

## Investigation of weld cracks by Microfocus tomography

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**Abstract**-The reliable of inspection and measurements in a non-destructive way is quite important in industrial area, mainly when it is related to quality control of weld joints. Ultrasound and Radiography can be used in order to check weld integrity. However they just can often be identified by visual inspection. 3D x-ray microtomography permits a real time quantitative investigation all over the micro architectural of the sample with a very good spatial resolution (micro order). The porosity parameter can be very important because it is related to the properties of alloy interconnects, such as degradation of mechanical performance. The goal of this work is to investigate critical welding flaws such as longitudinal, sagittal and transversal cracks, lack of penetration and porosity by 3D x-ray microtomography.

### I. Introduction

The constant and increasing use of natural gas and oil requires large investments dedicated to the design of new pipelines, which increases the manufacture demand of steel tubes for such application. Longitudinal welding steel pipes are used in oil and gas industry and they are manufactured mostly in accordance with API 5L specification. The structural integrity of welded joint in steel offshore arrangements is very important, such as an in-depth study of its microstructure. The presence of defects can lead to ultimate loss of structural integrity of the material and it can include cracks, inclusions, pores, incompletely jointed regions and microstructural degradations. For example, by knowing the dimensions of the defect it is possible to estimate remaining life of the component.

Non Destructive Testing (NDT) is regular used in order to inspect welder pipe [1]. The three most common methods are visual weld inspection; liquid dye penetrates testing and radiographic testing. However, new technologies can be applied in order to improve the assessment knowledge. X-ray imaging techniques are often used for inspection in medical diagnosis and it can be extended to industrial field. The development of new generation of detector system benefits industrial radiography mainly in terms of image quality, which leads to a better diagnosis because significant improvements can be achieved. Together with this the use of digital radiography in NDT leads to decreases exposure times and reduced shutdown periods.

Another X-ray based technique is the 3D x-ray microtomography (microCT), which can be very helpful in quantitative researches with the advantage to reveal the presence of 3D fine scale structures [2]. The fundamentals of this technique have been reviewed many times. Basically a series of x-ray radiographies are obtained at different rotation angles and after reconstruction step it can be used successfully to extract non-destructively valuable volumetric information, which is not possible in conventional radiography. Thus, it is possible to generate a map of the attenuation coefficient from measurements of projections. The usual x-ray tubes contains a broad range of energies that attenuate by different amount, which leads the attenuation coefficient function represents some complex average of attenuation integrated over energy and local directionally dependent intensity profile. That is the beam-hardening artifact is caused by the non linear relation between the attenuation values and the measurements values of the projection. In general, the low energies are more strongly absorbed than the high energies. This phenomenon leads an image error called beam-hardening artifact, which decreases the image quality in tomography measurements.

A strategy of recovering internal volumetric structure data evolved prior to computers and detectors. In the past tomography experiments, a Geiger Müller counter was used as a detector in pencil beam geometry. The third generation scanners were gas based detector arrays in fan beam geometry and even these days some scanners using high-pressure xenon gas are in use. However, nowadays it is very easy to find tomography systems equipped with solid-state scintillator detectors. It is quite usual systems in which an x-ray image intensifier and a charge coupled device television camera acts as the detector. More recently, flat panel detectors have becomes commercially available in tomography systems and the availability of them using both indirect and direct

detectors reinvigorate the using detectors in microCT. Basically, they convert x-rays energy into electrical signals for digitalization. They have sensor elements, which consist of a photodiode and a thin film transistor. Both are made of amorphous silicon on a single glass substrate. The pixel matrix is coated with x-ray sensitive layer, such as cesium iodide. The close interface between the cesium iodide crystals and the photosensitive diodes preserves the high fidelity transfer of the projection data from photon energy to digitized signals. Flat panel detectors offer several benefits. Image intensifier creates geometric distortions that must be addressed when processing the data in the software, while flat panel detectors (FPD) do not suffer from this problem. Also, FPD afford a greater dynamic range than offered by II plus CCD approach and they have a higher spatial resolution image than II.

In this context, the goal of this work is to investigate welding steels pipelines by analyzing its structures and internal architectural by x-ray imaging technique.

## II. Materials and Methods

For this study pipes manufactured with laminated carbon steel plate was used. The samples of API 5L, grade X65 were welded by shielded metal arc welding procedure. They contained introduced critical artificial defects, such as cracks, lack penetration, porosities and slag intrusions. This type of steel is used in the manufacture of pipelines in the oil, gas and petrochemical industries.

In order to inspect the samples digital (DR) and conventional (CR) X-ray radiographies were used (Figure 1). In DR digital detector array (DDA) with pixel size of  $127\ \mu\text{m}$  was used in two magnifications mode (maximum of 1.2), which depended of the wall thickness to be inspected. This inspection was done with an x-ray tube calibrated to operate at 225 kV and 8 mA, setting and geometric setup of 700 mm for the distance source-detector and 90 mm for the distance sample-detector, with acquisition time of 64 seconds. In CR industrial film class 1 was used [3,4].

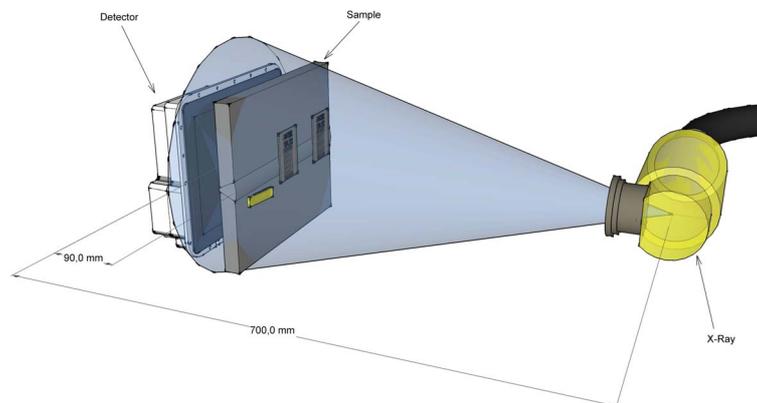


Figure 1: Draw of X-ray radiography setup.

1173 Bruker/Skyscan microCT model was used, which is combined with a flat panel detector and spiral scan geometry. The system was calibrated to operate at 130 kV of energy and a current of  $61\ \mu\text{A}$  with  $0.3^\circ$  of rotation degree over  $360^\circ$ . To reduce the contribution of low energy photons in order to minimize the effects of the beam hardening effect, a combination of steel and aluminum filters (0.5 mm of thickness) were used. After the acquisition process, the radiographic images were rebuilt. For that purpose, NRecon<sup>®</sup> (Nrecon, 2011) - version 1.6.4.1 and InstaRecon, (InstaRecon, 2011) - version 1.3.5.0 softwares were used. NRecon<sup>®</sup> and InstaRecon<sup>®</sup> allows the selection of many parameters in the reconstruction step creating a better quality image, such as artifacts and beam hardening corrections. The Skyscan, CTAn<sup>®</sup>, (CTAn, 2012) (v.1.11.8.0) software was used for image processing and analysis.

## III. Results and Discussion

The results show that it is possible to visualize the size and distribution of the defects presented in the samples in a non-destructive way. In Figure 2 show DR and CR images examples and it was possible to note the

performance of these two x-ray radiography types for a sample of 25.3 mm of wall thickness, base metal. In this figure, the DDA with 8 s and 32 s of integration time (b,c) and AGFA D4 film (a) are shown. It can be observed discontinuities type porosity, lack of fusion, lack of penetration, slag inclusion and longitudinal and transversal cracks thin, which are more easily seen in the images of digital technology.

After X-ray radiography inspection, several cuts were performed in order to inspect the internal structure of the defects. The square on figure 2(d) shows the piece scanned by microCT. Figure 3 and 4 show some microCT views of the sample and its defect, as well as 3D microCT representation. The scan was performed with a pixel size of 9.91  $\mu\text{m}$  and a Hamamatu flat panel detector made up 2240 x 2240 pixels grid, which are very important because the quality of a weld is directly linked to the weld are microstructure. In order to evaluate quantitatively the defect microCT evaluation was performed. The results are presented in Figure 5. It can be note the volume and the thickness distribution of the defect directly by 3D dataset. Although microCT is used only in a scientific level, the results lead to believe that with the improvement and refinement in image processing, this technique can be a great potential for industrial analysis, including quantification results, such as cracks volume.

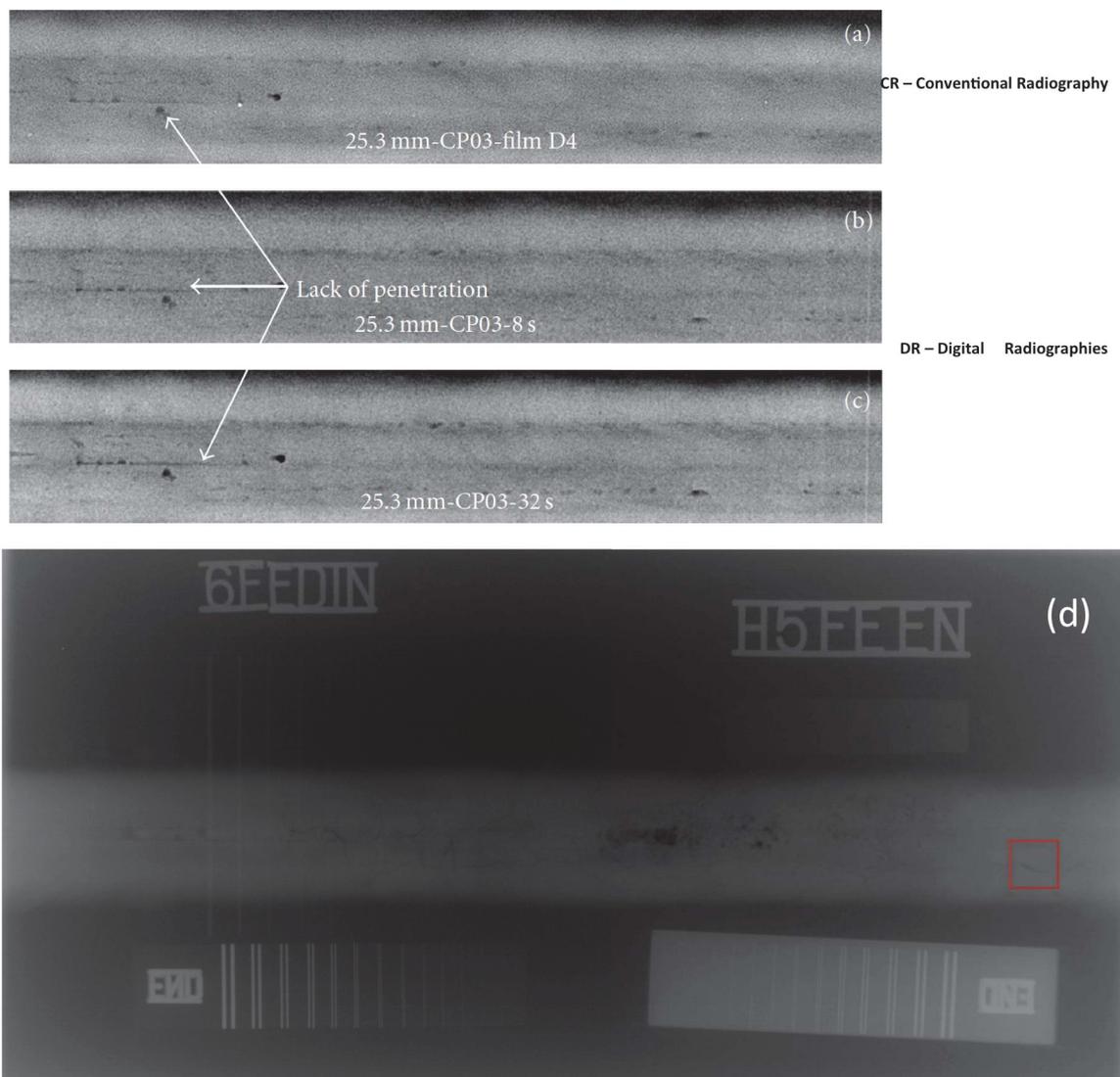


Figure 2. Conventional (CR,a) and digital (DR, b-d) radiographies for wall thickness inspection of 25 mm with 8s (b) and 32 s (c) of integration time and (d) fracture detail inspected by microCT.

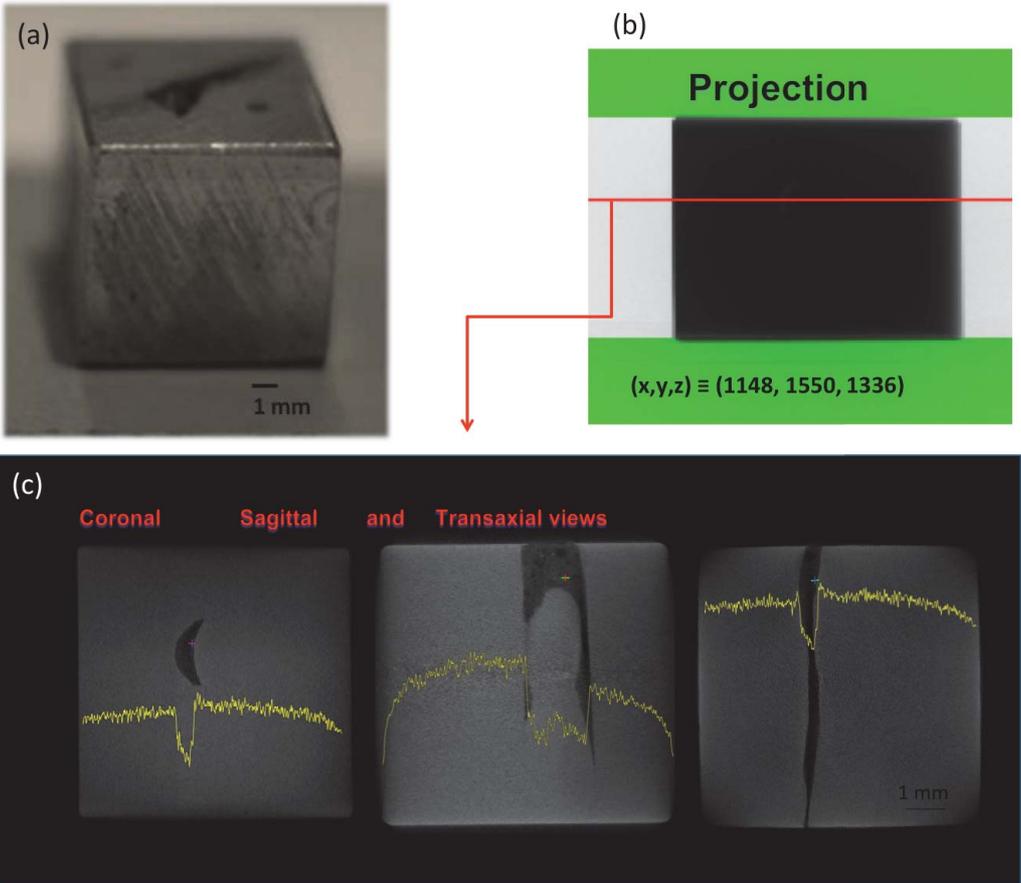


Figure 3. (a) Photography of the sample, (b) Projection Illustration, (c) microCT Views.

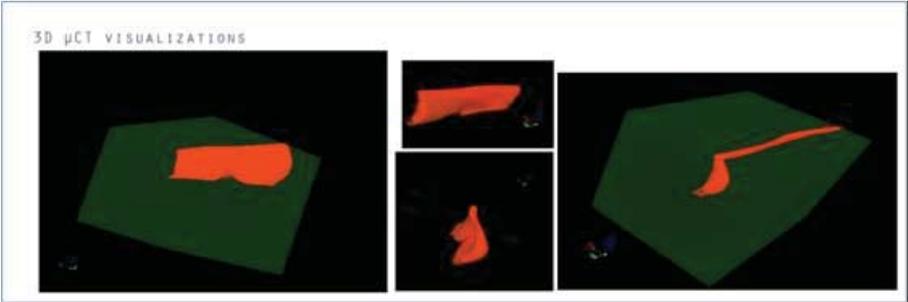


Figure 4. 3D views of the sample and illustration of the crack geometry.

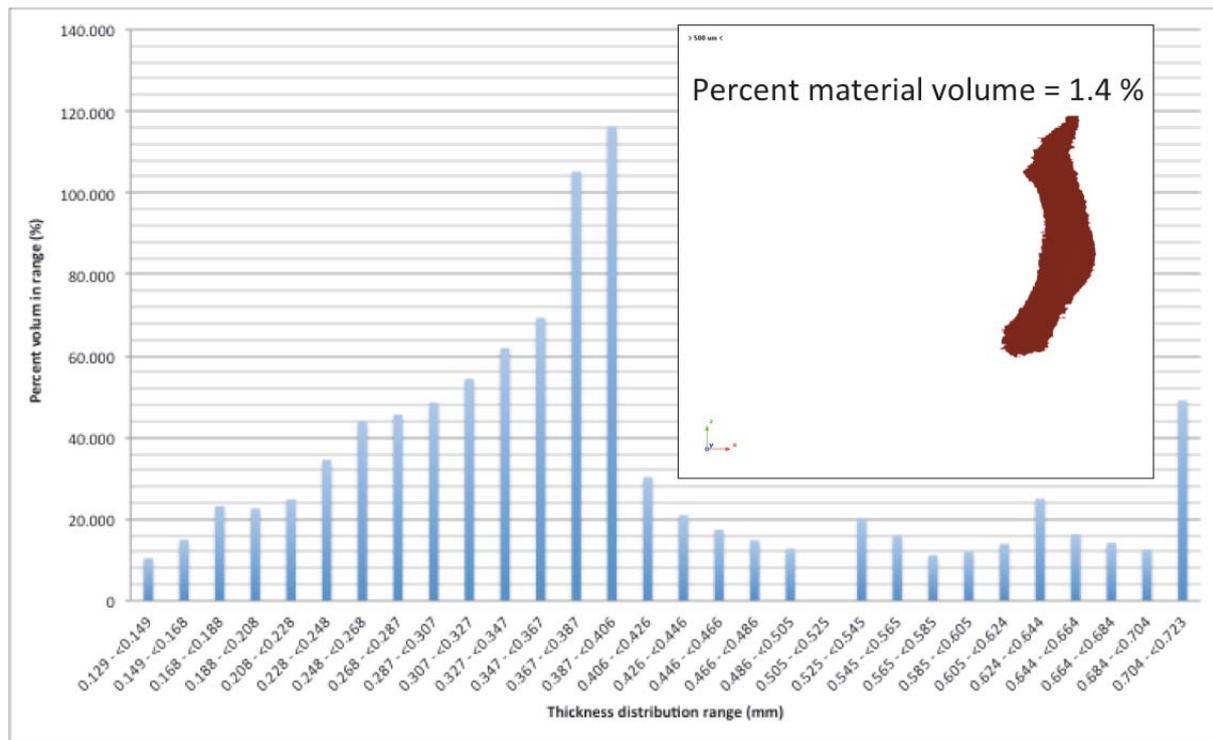


Figure 5: Crack thickness distribution and percent of volume microCT results.

#### IV. Conclusions

Digital techniques represent an advance in the quality of imaging testing, especially by 3D microCT, which shows to be a powerful technique in order to inspect carefully the geometry of the cracks presented in a welded steel pipeline. By microCT it was possible to evaluate of thickness distribution and percent material volume non-destructively.

#### References

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