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Influence of sand movement in the Sahara on the erosion of pipeline network

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Abstract. The influence of sandblasting on a surface notched of pipeline with API 5L X52 steel is studied. The purpose of this study is to determine the evolution of static characteristics and lifetime of material in both directions of pipeline (Longitudinal (L) and Transverse (T)). Specimens were taken from a pipeline and the material damage was made by projecting corundum particles (aluminium oxide). In order to justify the evolution of mechanical properties of material, residual stress analysis was realized by the technique of X-ray diffraction. The observation of damage mode and distribution of residual stress under the notch tip show that the material hardening, the notch radius and the compressive stress, play together an important role in stabilizing the material mechanical properties.

1 Introduction

Erosion is a mechanical process that causes an eroded volume on the surface of a material. The erosion phenomenon of metallic structures, in petroleum industry, subjected to fatigue process by sandblasting, is a problem which affects many industrial sectors. The shocks between the sand particles and the pipeline surface cause a severe damage. It is manifested by spalling craters of different shapes and depths [1]. The wall-thickness is gradually reduced and the rupture occurs when the stresses in the crater reach a limiting threshold.

The erosion rate increases according to the sanding duration up to a constant value [2]. The authors [2] divide the phenomenon of the eroded volume into four consecutive stages: the initial stage, characterized by high volume loss rate at the beginning of the test, the incubation stage (some cracks are observed because of the accumulating plastic deformation), the acceleration stage and the maximum rate stage where the original surface is completely removed.

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The main parameters of erosion are: the exposure time, the kinetic energy of particles [3, 4] and the impact angle [5]. Irrespective of the impact loading type, the materials stresses, strains and the damaged surfaces would increase with increase of the impact velocity [3, 6].

The mechanical, chemical and thermal actions are the cause of the material separation, but the means to achieve these actions, are different. According to Meng [7], there are four main mechanisms of erosion by impact of solid particles: Cutting, fatigue, brittle fracture and melting.

To study the material fatigue after the sandblasting operation, many tests were made. The sand erosion process improves resistance to fatigue under stresses [8, 9, 10]. This improvement comes from the introduction of residual stresses in compression at the hardened surface layers. Many studies show the benefits of the process on the material fatigue. De Los Rios [11] and Vo [12] show an improvement of endurance limit and material lifetime. This improvement is due to the surface state which improves by limiting the micro concentrations of stresses.

2 Experimental procedures

2.1 Material

Mechanical tests were realized on specimens with API 5L X52 steel taken from a pipe in both directions, Figure 1: Longitudinal direction (L) and Transverse direction (T).

This tube has an external diameter of 610 mm and a thickness of 11 mm. It is used in the European natural gas transporting network. This section is selected from the pipeline which was used in the 50s and was removed in the beginning of twenty-first century. It is therefore representing the actual European transport network.

The pipe was manufactured according to the standards of the American Petroleum Institute: API 5L X52. A measure of the chemical characteristics was done on this material, Table 1:

Table 1. Chemical composition of API 5L X52 steel (wt %).

C	Mn	Si	Cr	Ni	Mo	S	Cu	Ti	Nb	Al
0,206	1,257	0,293	0,014	0,017	0,006	0,009	0,011	0,001	<0,03	0,034

The microstructure of API 5L X52 steel was analyzed by optical microscopy after mechanical polishing and chemical treatment with Nital, Figure 2. The metallographic analysis confirms that the sheet used in the manufacture of this pipe is rolled in both directions (L and T). The rolling rate in both directions may be different. Indeed, we observe bands of perlite colored in black alternating with bands of ferrite in white which is a sign of rolling. We can also say that the ferrite is the main component of this structure. The microstructural study show that the grain diameters range from 7 to 15 µm.

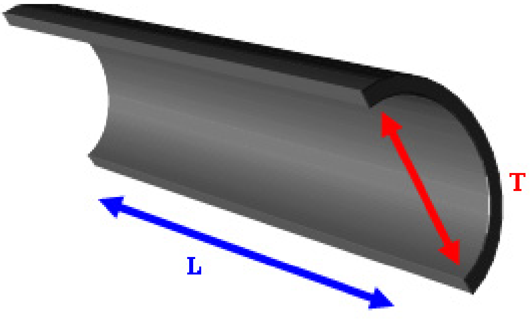

Fig. 1. L and T directions of pipeline.

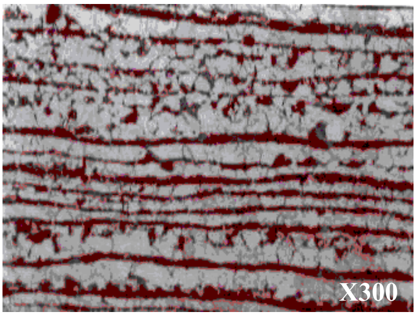

Fig. 2. Microstructure of pipeline API 5L X52 steel.

2.2 Sand erosion conditions

The basis of this study is to assess the material damage by sand impacting. For this purpose, we used a Blaster 2700 sandblasting machine, equipped with a pressure gauge, enabling it to adjust the desired power, Figure 3. Sand supply (Al_2O_3) is ensured by the venturi effect, with a constant sand feed throughout sandblasting operation. The air flow velocity (32 $m.s^{-1}$) was measured by means of a wind gauge using an anemometer. It represents the average wind velocity or the sandblasting velocity in nature (especially in the desert regions). It is evident that the flux velocity obtained by the anemometer does not correspond to the sand particles velocity. The sand particles velocity was not determined because of the complexity related to the variations in the nature, size and shape of sand. The sand grains have an angular shape and their average size is between 300 and 400 µm. The mechanical properties of sand are presented in Tables 2:

Table 2. Mechanical properties of sand (corundum) in air (industrial data).

Hardness Vickers (*HV*)	Tensile strength (*N/mm²*)	Bending strength (*N/mm²*)	Compression strength (*N/mm²*)	Young modulus (*N/mm²*)	Poisson's ratio	Stress intensity factor (*Mpa.m^1/2*)
180-200	200-250	200-600	1900-2000	$3.8\ 10^5$	0.25-0.3	4-5

In order to adjust the projection angle of the abrasive and to concentrate the particle impact on a predefined area, an assembly was made, Figure 4, with the following properties: nozzle diameter of 8 mm, an average sand feed during the erosion tests is about 1.57 g / s, an impact angle between the sand particles and the specimen surface is 90 °, a distance between the nozzle and the specimen is 200 mm (allowing to sand particles to impact all the notch area), an air pressure of 4 bars and a sandblasting duration varying between 60 and 480 min.

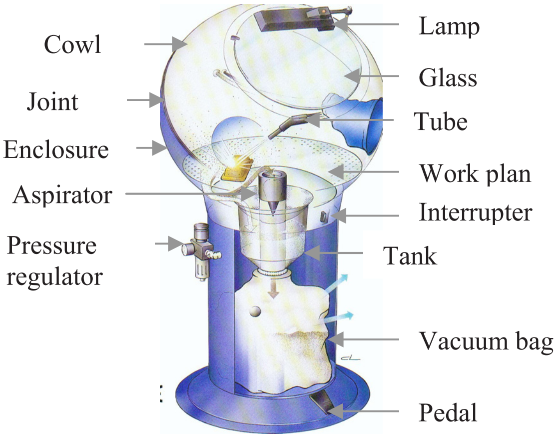

Fig. 3. Blaster 2700 Sandblasting machine.

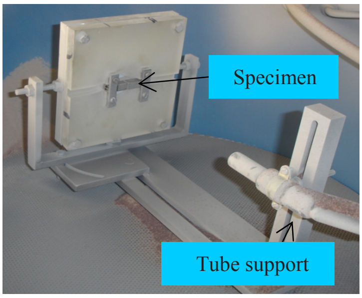

Fig. 4. Specimen holder assembly.

3 Results and discussions

3.1 Static characteristics

The behaviour law of the material was obtained by performing tensile tests on specimens taken from a pipeline in both longitudinal and transverse (L and T) directions, Figure 5. the extraction and manufacturing of specimens were carried out so that the area (of the neutral plane) of a pipe coincides with that of tensile specimens.

Tensile tests were realized on many specimens (L and T). The original specimens were treated as a reference and the others were impacted by sandblasting for eight hours; sanding was applied to one of the two specimen's faces.

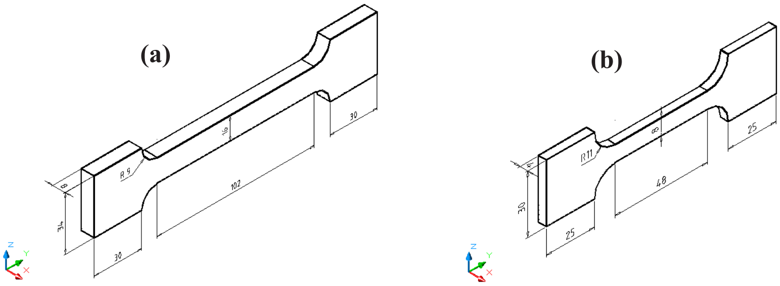

Fig. 5. Tensile specimen geometry: a) L direction, b) T direction.

These tests were performed on the machine INSTRON 5585H, equipped with a static load cell of ± 250 kN and pneumatic jaws, which is in agreement with the French standard AFNOR [13]. The specimen tensile strain in both directions, longitudinal and transverse, is controlled by using a video extensometer bidirectional.

The stress strain curves, Figure 6, represent one test of each configuration. The average values of all tests are presented in Table 3.

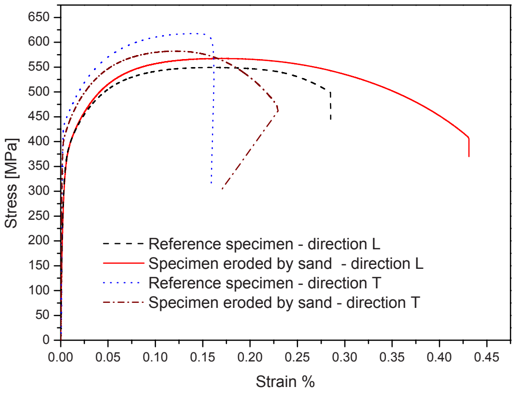

Fig. 6. Behaviour law of API 5L X52 steel in both L and T directions.

Table 3. Influence of sandblasting on the tensile properties of API 5L X52 steel in the both directions: longitudinal (L) and transverse (T).

Specimen type	Yield stress σ_y [MPa]		Ultimate strength σ_u [MPa]		Elongation at fracture A%	
	L	T	L	T	L	T
Reference	318	450	548	626	24,94	18,17
Impacted by sand	322	429	561	574	34	21,23

In view of these results, it is possible to conclude that:

1. API 5L X52 steel without pre-mechanical loading (reference specimens) is more resistant in the T than in the L direction. This behaviour is due to the ferrite and perlite bands, which are more compressed in the T direction. This effect is produced during manufacturing of the pipe (rolling and welding).
2. The material behaviour in both L and T directions, after eight hours of sanding, is different:
a) In the L direction, the sanding increases all the static mechanical characteristics. The increase of yield stress and ultimate strength is slight but the elongation at fracture is very large. It is about 36% more compared to reference specimens.
b) In the T direction, sanding reduces the yield stress by 4.7% and the ultimate strength by 8.3% while the fracture strain is increased by 16.8%.
c) In both L and T configurations, the sandblasting influence on the static properties of the material is expressed by the increase of elongation at rupture. This advantage is due to the plastification of the surface layers impacted by sand, which increases material ductility.

3.2 Fatigue characteristics

The purpose of these tests is to show the influence of sandblasting on the pipeline lifetime. In order to do that, several fatigue tests (3 points bending tests) on roman tile specimens were performed. Figure 6 shows the geometry of these specimens.

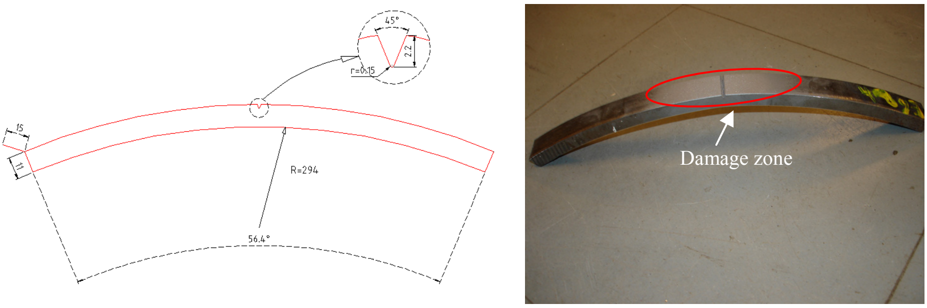

Fig. 6. Fatigue specimen geometry: “Roman tile” specimen.

The lifetime evolution study of the material, notched under the sand impacting, was carried out in two stages:

a) Specimen preparation: They were sanded during 8 hours. The geometry of the notch profile before and after sandblasting was measured, Figure 7. The form and the parameters of the notch are completely changed.

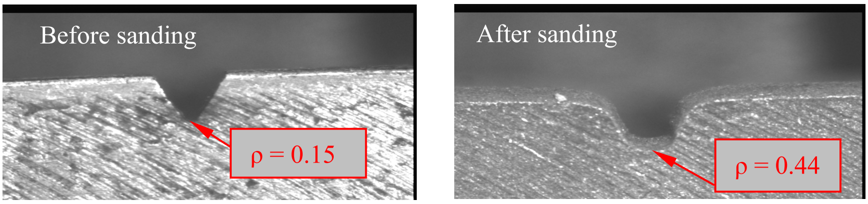

Fig. 7. Notch profile geometry before and after eight hours of sandblasting.

b) Realization of fatigue test

The roman tile specimens used in fatigue tests were subjected to a sinusoidal loading and for a load ratio of 0.5. The daily evolution of the internal pressure of these pipelines is between 40 and 70 bars. The average load applied is between 750 and 2625 N. This load is applied on the opposite surface to the notch and just in the middle of the horizontal distance between the two supports which is 180 mm. The specimen section is of 8.8 mm x 15 mm, Figure 6.

The cycle frequency was between 1.7 and 10 Hz. For the tests in air, it is possible to change the frequency from one test to another.

Wöhler curves obtained from the 3 points bending tests, for different cases, are presented in Figure 8. These curves show that sandblasting increases the life duration. The beneficial effect of sandblasting is due to three main parameters:

i) The local hardening

ii) The residual stresses are in compression at the notch bottom.

iii) The notch radius increases during sanding. After 8 hours of sanding, the radius increased from 0.15 to 0.44 mm, Figure 7.

The gain in the material lifetime by sanding, compared with the reference one (fatigue test in air carried out to reference specimens), is a function of applied load. This value varies from 32% at the highest load (more than 2250N) to 143% for a load less than 1000N.

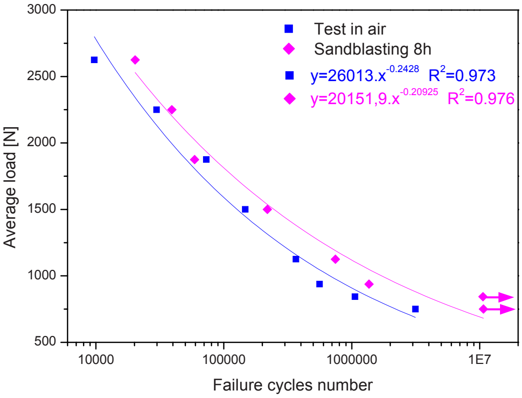

Fig. 8. Wöhler curves for API 5L X52 steel.

3.3 Residual stress analysis

This analysis allows us to answer the questions related to the evolution of mechanical properties of pipeline API 5L X52 steel under sandblasting. The residual stresses were measured by the technique of X-ray diffraction. This measurement was performed on Charpy L and T specimens (Figure 9) with two values of notch radius: 0.25 and 0.50 mm. Considering that the pipe's dimensions have high curvature and thin thickness, only the specimen width (w) varies (it is 10 mm in the L direction and 7.5 mm in the other T one).

After conducting sandblasting tests for different time intervals, the measurements were taken at several points from notch tip and through the specimen thickness (r), Figure 9. The plastification zone is just around the notch tip, so it is better to take the points very near to the notch.

The distribution of the maximum principal residual stresses at the notch bottom in both L and T directions is presented in Figure 10.

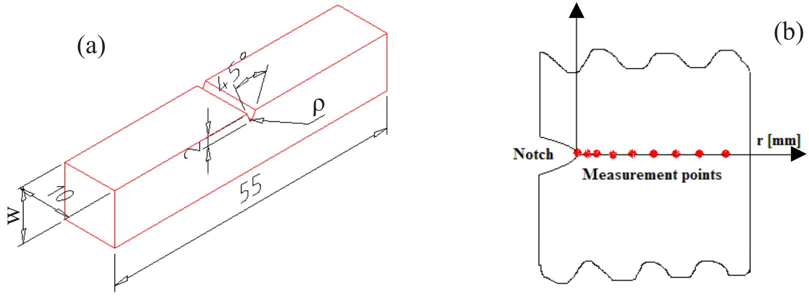

Fig. 9. Schematic view of : a) charpy geometry, b) measurement points.

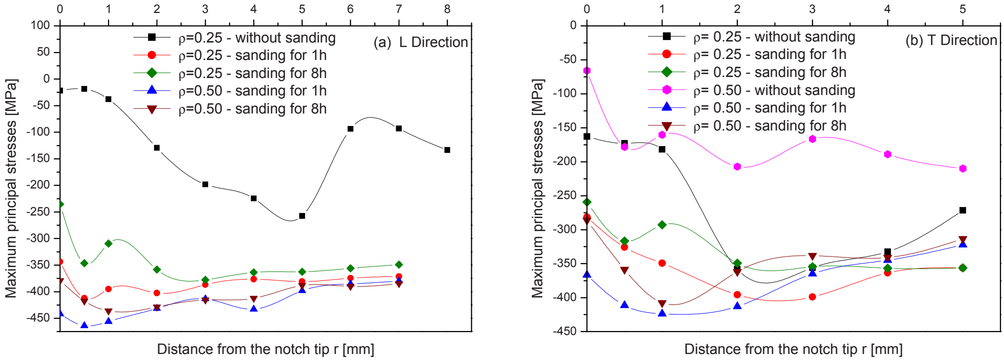

Fig. 10. Variation of the maximum principal residual stresses at the notch bottom, for different values of notch radius and sanding time, in two directions: a) L direction, b) T direction.

From these results, we find that:

- In all cases, the residual stresses are compressive. Sandblasting influences the level and distribution of residual stresses.
- Larger the notch radius, wider the impact area and more are the residual stresses.
- After 1 hour of sandblasting, the compressive stresses are more important than that after 8h of sandblasting. This situation is due to the material hardening. At the beginning of the erosion, the material hardens up to 1 hour of sandblasting. After this value, plastification starts, thus stress relaxation is followed by a more significant damage.
- In the L direction, we show that the sanding time until 1h produces more damage. We see a little difference between the two times (1 hour and 8 hours) starting from r = 2 mm for ρ = 0.5 mm and r = 3 mm for ρ = 0.25 mm.
- In the T direction, the same remarks as above are observed except that the stabilization of residual stresses starts from r = 4 mm for both values of the notch radius.
- The compressive residual stresses introduced by sandblasting are more important in the L direction than the T direction.

The variation of mechanical properties of API 5L X52 steel after sandblasting is due to material damage and the microstructure evolution. In order to observe these changes, a scanning electron microscope (SEM) is used. Figure 11 illustrates the decrease of grain size at the notch tip. For a depth up to 10 µm, we can see the fragmentation of grains at the notch tip. This transformation is a sign of large plastic deformation.

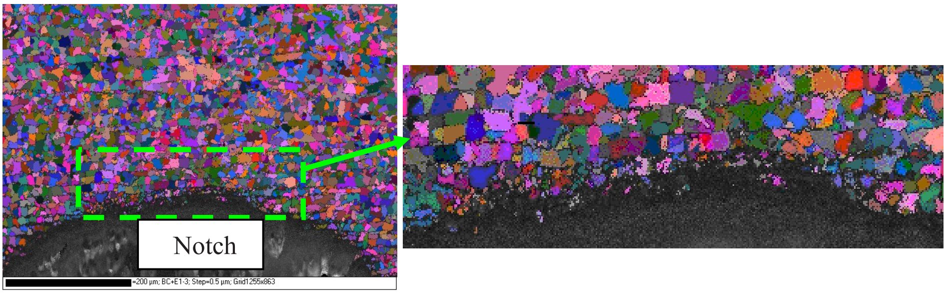

Fig. 11. Microstructure of API 5L X52 steel eroded during 8h.

4 Conclusions

The damage of pipeline surface notched with API 5L X52 steel, under sand impacting, was studied. In order to evaluate the material mechanical behaviour under the sand erosion, tensile and fatigue tests were realized. The evolution of the material microstructure was analysed by measuring the residual stresses and observation of damage mode.

One of the first effects of sandblasting on API X52 steel is the significant variation of the elongation at rupture. The yield stress and ultimate strengths are slightly affected. Generally, these remarks can be considerable whatever the configurations direction of pipeline: longitudinal or transverse.

For fatigue, sand erosion improves the life duration of the pipeline. The material lifetime under the influence of the sand erosion depends on the applied load.

The microstructure analysis at the notch bottom shows that at the beginning of the erosion, the material undergoes hardening until one hour of sanding. After this value, plastification starts, thus stress relaxation is followed by more important damage.

The material hardening, the notch radius and the compressive residual stresses, play an important role on the mechanical properties of the material. The hardening and damage are important parameters for estimating the life duration of a structure, namely pipes.

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