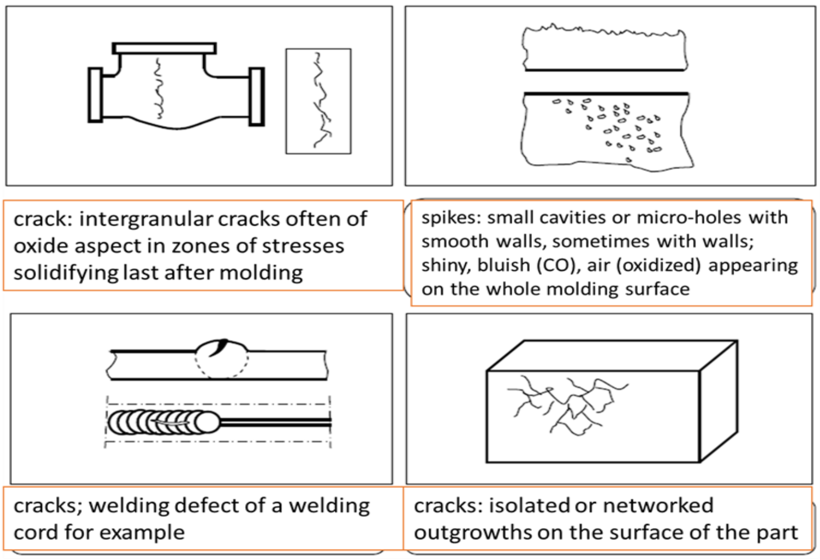


Figure 38:Defects

Chapter V:
Damage and repair technology of pipelines

Chapter V: Damage and repair technology of pipelines

1. Introduction

Pipelines are transported to construction sites for operation. After that, the so-called damage starts to occur. Studies have been carried out in the context of monitoring the harmfulness of surface defects in pipelines **[10,11]**

- At the time of transportation, pipelines are subjected to oscillations which can cause microscopic cracks in the material.
- At the time of pipe assembly, welds made on site can present cracks because they are sometimes made under difficult conditions and may not be controlled (lack of material penetration).
- During maintenance operations, by carelessness, a machine hits the pipeline, generating a deformation called, depending on the case (scuffing, denting or combined (scuffing + denting)
- Depending on the case of the pipeline (buried or aerial), the environment has a harmful influence by causing the corrosion phenomenon.

2. A little history on the Methods for evaluating pipelines with defects

The effect of defects in structures has been studied qualitatively since the **15th** century by Leonardo da Vinci. He measured the elongation force of an iron wire, and observed that the elongation force of the wire was greater for a short wire than for a long wire. He introduced the concept of volume distribution of defects.

In **1920**, **Griffith** first published a formula relating the stress at break to the size of irregularities (defects). This relationship was derived from a simple energy balance from an earlier analysis of stresses at an elliptical hole and the first law of thermodynamics. However, this work is only applicable to perfectly elastic materials.

Prior to the **1950s**, structural engineering did not take into consideration the presence of cracks, as they were considered unacceptable in terms of quality, without having been quantitatively evaluated.

In the **1950s**, there was a major interest in the aeronautical industry in the United States, especially for the failure of aluminum alloys, and in the **1960s**, this interest moved to the risks of failure in nuclear power plants. This will lead to the development of This led to the development of elastoplastic fracture mechanics using various approaches (stress intensity factor (K), J-integral and crack gap (CTOD)). The 1950's and 1960's were also a time when the safety of oil and gas pipelines began to be of concern to oil companies, primarily in the United

States due to the size and aging of these pipelines. The first research on the failure of pipelines with defects was done by John **F. Kiefner** et al. at the Battelle Institute **[12].** The majority of this work was based on pipe burst tests. The main objective of this work was to provide and understand the relationship between burst tests and the size of the defects detected. As a result of Kiefner's work, the **ASME 1 / ANSI 2 B31G** code, "Manual for Determining the Remaining Strength of Corroded Pipelines" was first published in **1984** in the United States. It was modified and republished in **1991.**

3. Different types of defects That can lead to pipeline failure

Pipelines are widely used for the transportation of fluids and gases because they are currently the most economical mode of transportation. The increase in diameter and operating pressure increases the risk of rupture initiated by defects. The presence of a defect in a pipeline associated with the effect of internal pressure can cause a localized rupture leading to a leak and possibly an explosion. Generally, for pipelines, the following defects are distinguished: corrosion craters, cracks, dents, scratches and the so-called combined defect (dents + scratches) **[13].** In this chapter we present a collection of different defects happened in the pipe as well as methods of renovation and repair of structures. What interests us most is cracks.

4. Methods of repair (rehabilitation) of pipelines.

After the assessment of the damage, the choice of the type of repair will be made according to

- The geometry of the pipe (diameter, bending, etc.)
- The grade of steel used in the manufacture of the steel.
- The location of the pipe.
- The operating conditions.
- The location of the defect.
- The nature and size of the defect

- Thus, we have a wide range of repair techniques. We can cite the main techniques of repair by composite patch such as:

- repairs by bonding
- Repair system by reinforcement of composite fibers

- However, there are other repair techniques such as
    - Grinding method
    - Drilling method
    - Welded half-shell repair
    - Re-coating
    - Cutting and replacement after draining. **[23]**

5. Pipelines problems:

5.1 Corrosion phenomenon

5.1.1 Definition of corrosion

Corrosion is generally defined as the destruction of metals that occurs as a result of chemical or electronic reactions when they are in contact with a gaseous or aqueous medium. **[14]**

Corrosion is a natural phenomenon, metals industrially elaborated from an ore as a result of often complex operations, tend when left to themselves to transform into more and more stable chemical compounds. The vast majority of corrosion problems encountered are related to the presence of liquid water in contact with metals.

Figure 39 : Corrosive attacks on the external wall of a metal pipe

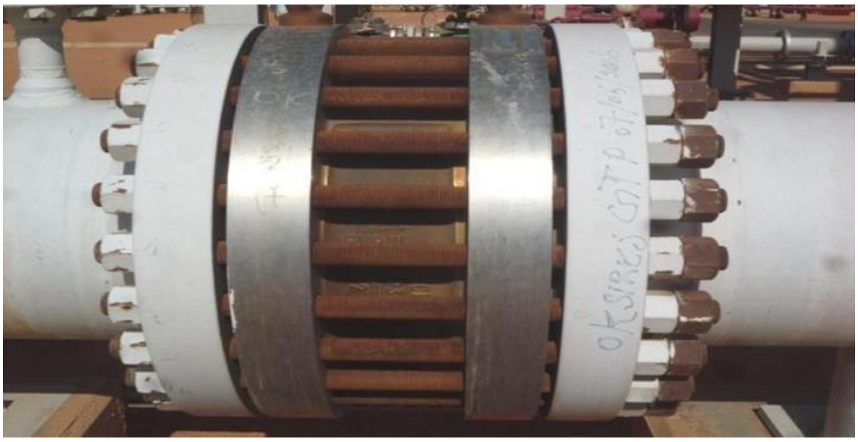


Figure 40 : Galvanic corrosion **[15].**

5.2 Welding defect

There are several types of weld defects as an example: crater, crack, arcing, Bits / Gaps, inclusions, lack of fusion, porosity ... etc... In our work, we will extend our study on the defect crack that is a defect cannot be underestimated because with time it will cause a degradation such as piercing.

5.3 Cracks

The appearance of cracks is a phenomenon that all constructions are confronted with during their life in service in the field for which they have been implemented, and that is regardless of the type of material used. For obvious economic reasons the prospect of repairing them is very desirable, in order to avoid financial losses due to the decline in the quality of the service.

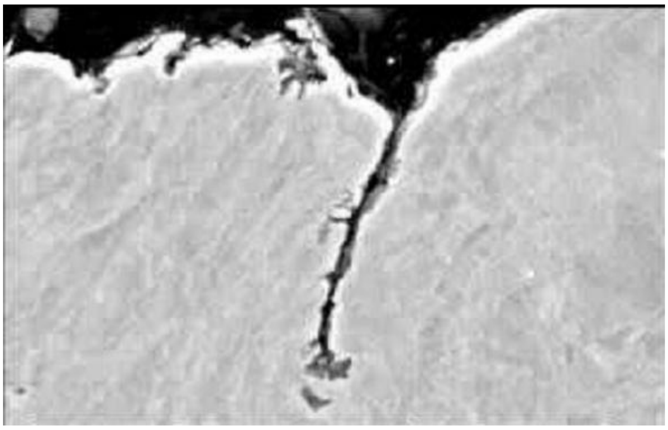


Figure 41: Crack in welded joints [**14]**

5.3.1 General:

Cracks are one of the most common welding defects. They are caused by the presence of excessive internal stresses inside the welded metal. The use of a filler metal incompatible with the base metal, an undersized bead or internal stresses created by shrinkage can cause cracks. The right choice of filler metal, appropriate preheating, good preparation of the joints and the formation of a bead respecting the required dimensions can therefore prevent cracks. Cracks in a metal are divided into two categories depending on where they appear: – Cracks can be located in the molten metal; they then depend on the nature of the filler metal and the conditions of execution of the weld. – Cracks can also be found in the base metal, in the bonding zone; the latter are generally related to a lower weldability of the metal. Two types of cracking can also be distinguished depending on when they occur following a weld: hot cracking and cold cracking.

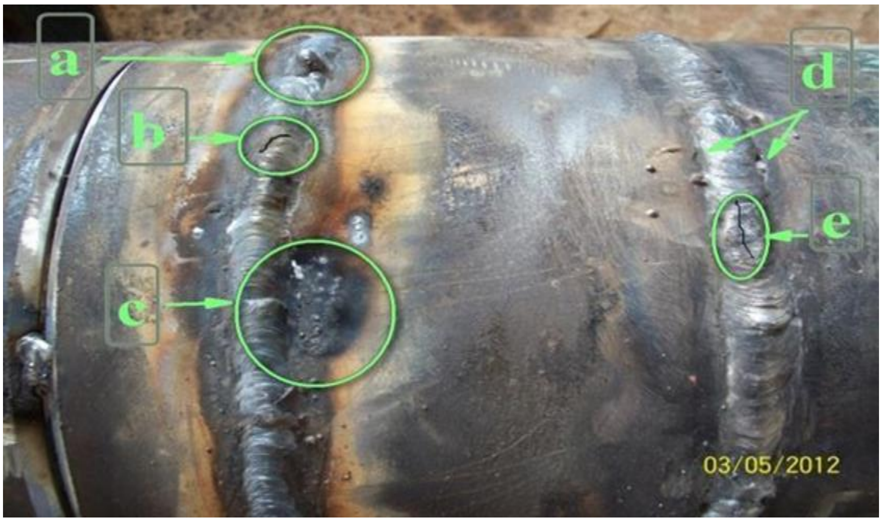


Figure 42: Weld seam with defects (crater, bites/channels, crack, Arcing initiations). [11]

5.3.2 Hot cracking:

Is due to the presence between the grains of a liquid film of iron sulfide or phosphorus during the shrinkage at solidification. This phenomenon results either from a solidification spread over a wide temperature range and thus to the late solidification of the elements having a low melting point, or from an inadequate bead shape or clamping, or from a welding speed too high. This type of defect is characterized by wide, open cracks, perpendicular to the solidification waves and generally oxidized inside.

The risk of hot cracking can be reduced by minimizing the clamping to facilitate shrinkage, by adjusting the welding parameters and especially the voltage and current, or by reducing the welding speed. Another possibility is to choose alloys with low carbon, phosphorus and sulfur content **[11].**

5.3.3 Cold cracking:

Is mainly due to hydrogen dissolved in the molten metal and diffused into the ZAT. In the vicinity of the molten metal, water decomposes and dissolves in large quantities (4 cm3 for MIG welding). During cooling, its solubility decreases and the hydrogen gathers to form H2 molecules and then blows. Due to the diffusion, the gas pressure will tend to increase and cause the appearance of cracks in the less ductile areas such as the overheated part of the ZAT. These cracks form at low temperature, often several hours after welding, most often in the heat affected zone. They are thin, non-oxidized and perpendicular to the directions of maximum stress.

In order to reduce the risk of cracking, it is important to minimize any hydrogen intrusion, either before, during or after welding. Welders often use preheating or post heating in this case. It is also possible, although more difficult, to reduce the stress level, either by relaxing residual stresses, creating favorable residual stresses or by improving the connection geometry.

5.3.4 Crack Orientation:

Cracks can be described as longitudinal or transverse, depending on their orientation. When a crack is parallel to the axis of the weld, it is called a longitudinal crack, regardless of whether it is a center crack in the molten metal or a crack in the heat-affected base metal joint area.

- Longitudinal cracks:

In small welds between large sections are often the result of high cooling rates and residual stresses. In submerged arc welding, they are usually associated with high welding speeds or may be related to problems with unseen porosities in the weld surface. Longitudinal cracks in the heat affected zone are usually caused by dissolved hydrogen.

- **Transverse cracks:**

Are perpendicular to the axis of the weld. These may be limited in size and contained entirely within the weld metal or they may propagate into the adjacent heat-affected zone and then into the base metal from the weld metal. In some welded joints, transverse cracks form in the heat-affected zone and not in the weld. Transverse cracks are usually the result of longitudinal shrinkage stresses acting on the low ductility molten metal. Hydrogen cracking of the melt can be oriented in the transverse direction (Figure 3.36)

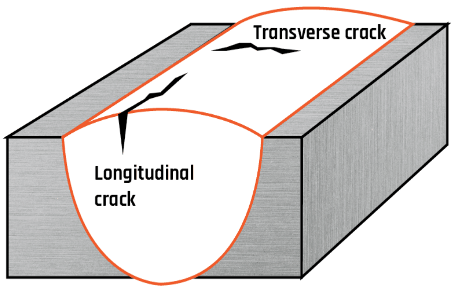


Figure 43: Types of cracks

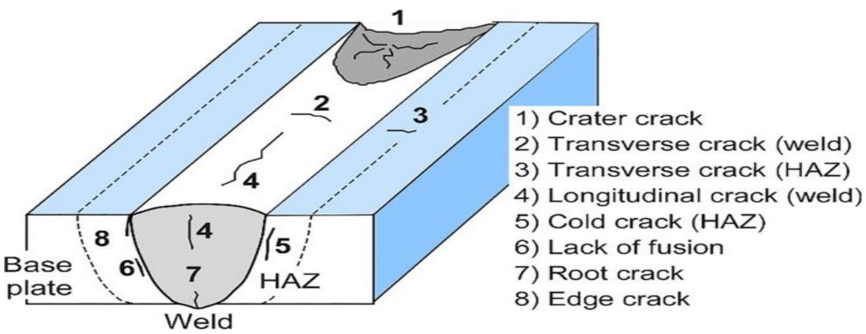


Figure 44: Different types of cracks **[11].**

5.4 Scratch

A scratch is a superficial damage of the surface due to a contact with a foreign object which causes a removal of material. This scratch can be considered as a notch. The dimensions of a scratch are defined so that the length is greater than the width. The worker's tool causes an impact (e.g., a pick) or a piece of equipment (e.g., a bucket tooth impact); most of the time, the incident goes unnoticed or is simply not reported.

Figure 45: Example of a pipeline containing a notch [**1*6*].**

5.5 Indentation

A dent in a pipeline is a permanent plastic deformation of the circular section of the pipe wall due to an impact with a foreign body (e.g.: the bucket of a machine during work for buried or land-laid pipelines, ship anchors for submerged pipelines).

In other words, a dent is a change in the curvature of the pipeline wall without a change in thickness. The depth of this dent is defined as the maximum reduction in the diameter of the pipe from its original diameter.

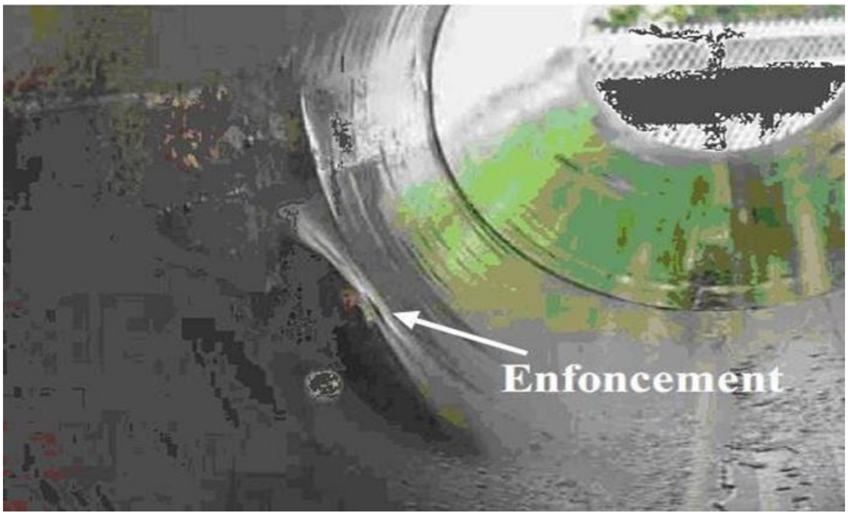


Figure 46 : A depressed pipeline [17].

5.6 Combined damage (scuffing + denting)

This type of damage is very dangerous because it results from the concentration of stresses caused by the external aggression (denting) and the reduction in the thickness of the pipeline (scuffing), which leads to a local reduction in mechanical strength. As a result, there is a local decrease in the mechanical strength of the pipeline. (See figure 47 and 48)

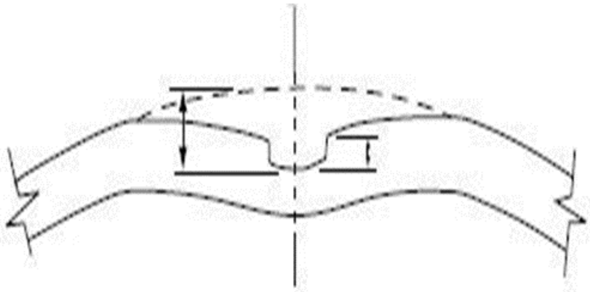


Figure 47: Geometry of a combined defect Figure

Figure 48: Photo of a scratch in an indentation

6. Inspection and maintenance of pipelines in service

The inspection and maintenance of pipelines in service is a multidisciplinary field, combining three technological sectors: Inspection, Materials and Mechanics **[18].** These three sectors are presented with their various functions.

These three sectors are represented by the vertices of the triangle. the inspectors are the eyes and ears of each operational unit; they examine, look at, and collect critical data at the end of the inspection. They examine and specify the type and procedure for repair. Materials specialists represent the second sector, they have knowledge of the different materials used as well as their different mechanical and physical properties to optimize their choice.

The third and last sector is the mechanical sector, its objective is to evaluate the stresses to which the pipes are subjected by means of various analytical and theoretical techniques and theoretical techniques available today (e.g finite elements, fracture mechanics, limit analysis fracture mechanics, limit analysis, ...). The economic and safety needs have led researchers and engineers to conduct and engineers to carry out very thorough studies in this perspective in order to make a more precise evaluation of the evaluation of the harmfulness of the defects encountered in the pipes.

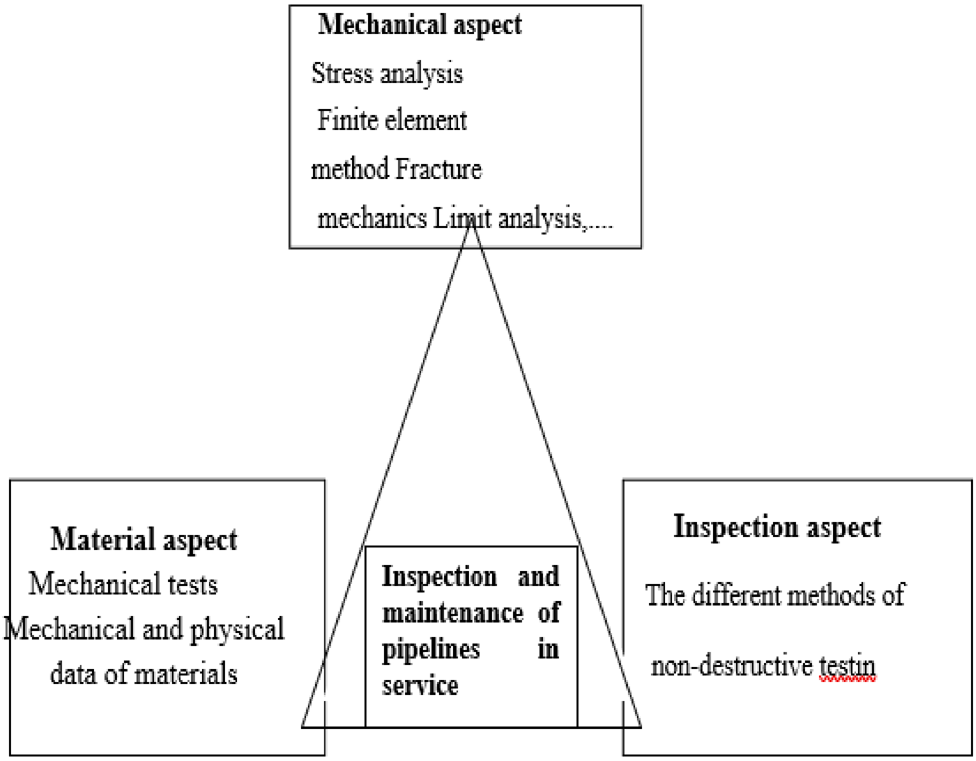


Figure 49 :Pipelines in service

6.1 Pipeline repair method

Faults in pipes can be repaired by various methods. Those that have been Those commonly used by pipeline operators are as follows:

- The removal of a section of pipe and its replacement with a new pipe.

- Grinding of an anomaly in order to significantly reduce its effect as a stress concentrator or crack initiation site. crack initiation site

- Reinforcement of a defective section of pipe using a peripheral sleeve.

Placing a sealed pressure containment device (clamp or sleeve) over a defect, including one that is leaking:

• Applying a composite wrap over corrosion and blunt wall-loss defects

• Applying deposited weld metal in a defect to fill it with new material

• Placing a patch or sole (partial encirclement reinforcement device) over a defect

• Hot tapping to remove a defect Descriptions of these methods are provided in this manual for the benefit of those who may not be familiar with one or more of them. Throughout this manual, we refer to temporary repairs. For our purposes, a temporary repair is a repair that will be reevaluated within a period specified by the pipeline operator's written procedures. Any repair that is left in service for a period greater than five years, without being reexamined, should be considered to be permanent.

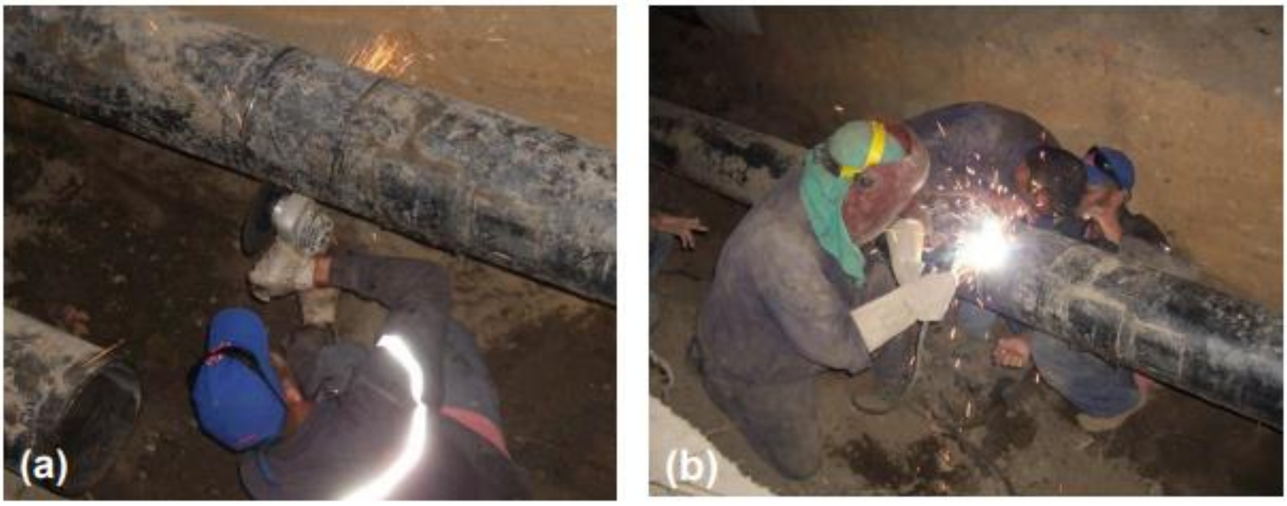


Figure 50 :Pipeline repair method

Pipeline Research Council International...

7. Different repair methods

7.1 Re-coating

This type of repair is performed in the case where the coating has been affected or after an intervention on the intervention on the pipeline to restore its original insulation.

Figure 51: (a) surface repair for recoating, leakage of bentalha (Oran, Algeria), (b) re-coatin

7.2 Cutting and replacement after draining and inerting

This method is recommended when the damaged part loses the mechanical properties for which the pipeline was designed.

The rehabilitation consists of a partial change of the pipe line. Given the high cost of this operation, it remains the final solution to repair the damaged structure. damaged structure.

7.3 Repair of structures with composite patches

For almost two decades, composite materials have been used to repair and strengthening of transmission pipelines. This effort has been accompanied by an extensive selection analysis and testing programs by pipeline operating companies, research organizations, and organizations, and designers .

Composite materials have been used for the repair of pipe structures and other equipment for many and other equipment for many years. However, the original use of composite materials was to repair corroded pipes where the intent was to restore strength to the damaged section of the pipe. In addition to repairing corrosion, composite materials have been successfully used to repair nicks, bends, elbows and bends, elbows and offshore pipelines. Today, most pipeline operating companies pipeline operating companies are primarily using composite materials in rehabilitation and repair rehabilitation and repair programs

Figure 52 : composite patches repair

7.4 A Repair by bonding

Composite materials are high-performance materials made up of a microscopic combination of several materials with complementary characteristics. This makes it possible to combine a set of mechanical or physical properties that would be impossible to obtain with the components taken in isolation. In addition to the weight saving, another advantage of composite materials is the multifunctional character that is conferred to them by their orthotropic properties. They are indeed more widely used as knowledge about the manufacturing process, their mechanical and physical characteristics as well as their durability and behavior under load accumulates. In our case, we will focus more on fiber and resin composites. The characterization of fiber and resin composite materials is generally complex. Unlike metallic materials that require a relatively small number of tests, fiber-resin composites are characterized by the need for a multitude of tests to achieve mechanical characteristics. The following figure shows the composite repair of a steel pipe **[23].**

Figure 53: Composite repair of a steel pipe

8. Other methods of emergency repairing metal structures

It is well known that the singularity at the tip of a defect (crack, notch) contributes to accentuate its progression. This tends to reduce the life span of damaged structures. One of the most common techniques to repair the adverse effects of a defect, is to remove this singularity by eliminating this singularity by removing material **[19-20].** In this case we find the molding and drilling in the vicinity of the defect

8.1 Drilling methods

The drilling of a hole at the bottom of a crack allows a temporary stop of the propagation of the crack propagation. This method is based on the geometrical modification at the bottom of the crack. It is a widely used method for the repair of damaged metal structures. It is carried out with the aim of increasing the service life, which leads to a reduction of the maximum stress (figure 54). This technique has several advantages it is simple to perform, reproducible and can be used for structures that are only accessible from one side. accessible only from one side. It allows to keep the structure in service while waiting for a possible change of the damaged part. The initiation of the crack is delayed by the drilling of the crack initiation is delayed by the drilling of the hole and the service life increases with the increase of the hole diameter. The drilling one or more holes around the defect is another method proposed by several researchers to researchers to repair the cracked structure.

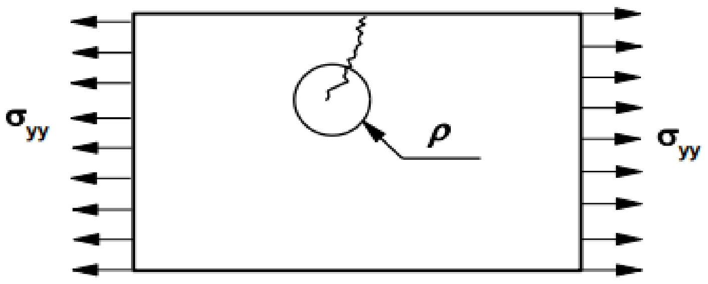


Figure 54 : drilling at the bottom of the crack

This repair process causes the delay in crack propagation. A larger hole radius reduces the stress concentration factor, but attention must be paid to the reduction of the decrease in the cross-sectional area of the remaining ligament.

8.2 Repair by grinding

M.Belalia et al [7] proposed a solution based on the modification of the geometry of the defect (figure 51). This is a geometry treatment that improves the defect profile by eliminating existing cracks and reducing the concentration of related stresses.

Figure 55:Scratch removed by grinding [7]

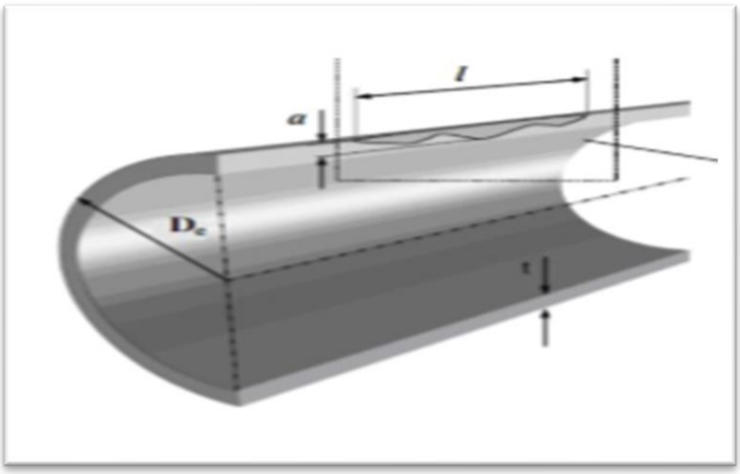


Figure 56 : Geometry of a corrosion defect in a pipeline according to ASME B31 **[13]**

9.2.1 Grinding method

This repair technique is based on the principle of eliminating defects by material removal, (figure 57). It allows to eliminate the singularity created by the front of the crack.

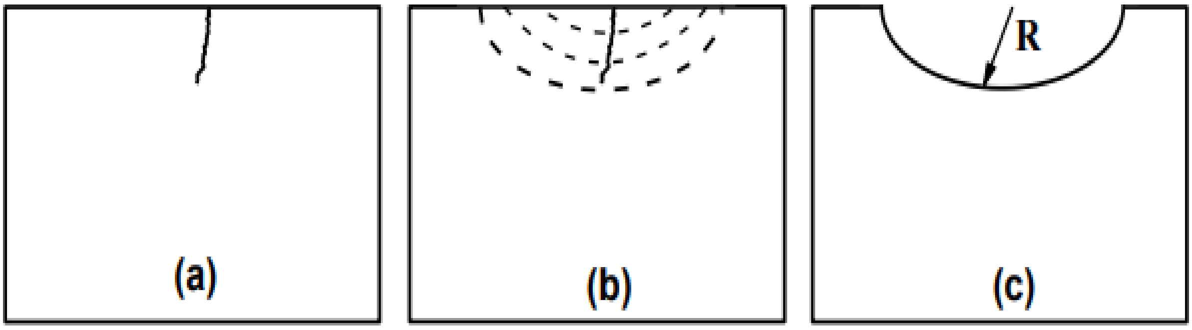


Figure 57: Grinding method,

(a) crack defect, (b) repair by grinding, (c) structure after repair

It is a simple technique that requires less expensive means. Grinding can give good results in terms of life span of the repaired structures. However, this However, this technique can weaken the structure due to the localized reduction of the section. This requires a verification by calculation of the mechanical strength of such structures after repair.

It is often recommended in the case of repairing cracks in thick structures (pressure vessels, rails, ...). (pressure vessels, rails, ...) **[21].** It is also used as a finishing technique for in the case of welded joints in order to extend their service life **[22].**

Hand filing or power disk grinding can be used to repair a defect or imperfection in a pipeline if the following criteria are satisfied:

1. The stress concentrating effect of the defect or imperfection is eliminated.

2. All damaged or excessively hard or soft metal (metal with an altered microstructure) is removed.

3. The amount and distribution of removed metal does not significantly reduce the pressure-carrying capacity of the pipeline. Historical precedents for using grinding as a repair technique are discussed in this section. Then, guidelines for its application to pipelines are presented. API Specification 5L for line pipe (15) permits manufacturers to remove a defect from new pipe by grinding so that the ground area blends in smoothly with the pipe contour, provided that it can be eliminated without reducing the remaining pipe wall thickness to a value less than a specified limit. For welded pipe greater than or equal to 508 mm (20 inches) in diameter and of Grade X42 or higher, the minimum allowable thickness after repair grinding is 8% less than the nominal thickness. For seamless pipe greater than or equal to 508 mm (20 inches) in diameter and of Grade X42 or higher, the minimum allowable thickness after repair grinding is 10% less than the nominal thickness. For all Grade B or lower pipe and for Grade X42 or higher pipe

less than 508 mm (20 inches) in diameter, the minimum allowable thickness after repair grinding is 12.5% less than the nominal thickness.

The ASME B31.4 Code (16) indicates that defects found in service may be removed by smooth contoured grinding.b The amount of metal removed by grinding is limited by the same criterion used to evaluate local wall loss caused by corrosion. The methods of ASME B31 G(3) may be used for guidance in evaluating the allowable local wall loss as a result of grinding. For example, ASME B31 G (3) gives the following expression for evaluating the maximum allowable length of wall loss:

For depths of 10% or less, there is no limit on the grinding length. Values computed using are less (more conservative) than comparable ones computed .After grinding, the surface should be inspected to make sure that no detectable cracks are present and examined after etching to make sure that metallurgically altered material has been removed.

9. Conclusion

Pipelines carrying gases and fluids often contain defects that can lead to their failure. These defects are classified into five major types: corrosion pits and craters, cracks, notches (scratches), indentations and combined defects (indentations + scratches). The difference in geometry and nature of the defects led researchers to create specific tools for each type of defect based on limit analysis, linear and non-linear fracture mechanics, finite element analysis and experimentation.

The study of this chapter corresponds to the state of the art on the different types of defects and techniques for repairing faults in pipelines. and among the different repair methods cited, the most emergency promising repair by **GRINDING** to quickly and inexpensively resolve pipe damage **[17].**

Chapter VI:

Modeling and Numerical Simulation

Chapter VI: Modeling and Numerical Simulation

1. Introduction

Pipelines are subject to various problems (corrosion, cracking) due to excessive loads resulting from soil movements or particular environmental conditions (flow erosion, soil alkalinity, etc.). The repair by grinding allows to eliminate cracks and consequently to increase the life span of the repaired structures. **[17]**

In our study we are interested in the study of the variation of Von Mises stresses in a cracked pipe. As well as the concentration of stresses at the crack front by repairing pipe in service by grinding with the calculation code ANSYS workbench and APDL.

ANSYS, which is one of the most widely used finite element codes in the world.

2. Numerical simulation

Numerical simulation consists in reproducing by calculation the functioning of a system, previously described by a set of models. It is based on specific mathematical and computer methods. The main steps of a numerical simulation study are common to many sectors of research and industry, including nuclear, aerospace and automotive. In a numerical simulation, the numerical device is a set of computer programs running on computers. The codes or calculation software are the translation, by numerical algorithms, of the mathematical formulations and physical models studied.

2.1 Description of the computational code

At present, there are a number of user-friendly industrial three-dimensional codes, among the industrial software available on the market, we can mention ABAQUS, ADINA, ANSYS, ASTER (in open source since fall 2001), MSC/NASTRAN, SYSTUS, DYNA3D, LS-DYNA, and many others.

The purpose of this last part is to highlight the efficiency and accuracy of the numerical techniques developed in structural dynamics for an industrial type of complexity.

We will study the evolution of the Von Mises stress in the following cases:

1) Evolution of Von Mises stresses in a cracked pipe with different size.

2) Evolution of Von Mises stresses in a cracked pipe repaired by grinding

- Effect of pipe thickness variation.
- Effect of variation of the width of the defect after repair

2.3 Numerical method "Finite element method"

Chosen by ANSYS Workbench software, is a general method for solving industrial problems by very efficiently building simulation models. She is currently applied in a wide variety of fields to solve problems of mechanics of solids and/or mechanics of fluids, thermal problems, Electricity, electromagnetism etc.

The realization of the finite element model is obtained by the assembly of elements. That operation is called discretization or meshing of the mechanical model of the structure at to study. The quality of the results is very strongly conditioned by the mesh adopted. This is one of the reasons why it is not enough to have a program to produce suitable simulations of reality.

2.4 Conditions to the limits:

For simulations concerning the operation of cavities and holes and tubes, the definition of the boundary conditions has great importance on the results obtained. In practice, these conditions reflect the fixing conditions of the cavity. Thus, if one wants to later compare the results of simulations with the results of measurements, the prediction of fixation of the cavity must be as realistic as possible. On the other hand, the simulations allow to see the possibilities of better distributing the stresses, by modifying the parameters and the boundary conditions so that the choice of the fixing level is the most judicious. It is then necessary, when carrying out the experiments, to respect as much as possible the specifications optimized by the calculations.**[34]**

3. Study of the semi-elliptic crack in a pipe

3.1 Pipe design on ANSYS WORKBENSH:

Before manufacturing a product (**pipe**) it is necessary to design this product, for reasons of symmetry, only half of the pipe for this we have chosen ANSYS **Workbench 19.0** to model the same pipe (pipeline with normalized dimensions)

3.2 Geometric model :

The model studied represents an API 5L X70 steel pipeline with a crack due to operating conditions. In the following we will present:

- The geometrical characteristics.
- Mechanical properties.
- Boundary conditions and applied loads.
- The mesh used.

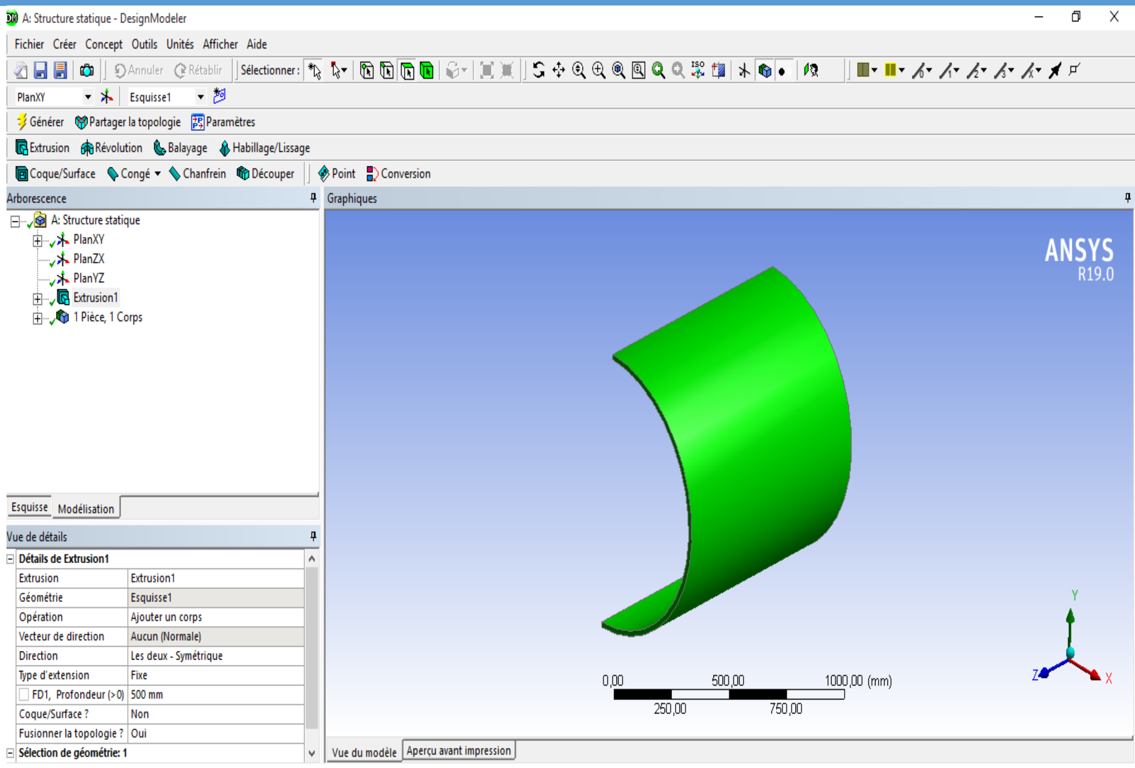


Figure 58 : Geometric model in ANSYS Workbench 19.0

3.3 Mechanical characteristics and dimensions of the material

3.3.1 Mechanical properties:

Producers of steels for gas transmission pipelines have continuously doubled their efforts to improve the mechanical and physical characteristics of these materials. They are often forced to seek a compromise between antagonistic properties. These include:

- Yield strength;
- Impact strength and transition temperature, ductile/brittle;
- Weldability

These are very important not only in the field of pipeline manufacturing but also for industrial applications. The material used in this study is API 5L X70 steel, a material frequently used in pipeline structures. The mechanical properties of the pipe used in this simulation are given in the following.

Table 3 : Mechanical properties of API X70 grade steel.

E (MPa)	ν	$\sigma_{E\ 0.2}$ (MPa)	σ_U (MPa)	A %	k	n
$2{,}22.10^5$	0,3	483,03	673,14	40.55	855,70	0.094

Mechanical properties of tensile strength will comply with the requirements of Table 3 with E the Young's modulus, ν the Poisson's ratio, σE 0.2 the elastic limit according to the standard, σU the ultimate stress, A % the elongation at break, and k and n being the Hollomon settings.

The dimensions of the half pipe are shown below:

- Outer radius Rext=508mm
- Inner radius Rint= 489 mm
- The thickness of the pipe t= 19 mm
- pipe length is L=500mm
- Operating pressure: P = 7 bars.

3.4 Boundary conditions and loading

The behavior of a crack under a given stress depends particularly on its size and shape. To estimate the influence of each of these parameters, we study the evolution of stress intensity factors on the front of a semi-elliptical crack inside and outside a pipe subjected to internal pressure.

In this work we consider only the case where the ends of the pipe are blocked with the boundary conditions presented in the following figure:

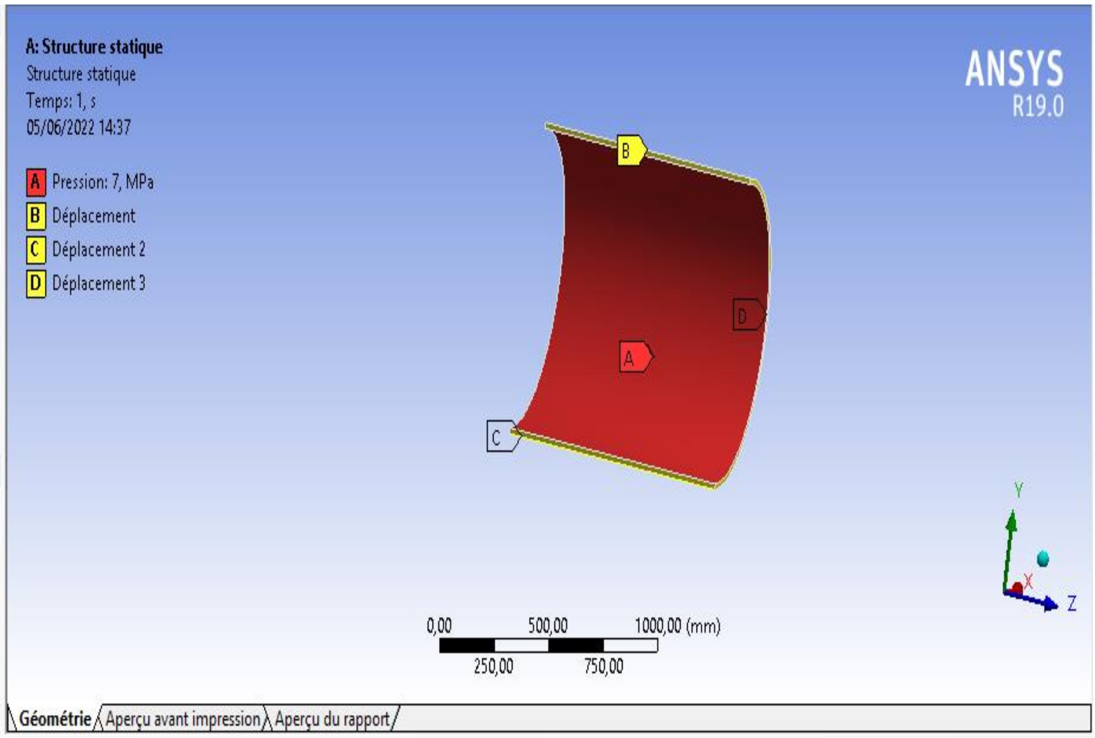


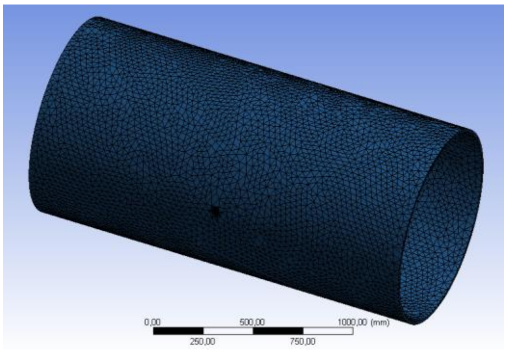
Figure 59: Boundary conditions of studied pipe.

3.5 Meshing

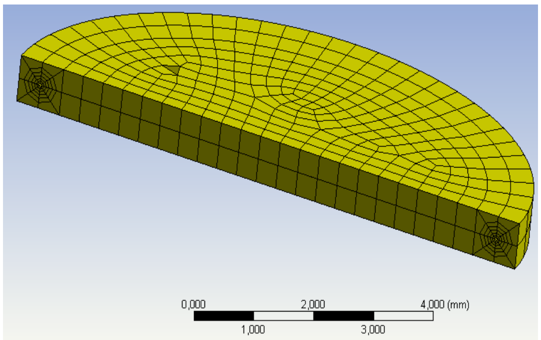
Due to the existence of the crack bottom singularity, the usual elements surrounding the crack bottom must be generated in refined mesh in order to derive reliable stress intensity factor results.

ANSYS Workbench requires that the body of the part structure with cracks be meshed with tetrahedral elements, while other bodies without cracks can be meshed with elements of arbitrary types. .

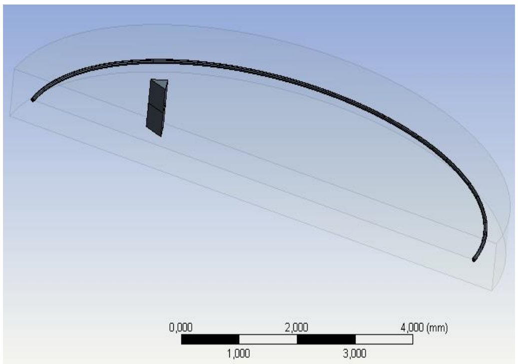
Otherwise, in our case we represent the element type used in each part of the geometry Quadratic tetrahedron.



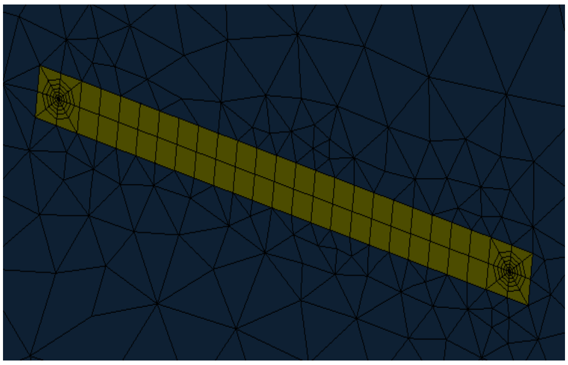
(a) Quadratic tetrahedron.



(b) Quadratic hexahedron.



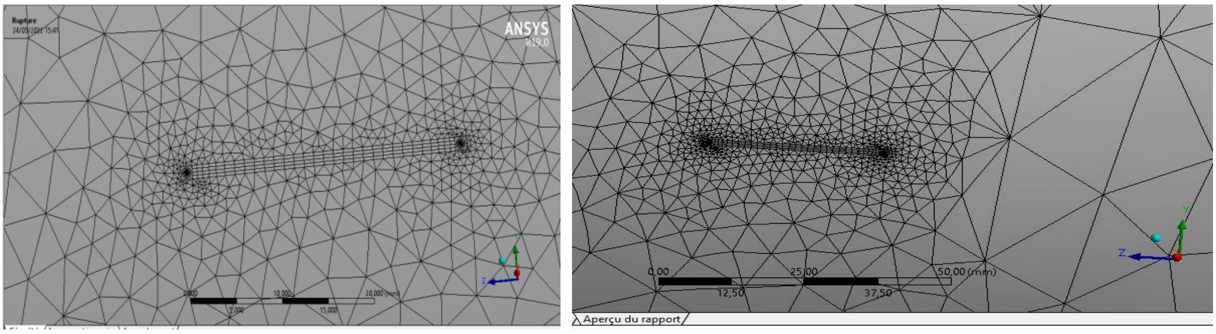
(c) Quadratic prism.



(d) Domain discretization with three different elements.

Figure 60: Representation of the type of element used in each part of the geometry (WORCKBENCH).

- Under the ANSYS Workbench environment, the refinement of the crack bottom mesh is automatically generated after the global mesh is executed.



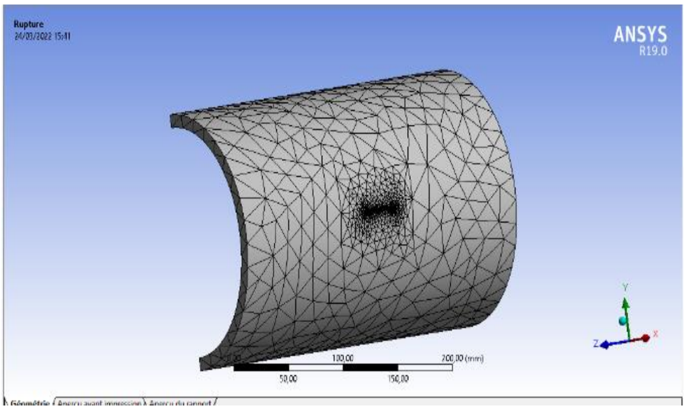


Figure 61: Finite element modeling of the cracked pipe

- Figure 37 shows the mesh used with tetrahedral elements for the cracked pipe analysis as well as the crack tip refinement using special singularity elements with six contours.

3.6 Analyses and results

3.6.1 Effect of Von Mises stress variation in a pipe without crack

In this part the objective is to see the variation of Von Mises stresses in a sound pipe under different pressures. It can be seen that these stresses remain below the elastic limit of the pipe material (X70) for operating pressures of 1;2; 3; 4; 5; 6,7Mpa.

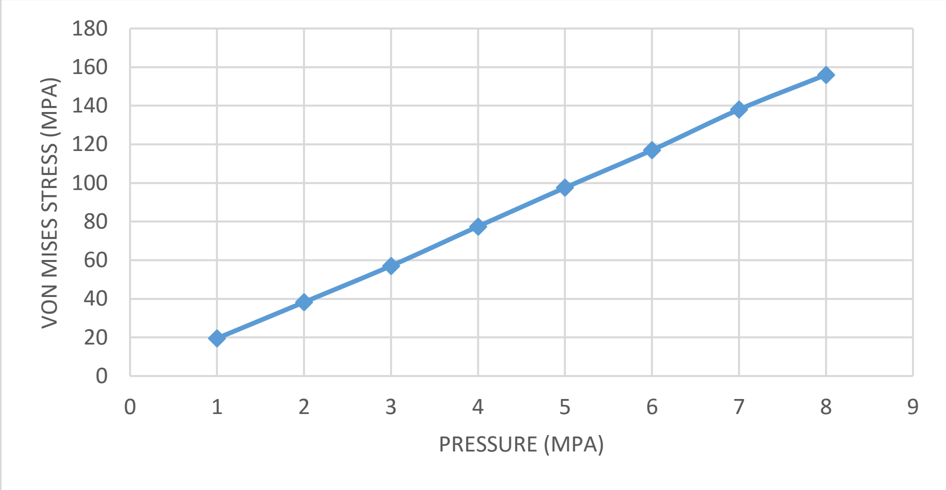


Figure 62: variation of the von mise stress as a function of the pressure (pipe saint)

3.6.2 The variation of Von Mises stresses in a cracked pipe

Figure (..) presents the variation of Von Mises stresses in a cracked pipe under different pressures. We can see a concentration of Von Mises stresses at the crack front with the increase of the internal pressure compared to a healthy pipe (without crack). We notice that this concentration is due to the presence of a crack. This shows the negative effect of the presence of a crack in a pipeline.

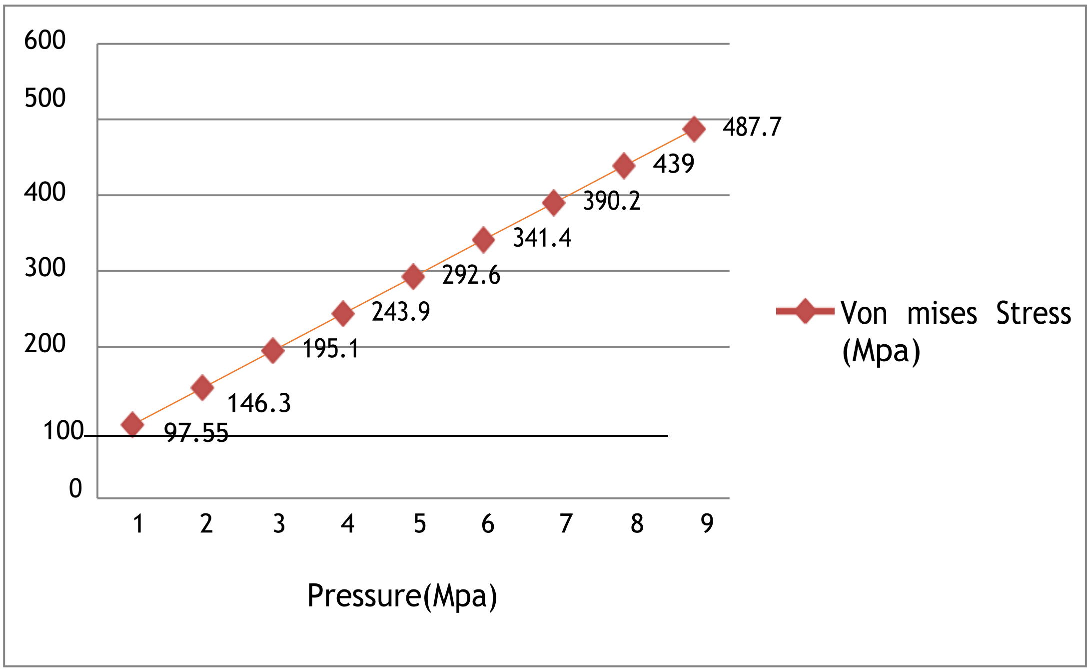


Figure 63: variation of the von mise stress as a function of the pressure in a cracked pipe

3.6.3 Effects of crack geometry

Before studying the optimal repair by grinding we will make a preliminary study on the influence of the orientation and size of the crack on the FIC to determine the worst case to take as a model in the rest of this study. Cracks with a semi-elliptical shape, as shown in Figure 4, are characterized by the small half-axis (a) and the large half-axis (c).

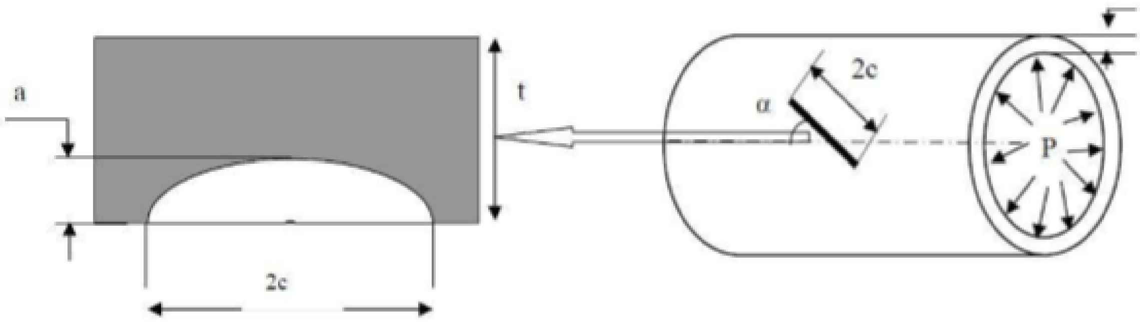


Figure 64: Pipe with a semi-elliptical crack

3.7 Behavior of an unrepaired crack

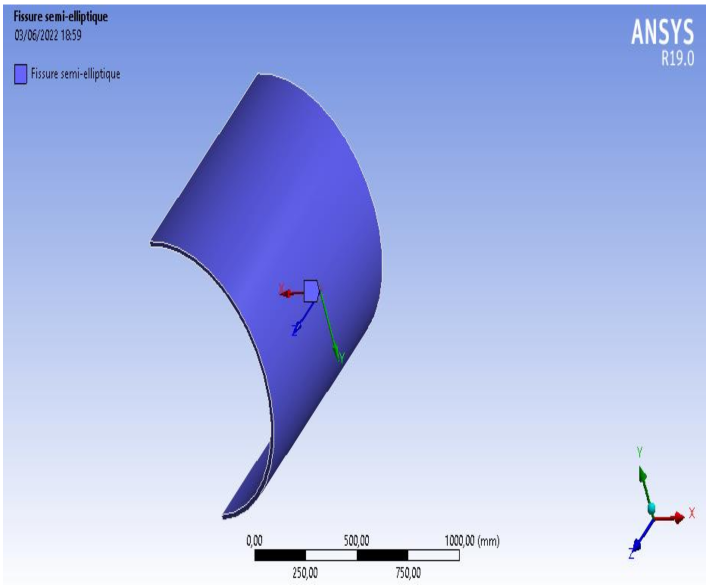
3.7.1 Effect of crack depth and length

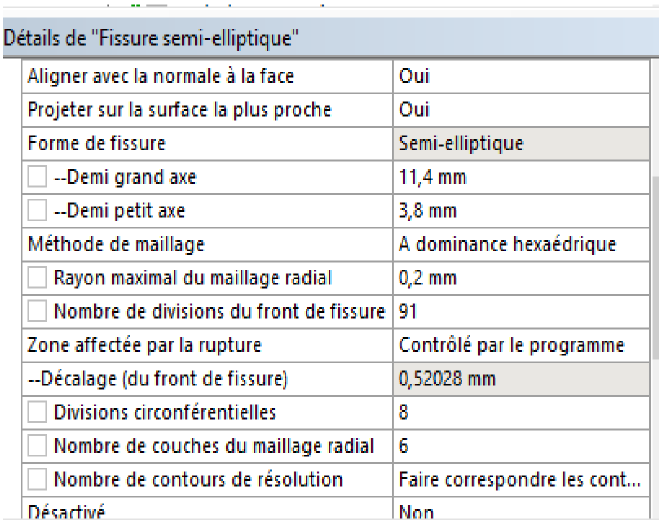
According to the experimental studies of Gamboa et al [59] for the behavior of different geometries of longitudinal cracks of a semi-elliptical shape characterized by its small half-axis (a) and its large half-axis (C) (Figure 60). We numerically modeled the same geometrical features of the cracks summarized in Table 4.

Table 4 : Geometric parameters of cracks [59]

cases	C (mm)	a(mm)
a	8.55	2.85
b	11.4	3.8
c	14.25	4.75
d	17.1	5.7
e	19.95	6.65
f	22.8	7.6

In this case we have chosen to take the depth in every case **d/t**=15%,20%,25%,30%,35%,40% with a maximum radius of the radial mesh r=a/10, The number of circumferential divisions is N1=8, The number of layers of the radial mesh is N2=6, The number of divisions of the crack front is N3=91 (figure).





Détails de "Fissure semi-elliptique"

Aligner avec la normale à la face	Oui
Projeter sur la surface la plus proche	Oui
Forme de fissure	Semi-elliptique
--Demi grand axe	11,4 mm
--Demi petit axe	3,8 mm
Méthode de maillage	A dominance hexaédrique
Rayon maximal du maillage radial	0,2 mm
Nombre de divisions du front de fissure	91
Zone affectée par la rupture	Contrôlé par le programme
--Décalage (du front de fissure)	0,52028 mm
Divisions circonférentielles	8
Nombre de couches du maillage radial	6
Nombre de contours de résolution	Faire correspondre les cont...
Désactivé	Non

Figure 65: The characteristics of the mesh at the crack front in ANSYS workbench for c with: C = 11.4 mm and a = 3.8 mm

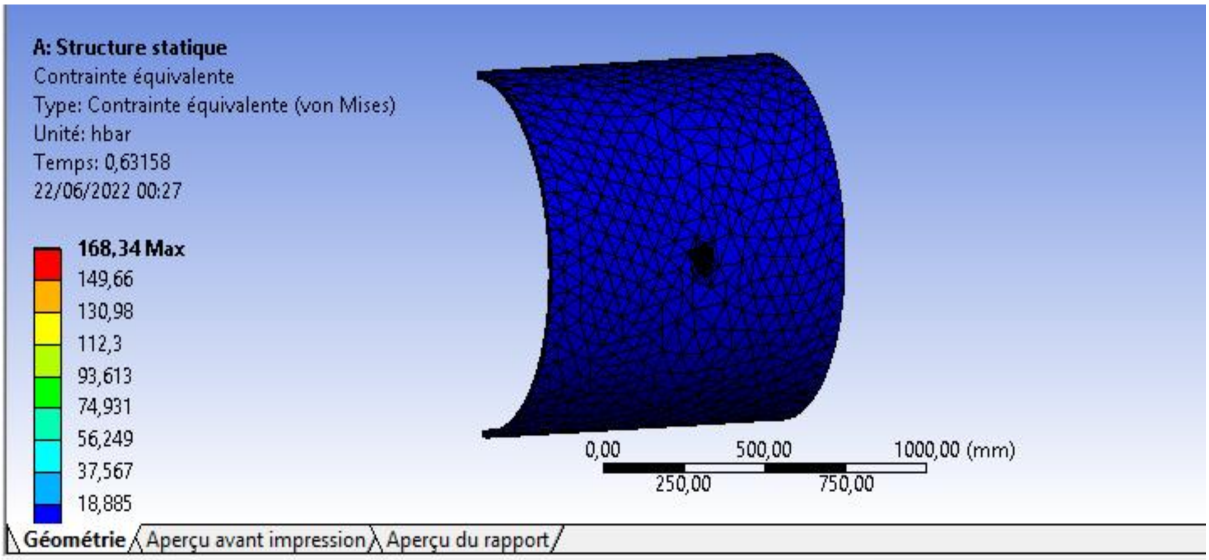


Figure 66 : Von Mises stress contribution

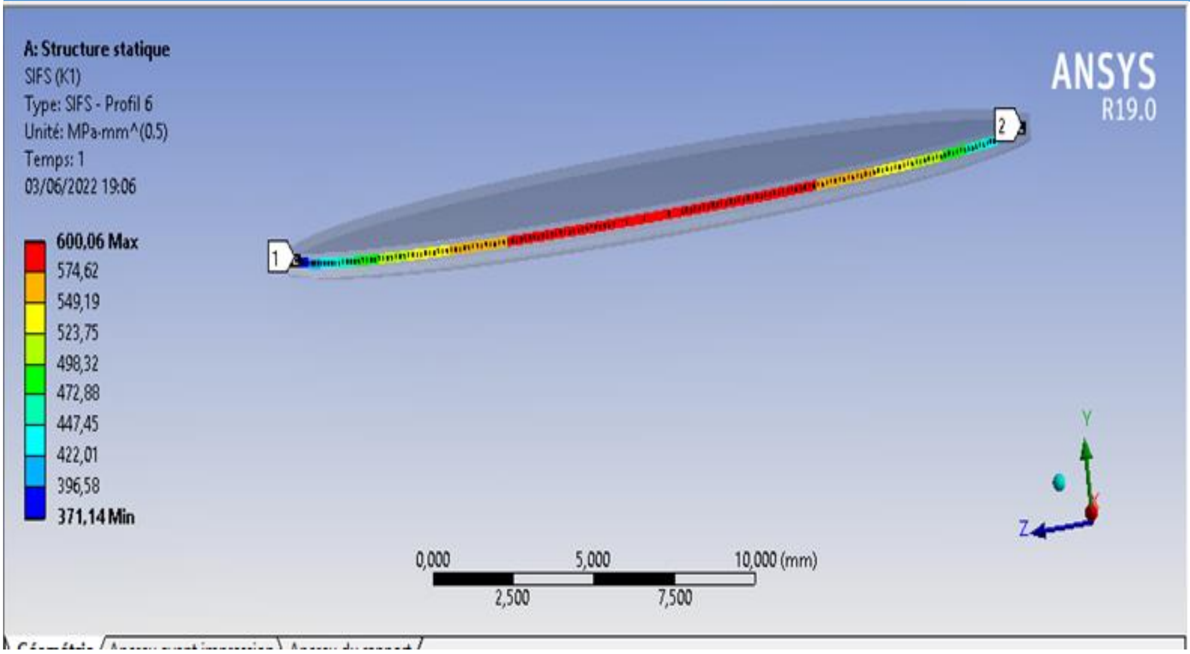


Figure 67 :la distribution de FIC en fonction de l'angle φ

3.7.2 Calculations in the elastoplastic behavior

In this part we have added data in the calculation code, these data is mainly the traction curve of the studied material.

The results obtained are presented in the following figure:

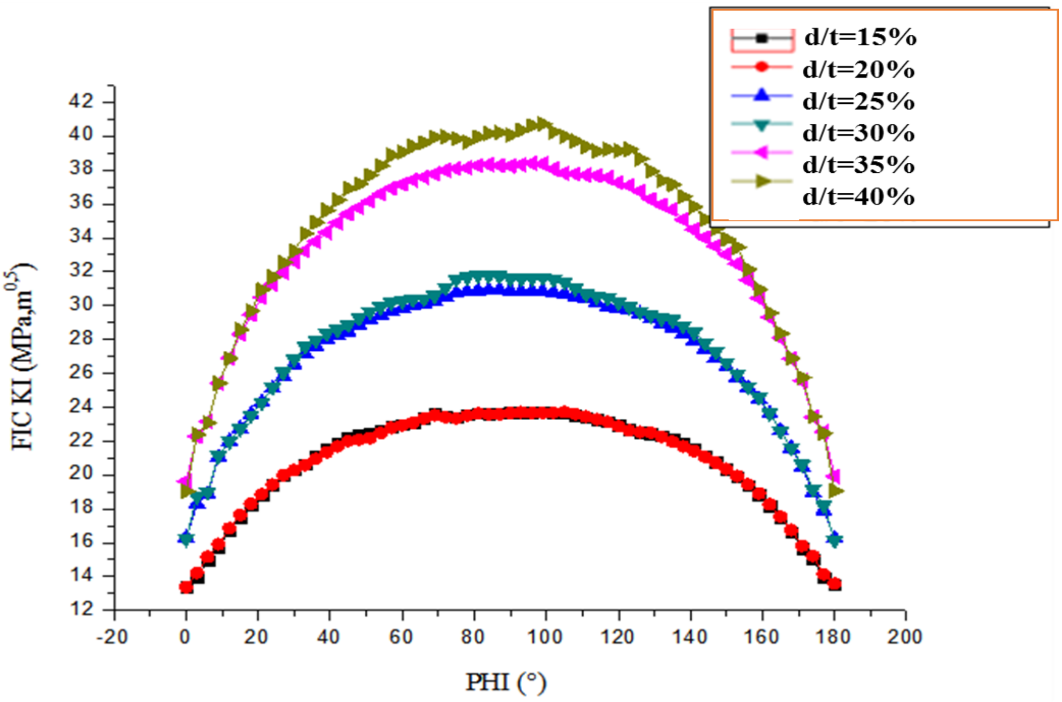


Figure 68: Comparison of FIC distribution as a function of angle φ between the two elastic and elasto-plastic behaviors with d/t=0.15,0.20,0.25,0.30,0.35,0.40

3.8 Discussion and Interpretation:

As can be seen, the length c has a significant influence on the behavior of the crack.

- For d/t=0.25, there is a maximum value of the stress intensity factor which is found in the deepest point (φ=90°).

4. Numerical modeling of a pipe with crack repaired by Grinding (Type of emergency repairs)

4.1 Grinding method:

ASME B31.4 states that defects found in service can be removed by smooth profile grinding. The amount of metal removed by grinding is limited by the same criterion used to evaluate local wall loss due to corrosion. The methods in **ASME B31 G** can be used as a guideline to assess the allowable local wall loss from grinding. For example, **ASME B31 G** gives the following expression for estimating the maximum allowable wall loss length:

$$L = 1.12 \bullet 4\sqrt{Dt} \qquad \text{for } 10\% \leq d/t \leq 17.5\%$$

$$L = 1.12\sqrt{Dt\left\{\left(\frac{d/t}{1.1d/t - 0.15}\right)^2 - 1\right\}} \qquad \text{for } 17.5\% < d/t \leq 80\%$$

- Repair and removal of defects by mechanical grinding is permitted by ASME B31.8 to depths up to 40% of the nominal wall thickness if the length of the pipe surface does not exceed the value given by the following equation

$$L = 1.12\sqrt{Dt\left\{\left(\frac{d/t}{1.1d/t - 0.11}\right)^2 - 1\right\}}$$

D = nominal outside diameter of the pipe
L = maximum allowable longitudinal extent of the ground area
d = measured maximum depth of the ground area
t = nominal wall thickness of the pipe

Table 5: The results of repair length for different depths

Depth (d/t)	Length (L)
15	200.71
20	133.8
25	111.5
30	100.3
35	93.66
40	89.20

We suggest to vary the width for each depth from 15% to 40% in a constant length and find the reel width for every depth of the cracks as shown in the table 00

Table 6: geometric parameters of our work simulation

Depth (%)	15	20	25	30	35	40
W	W(real)					
10	9.75	9.87	9.90	9.91	9.93	9.94
15	14.45	14.58	14.66	14.72	14.76	14.79
20	18.75	19.04	19.22	19.34	19.43	19.50
25	22.67	23.19	23.52	23.75	23.92	24.05
30	26.20	27.01	27.54	27.91	28.18	28.39
35	29.34	30.49	31.25	31.80	32.20	32.51
40	32.10	33.63	34.66	35.40	35.96	36.40
45	34.51	36.44	37.76	38.73	39.47	40.05
50	36.62	38.94	40.57	41.78	42.71	43.45
55	38.45	41.04	43.11	44.56	45.70	46.61
60	40.04	43.14	45.39	47.10	48.44	49.53
65	41.43	44.89	47.44	49.40	50.96	52.23
70	42.64	46.44	49.28	51.49	53.26	54.72
75	43.69	47.82	50.93	53.38	55.37	57.01
80	44.62	49.04	52.41	55.10	57.29	59.11
85	45.43	50.12	53.74	56.65	59.04	61.04
90	46.15	51.09	54.94	58.06	60.63	62.81
95	46.78	51.95	56.02	59.33	62.09	64.44
100	47.38	52.73	56.99	60.49	63.42	65.93

4.2 Geometric representation

We considered a model formally identical to the previous model. The repair is carried out by grinding. Using APDL we have done the geometry of the defect

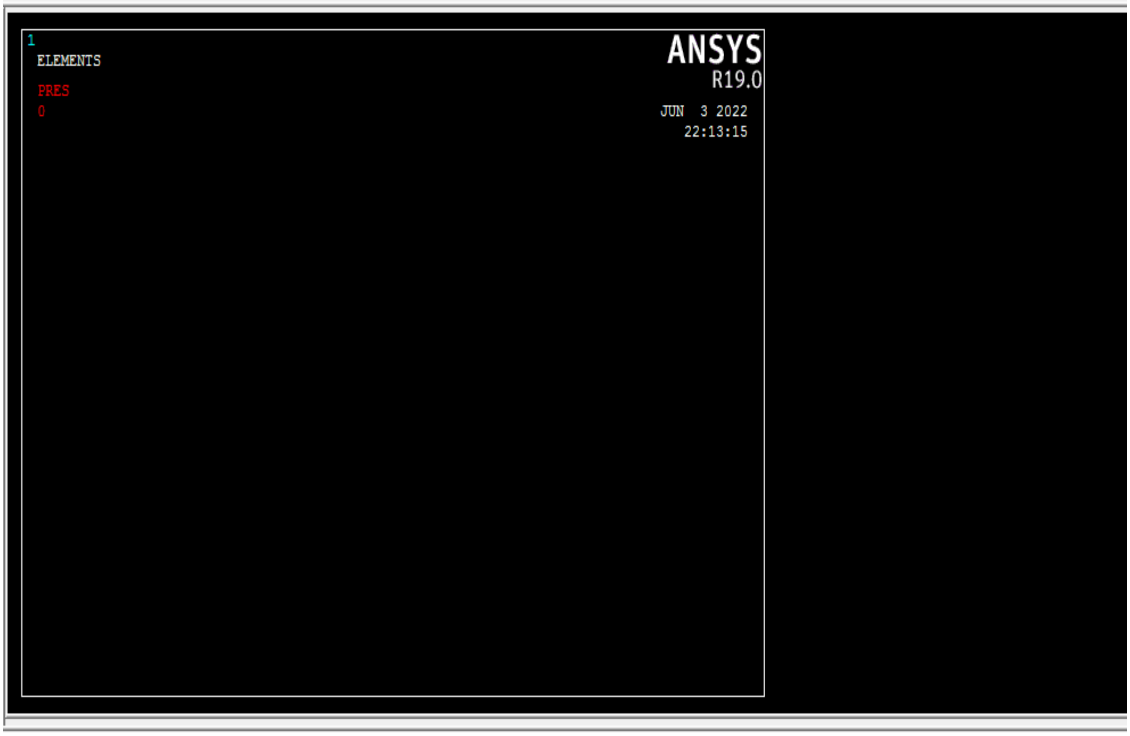


Figure 69: interface of APDL software

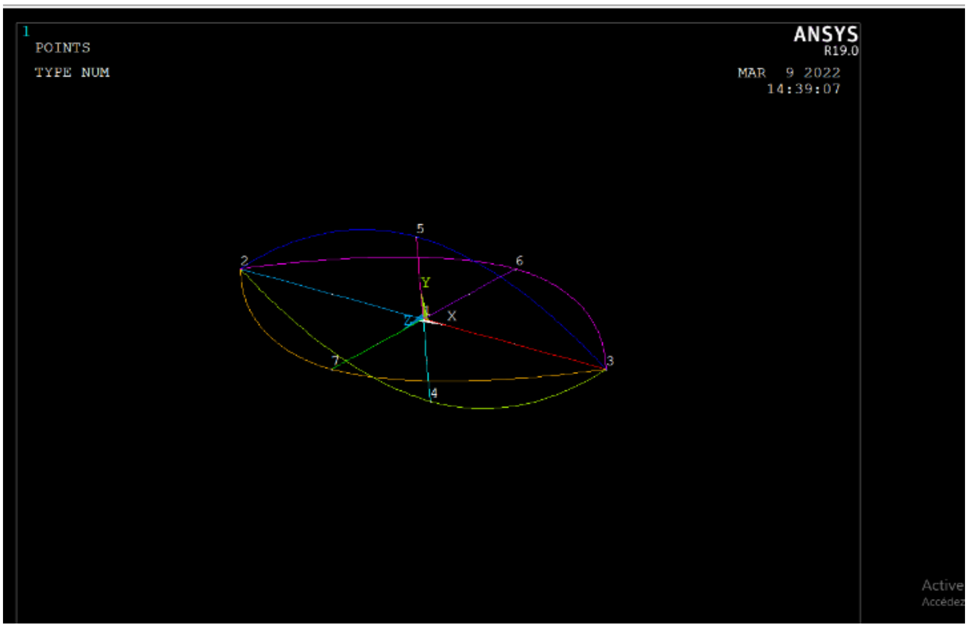


Figure 70: The geometry of the defect chosen 3D

4.3 Boundary conditions

Any finite element calculation requires the definition of boundary conditions. To begin with, it must be said that the pipe geometry has been simplified by considering half, because it is symmetrical with respect to the median plane and we use the following dimensions to define the fault geometry on APDL software.

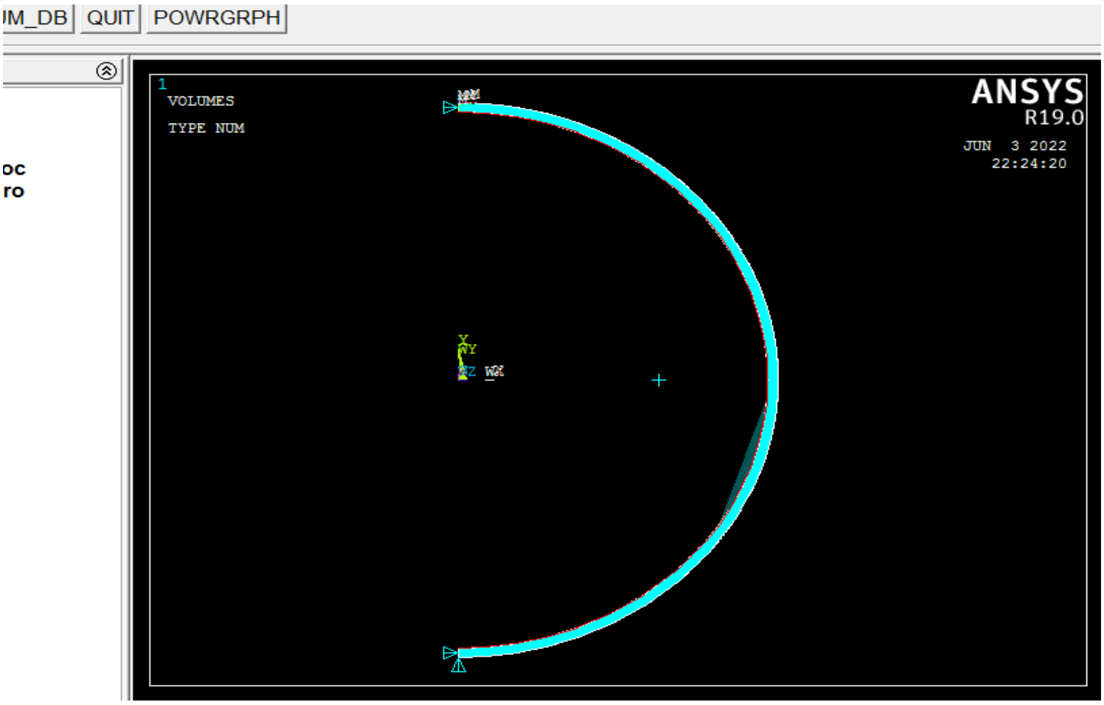


Figure 71 :Boundary conditions

4.4 Meshing

The analysis is performed by the three-dimensional finite element method with APDL, so an automatic mesh will be performed on the structure and the type of element used. Figure (6.86) represents the mesh of the structure. This mesh remains the same throughout the calculation to avoid any influence of the mesh on the results.

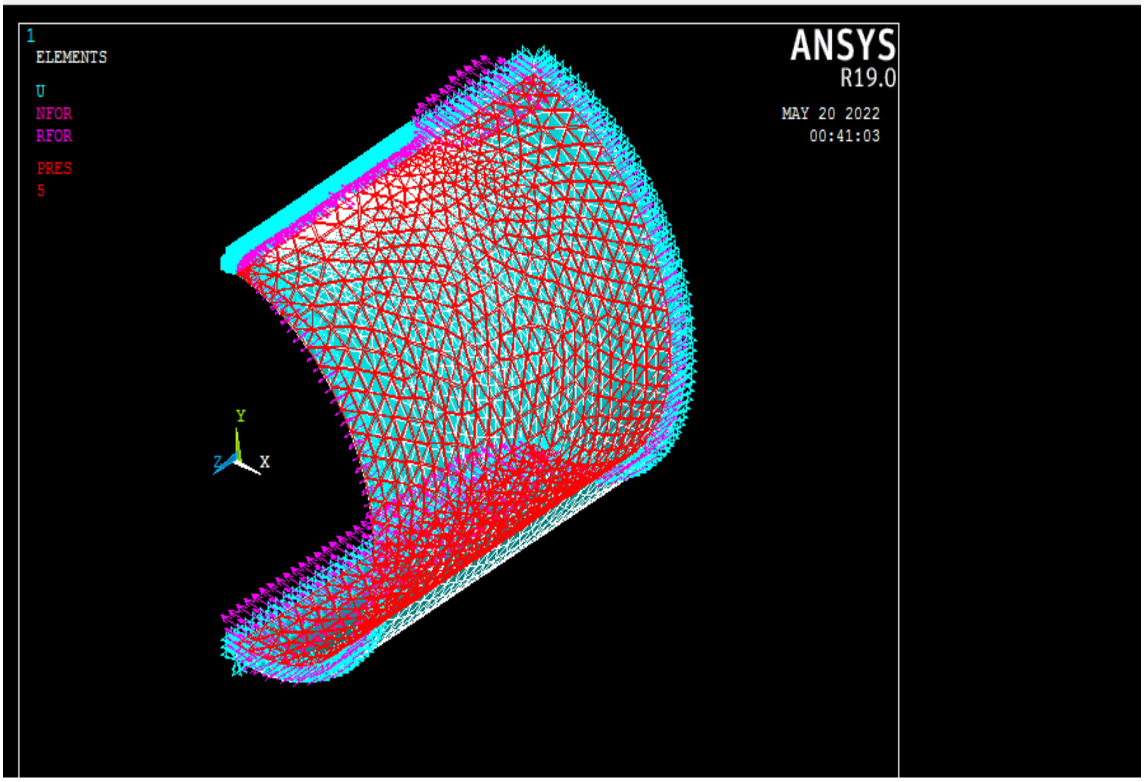


Figure 72= meshing result on a pipe for depth 20%

4.5 Analysis and Results:

4.5.1 Von Mises stress variation in pipe repaired by grinding

4.5.1.1 Effect of constant length in different thickness:

The following figure represents the variation of the Von Mises stresses as a function of a length of the defect is calculated and the width varies at a constant depth.

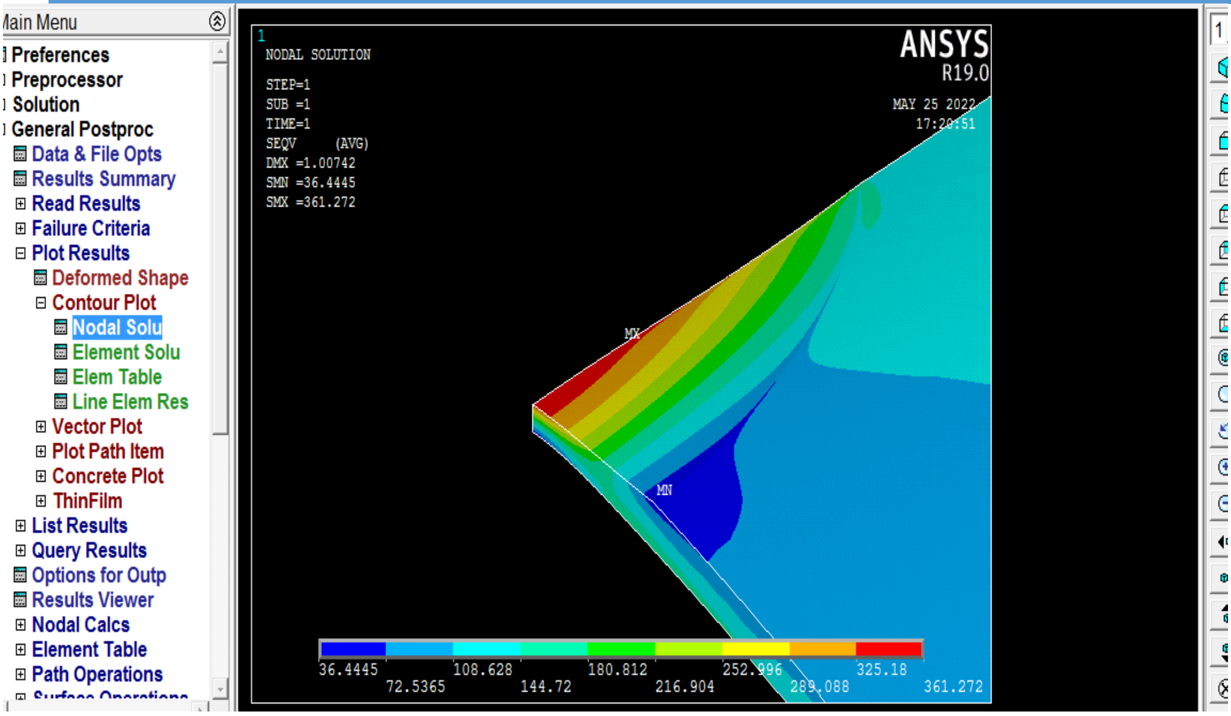


Figure 73 : plot results of the simulation with APDL

The results of the simulation are presented in the following figures as:

- Von Mises equivalent stress figures on constant length and vary the depth (d/t)
- Von Mises equivalent stress curves as a function of the variation of the real defect width to analyze the influence of the notch depth and the repair width on the stress distribution along the ligament;

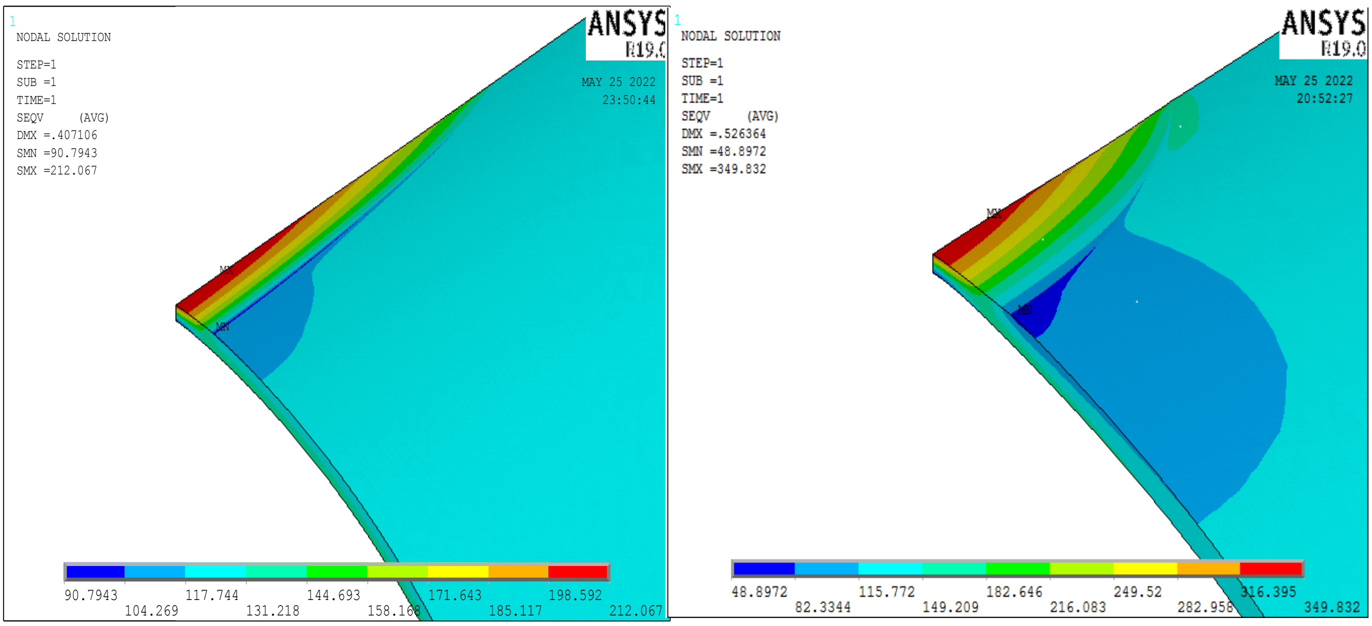


Figure 74 : Von mises stress concentration results for d/t =15% ,35% with r $_{reel}$ = 50 mm

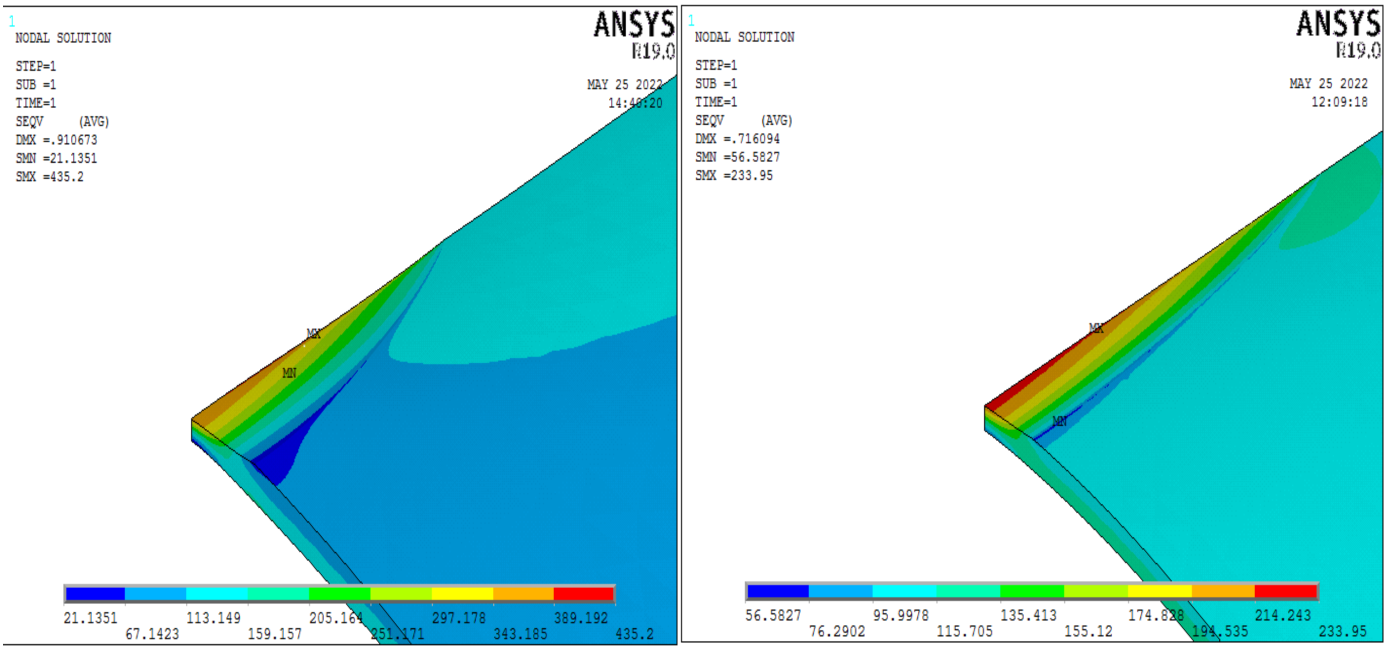


Figure 75 : Von mises stress concentration results for d/t =40% ,20% with r reel =50 mm

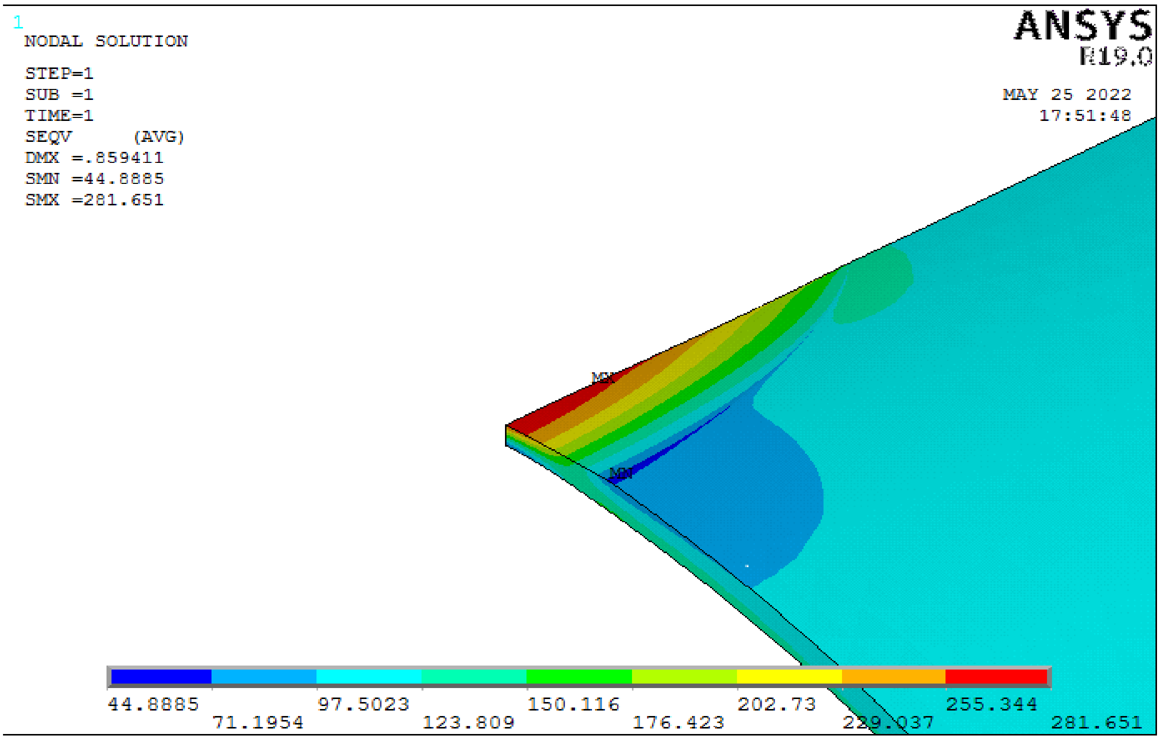


Figure 76 : Von mises stress concentration results for d/t =30%, with r reel =100 mm

5. Analysis and Interpretation of the Numerical results

In order to better understand the influence of the emergency repair by the grinding method, different types of graphs have been traced, on which the length of the defect is calculated and the width varies at a constant depth.

- The results presented in the above figures shown that Von mises stress concentration increase with the increase of crack depth .
- The results presented in the following graphs (77,……,82) for (d/t) = 0.15,0.20,0.25,0.30,0.35,0.40 is confirmed the beneficial effect of the reel width of the defect by the reduced stress concentration at the crack front with the increase in the reel width of the defect, for an internal pressure of 7 Mpa..
- We notice also that the distribution of the stress of opening in the vicinity of point of crack always presents a maximum, then, it slows down gradually in order to reach a stable value. We report that **the maximum** of the **Von Mises stresses** is recorded in the case 6 having **a minimum width** and a **maximum depth 40%,** which represents the most unfavorable case.

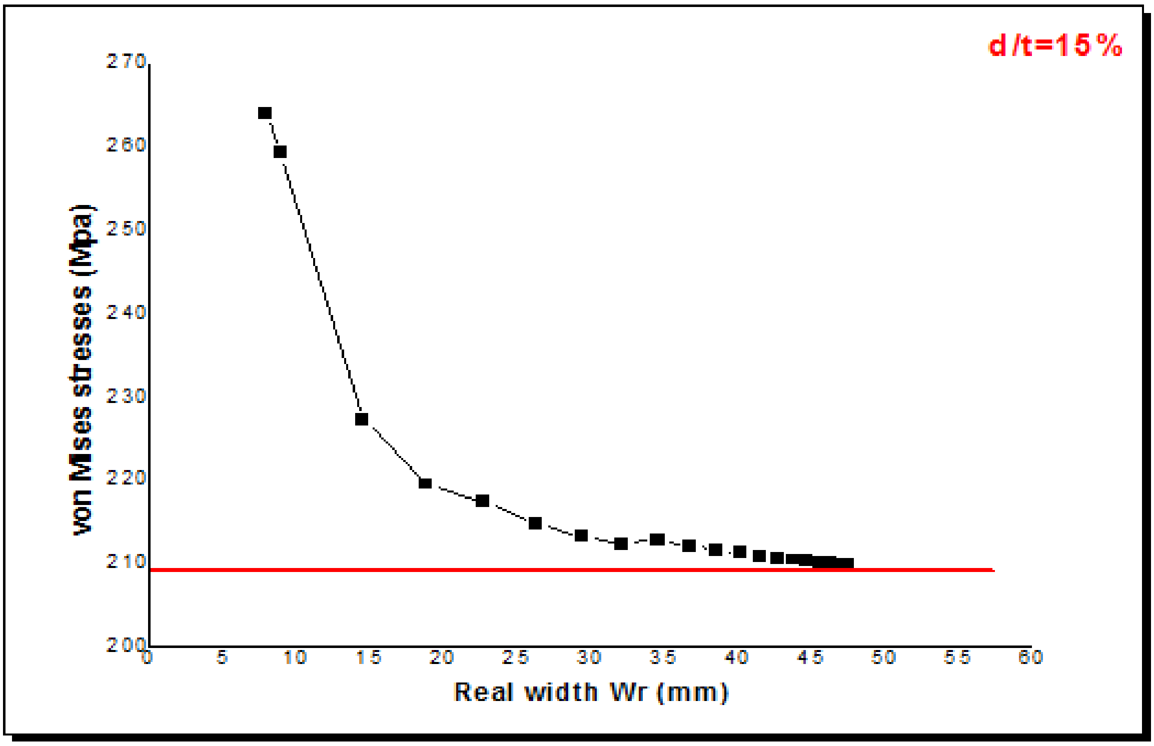


Figure 77 : Effect of variation in real fault width on Von Mise stress concentration d/t=15%

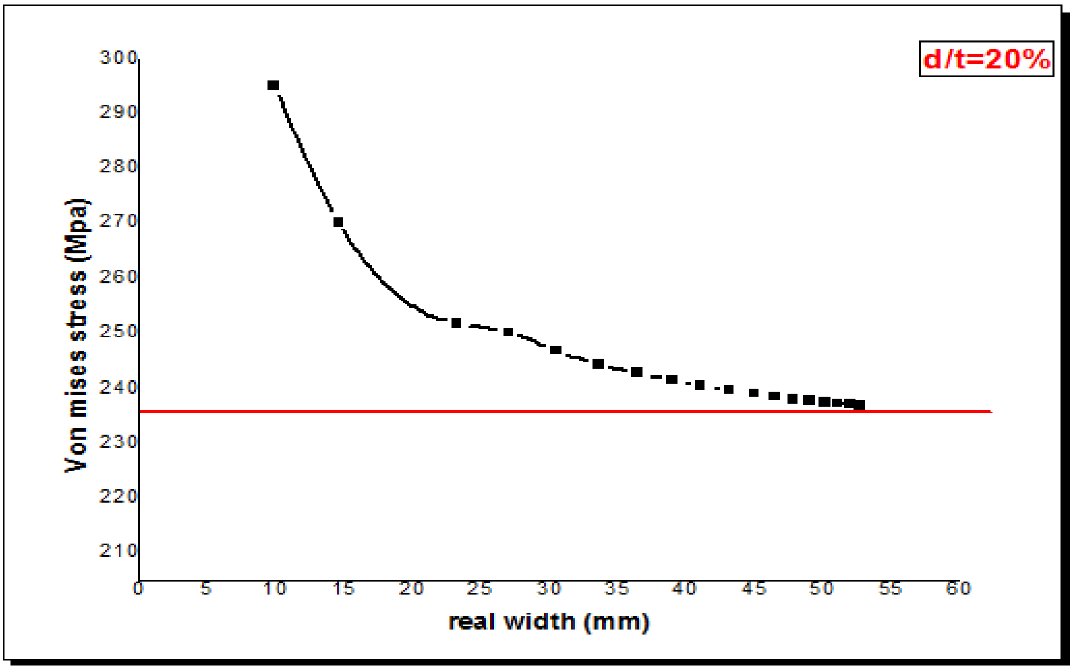


Figure 78: Effect of variation in real fault width on Von Mise stress concentration d/t=20%

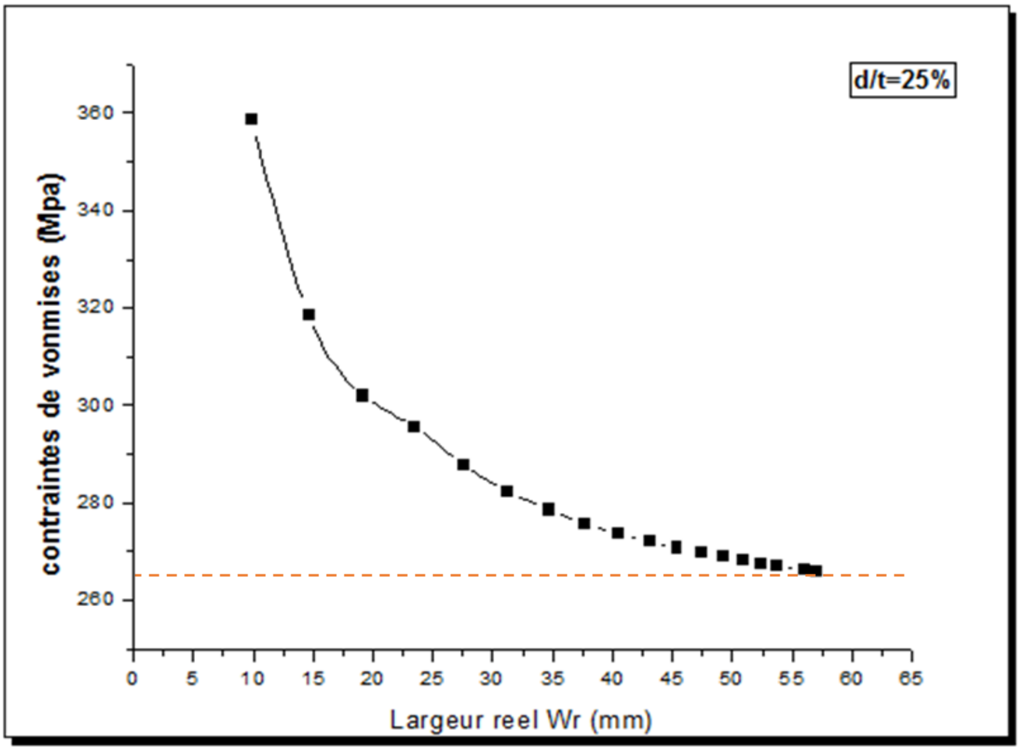


Figure 79: Effect of variation in real fault width on Von Mise stress concentration d/t=25%

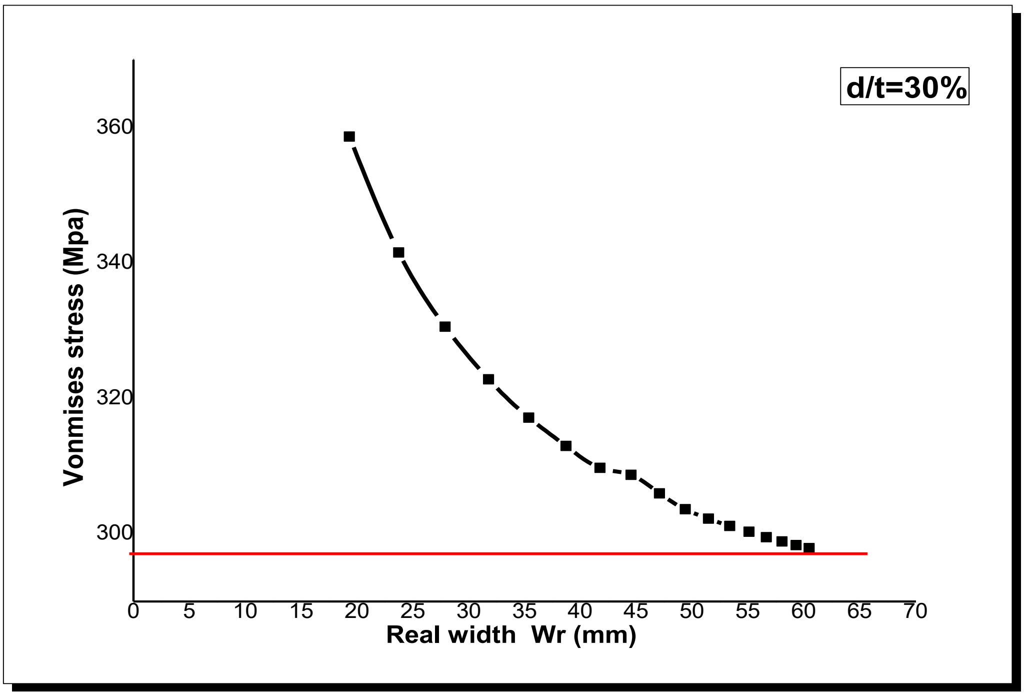


Figure 80: Effect of variation in real fault width on Von Mise stress concentration d/t=30%

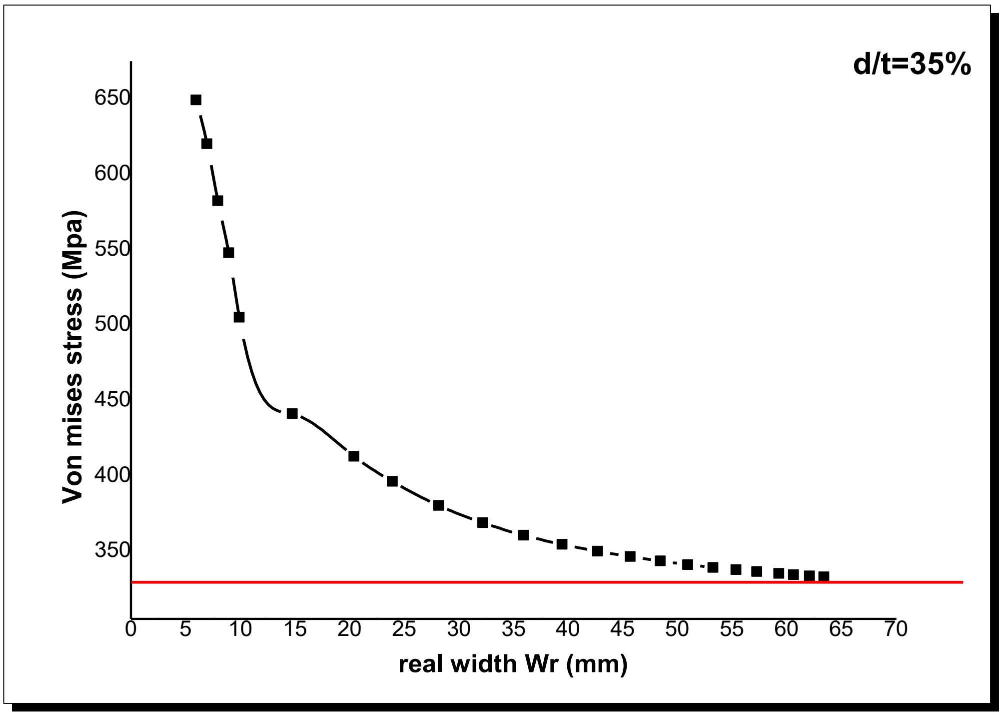


Figure 81: Effect of variation in real fault width on Von Mise stress concentration d/t=25%

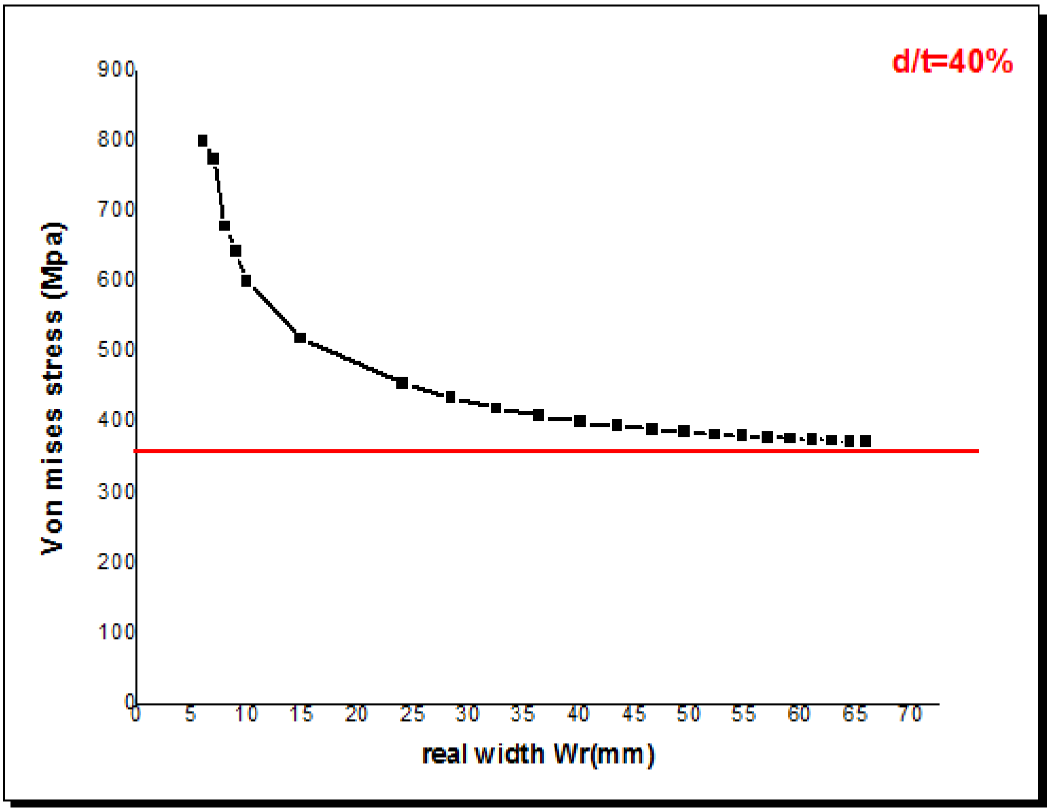


Figure 82: Effect of variation in real fault width on Von Mise stress concentration d/t=40%

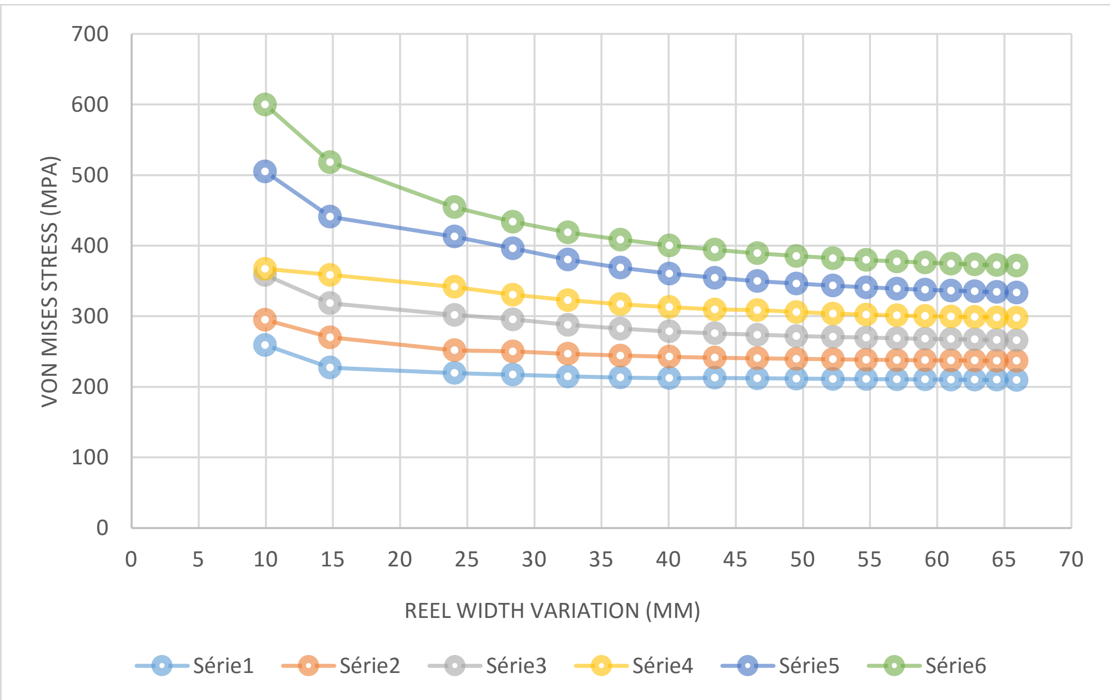


Figure 83: Effect of variation in real fault width in different depth and constant length on Von Mise stress concentration

6. Discussion

Grinding repair of a cracked cylindrical structure is an effective type of emergency repair to increase the life of a damaged pipe.

The load transfer between the cracked pipe and the grinding can greatly reduce the stress intensity around the repaired crack, which leads to the improvement of the fatigue strength of the pipe

the optimal width positively influences the stresses near the crack in order to improve the service life to increase the efficiency of the grinding repair, it is important to optimize the geometrical repair parameters since the stress intensity around the crack depends on all these parameters.

General conclusion
&
Perspective

Conclusion General

The objective of this study is to understand the harmfulness of cracks in pipes subjected to internal pressure

For this purpose, we presented in the first chapter a history on ALTUMET company spa, we presented the main manufacturing processes of the pipes based on the respect of the requirements of the American standard API 5L (American Petrolium Institute), which passes by several stages of control; of the reliability of the manufacturing process and of good training of service teams maintenance and production.

We are particularly interested in our contribution to the problem of external semi-elliptical cracks.

The study, conducted within the framework of the application of fracture mechanics is approached by a numerical approach by finite elements, we used a numerical calculation code that can calculate quickly and reliably the values of stress concentration and stress intensity factors at the front of a 3D crack, such as WORKBENCH and APDL

We studied the influence of the influence of the size and shape of the crack on the stress variation and shown his influence with the optimal width of the grinding repair on the concentration of Von Mises stresses at the crack face in constant length

otherwise, the choice of the optimal width of the grinding repair represents a sensitive issue because the standard didn´t talk about

The present study, presented allows to describe satisfactorily the behavior of a cracked pipe repaired by grinding and shows that the repair process structures using grinding is an effective and reliable emergency method for significantly to significantly increase the life span of damaged structures.

Perspective

As prospects, in future work, it could be interesting to develop an algorithm that would allow the prediction of crack growth in complex and industrial structures like pipelines where there is, for example, a deformation gradient. Knowing the fracture behavior of the ferritic steel used, it is possible to use this information to predict if, in a given loading situation, the crack present in the structure tends to propagate or not and to predict the length that the crack will reach. To do this, it seems necessary that the implementation of this algorithm to a finite element software such as ANSYS.

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Appendixes

Appendixes

Appendix 1

Table 7:Chemical composition of API X70 grade steel.

	C	Mn	Si	Cr	Ni	Mo
%	0.125	1.680	0.270	0.051	0.040	0.021
X70	S	Cu	Ti	Nb	Al	p
	0.005	0.045	0.003	0.033	0.038	0.012

Appendix 2: Anatomy of smart tools

A smart tool generally consists of 4 functionally distinct sections: a traction unit which ensures the drive of the scraper by the transported fluid, an on-board power supply, a measurement system and a measurement acquisition and recording system. These different systems are grouped together in elements linked together by gimbals ensuring the flexibility of the whole (figure above).

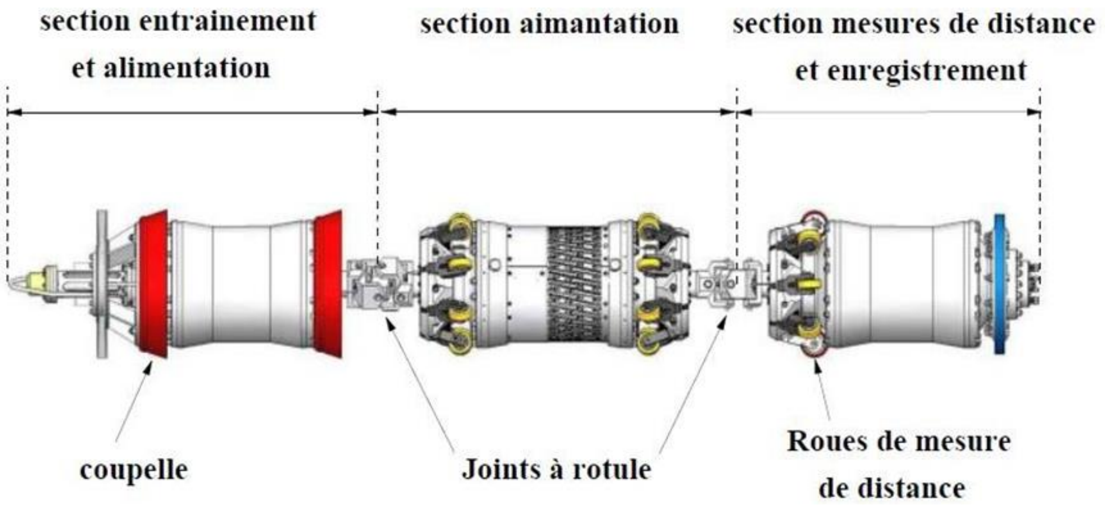


Figure 84 : smart tool; Instrumented piston based on the principle of loss of magnetic flux

This flexibility is necessary so that the pigs can evolve in the bends of the pipes to be inspected. The smaller the diameter of the pipe, the more it is necessary to stretch the scrapers in length and multiply the number of elements in order to carry all the modules. This leads to scrapers up to 6 meters in length.

This technology is based on powerful magnets placed in the tool. The longitudinal magnetic flux thus generated circulates in the wall of the tube between the two poles of the magnet. He is calibrated so as to saturate it and that part of this flow circulates in the fluid and outside the tube. Sensors are placed against the wall of the tube and bathed in this flow. When a lack of metal is present in the wall of the tubes, the magnetic flux must escape a little more from the wall to be able to circulate and the sensors react to this increase in the leakage of magnetic flux (Magnetic

Flux Leakage or MFL) .

Reacting to changes in magnetic signals, this technology gives a relative dimensioning of metal losses in relation to the assumed thickness of the tubes.

To detect longitudinal cracks, magnetic fields oriented perpendicular to the axis of the tubes are used so that the magnetic flux "sees" the side of the cracks. These then cause sufficient reductions in the cross section of the metal wall to generate a detectable increase in magnetic flux leakage. These tools currently allow the detection of large cracks or very open cracks (large spacing between the two crack flanks).

These sensors have improved considerably to the point where the detection of metal losses is even possible at the level of the weld beads and on the internal and external face of the wall. They can even be adapted to measure the absolute thickness of the stress. The amount of recorded data increased considerably to such an extent that BRITISH GAS, in a document, claims that the equivalent of the bible was recorded every six seconds

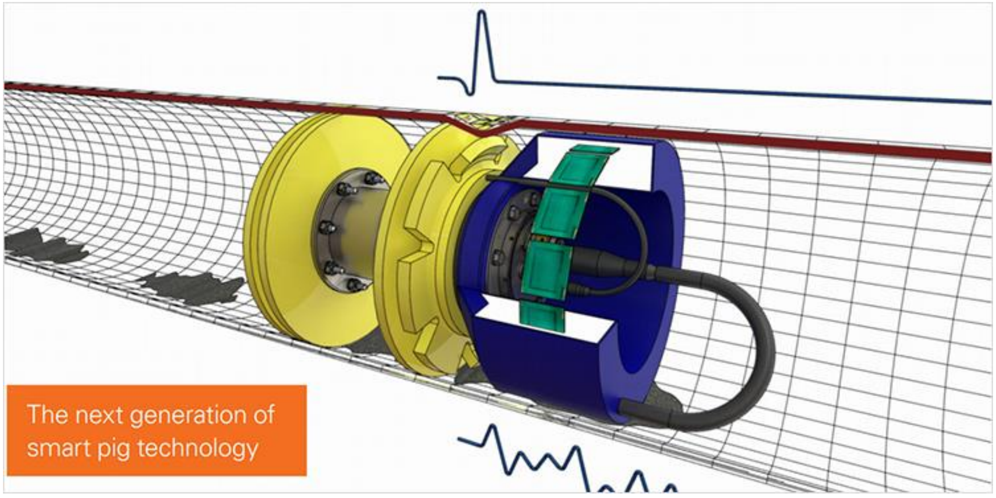
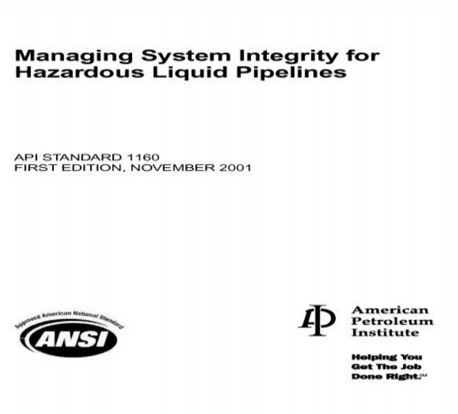


Figure 85: description of the smart tool

Appendix 3:

Table 8 : summary of commonly used permanent pipeline repairs

Anomalies		PRIMARY REPAIR STRATEGIES[1]				
		Weld Metal Deposition[2]	Type A Sleeve	Type B Sleeve	Composite Reinforcement	Hot Tap
External Metal Loss ≤ 80% w.t.	Pipe Seam	Yes	Yes	Yes	Yes	No
	Girth Weld	Yes	Yes	Yes	Yes	No
	Pipe Body	Yes	Yes	Yes	Yes	Yes
	Bend	Yes	Yes[3]	Yes[3]	Yes[4]	Yes
Internal Metal Loss ≤ 80% w.t.	Pipe Seam	No	No	Yes	No	No
	Girth Weld	No	No	Yes	No	No
	Pipe Body	No	No	Yes	No	Yes
	Bend	No	No[3]	Yes[3]	No	Yes
External Metal Loss > 80% w.t.	Pipe Seam	Yes	No[8]	Yes	No[8]	No
	Girth Weld	Yes	No[8]	Yes	No[8]	No
	Pipe Body	Yes	No[8]	Yes	No[8]	Yes
	Bend	Yes	No[8]	Yes[3]	No[8]	Yes
Internal Metal Loss > 80% w.t.	Pipe Seam	No	No	Yes	No	No
	Girth Weld	No	No	Yes	No	No
	Pipe Body	No	No	Yes	No	Yes
	Bend	No	No[3]	Yes[3]	No	Yes
Leaks, Cracks, Arc Burns and Girth Weld Flaws[12]	Pipe Seam	No	No	Yes	No	No
	Girth Weld	No	No	Yes	No	No
	Pipe Body	No	No	Yes	No	No[10]
	Bend	No	No	Yes[3]	No	No[10]
	Thread Collar	No	No	Not Practical	No	No
Dents with Stress Concentrators	Pipe Seam	No	Yes[5,6]	Yes[6]	No	No
	Girth Weld	No	Yes[5,6]	Yes[6]	No	No
	Pipe Body	No	Yes[5,6]	Yes[6]	No	Yes[11]
	Bend	No	Yes[3,5,6]	Yes[3,6]	No	Yes[11]
Plain Dents	Pipe Seam	No	Yes[5]	Yes	No[7]	No
	Girth Weld	No	Yes[5]	Yes	No[7]	No
	Pipe Body	No	Yes[5]	Yes	No[7]	Yes[11]
	Bend	No	Yes[3,5]	Yes[3]	No	Yes[11]


Managing System Integrity for Hazardous Liquid Pipelines

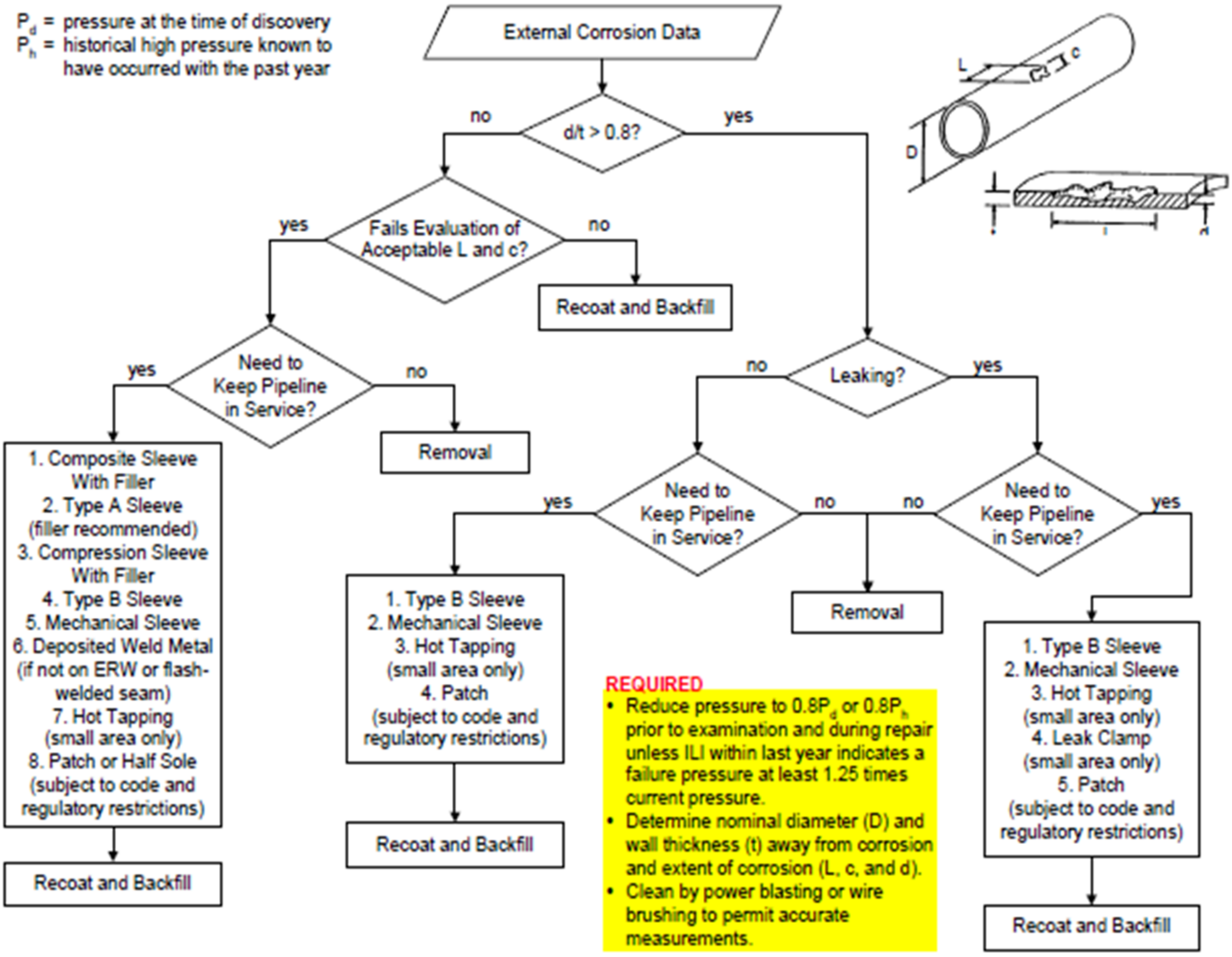
API STANDARD 1160
FIRST EDITION, NOVEMBER 2001

American Petroleum Institute
Helping You Get The Job Done Right.

API STANDARD 1160

Appendix 4:

Appropriate repairs for various types of defect



Assessment of depth and circumferential width