Simulation Study on X-Ray Radiographic Testing of Welds

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Abstract

Despite the acknowledged advantages that computer simulations can offer to Radiographic Testing, simulation solutions are uncommon in the industry. This paper presents an effective strategy for the simulation of Radiographic Testing techniques using Geant4 Application for Tomographic Emission (GATE), which is a medical imaging software toolkit. Models for X-ray emission, test specimen geometry, radiation interaction with the test specimen, and image receptors were created in GATE. Single Wall Single Image and Double Wall Single Image techniques were set up to evaluate the simulation models. The results showed that GATE can afford a reliable and cost-effective solution in the simulation of radiographic Non-Destructive Testing procedures.

Keywords: Non-Destructive Testing, Radiographic Testing, simulation, Geant4, GATE

I. Introduction

Non-Destructive Testing (NDT) technology comprises methods and techniques used to test and evaluate engineering materials and structures without affecting deformation, alteration, or harming their serviceability [1]. Radiographic Testing (RT), also known as industrial radiography, is one of the NDT methods that employs gamma-rays or X-rays to provide images of the internal structure of a material to reveal, identify, and characterize potential defects [2].

NDT plays a crucial role in the nuclear industry, where it is extensively used to ensure reliable construction and safe operation of mechanical structures.

Computer simulation of RT offers numerous advantages, such as optimizing the testing procedure by analyzing the parameters that can influence the testing sensitivity and studying the radiation field and dose distribution. Furthermore, RT simulation affords an efficient approach to personnel training because it overcomes the limitations of radiation exposure and the large number of required training test specimens. Several RT simulation tools are available, including XRSIM [3], RTSIM [4], aRTist [5], and CIVA [6].

Geant4 Application for Tomographic Emission (GATE) toolkit, which is a medical physics simulation software, is used in this work to simulate an RT using X-ray. A novel use of GATE for industrial radiography has been reported in [7], which is extended in this work to evaluate the performance in different RT configurations.

The versatility and accessibility (open-source software) of GATE enable the users to effectively explore building RT simulation environments to envision and facilitate the various operations and foster advancements in the field.

II. Materials and Methods

GATE is a Monte Carlo open-source simulation toolkit [8]. It was mainly developed to facilitate Medical Physics simulations. It offers various methods for modeling geometry, including generating geometrical models from Computed

Tomography data of an object and Computed-Aided-Design (CAD) models [9].

In GATE, an X-ray source was placed directly above a test object. The test object is either a carbon steel plate or a carbon steel pipe, and the image receptor was below the test object. Both objects were modeled using the CAD software SolidWorks and imported into GATE. Each object includes two welding defects: lack of fusion and lack of penetration. The objects' 3-dimensional models alongside the introduced defects are illustrated in Figures 1 and 2. For imaging the carbon steel plate, a BaBrF Computed Radiography (CR) image receptor was used. The imaging technique used with the plate is known as Single Wall Single Image Technique (SWSI), which is depicted in Figure 3. However, for the carbon steel pipe a silver bromide (AgBr) film was used. The film was wrapped around the pipe to mimic the RT technique known as Double Wall Single Image (DWSI), which is depicted in Figure 4. Since CR image receptors cannot be bent, it could not be used with the DWSI technique. All simulations were run on the European grid, where each run is split on up to 500 jobs to speed up the simulation process [10]. The pipe testing setup within GATE is illustrated in Figure 5

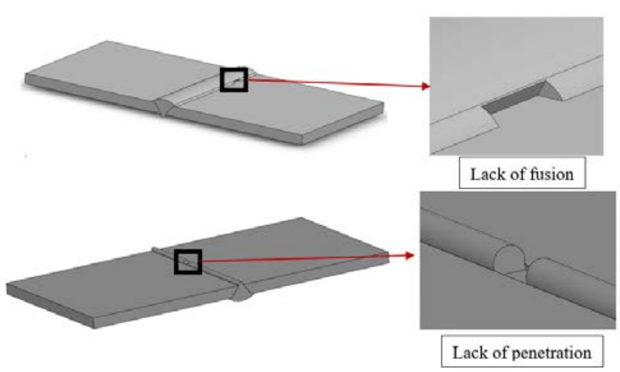


Fig.1. The carbon steel plate.

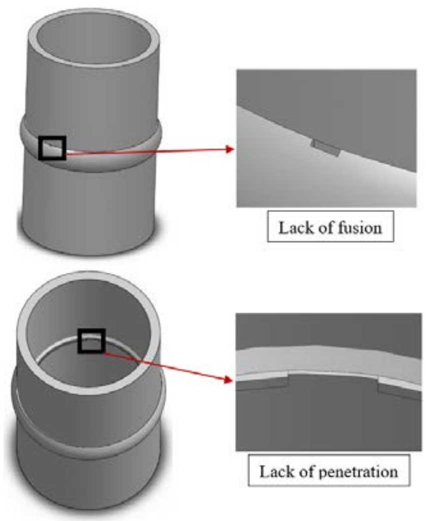


Fig.2. The 4-inch diameter Carbon steel pipe.

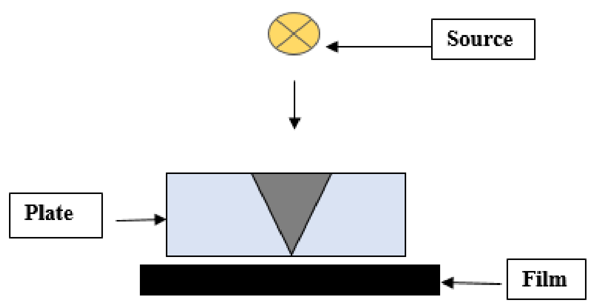


Fig.3. The SWSI technique

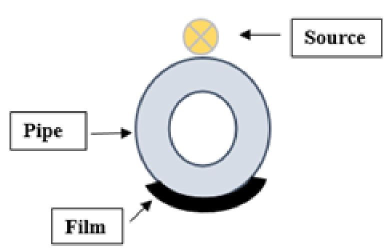


Fig.4. The DWSI technique

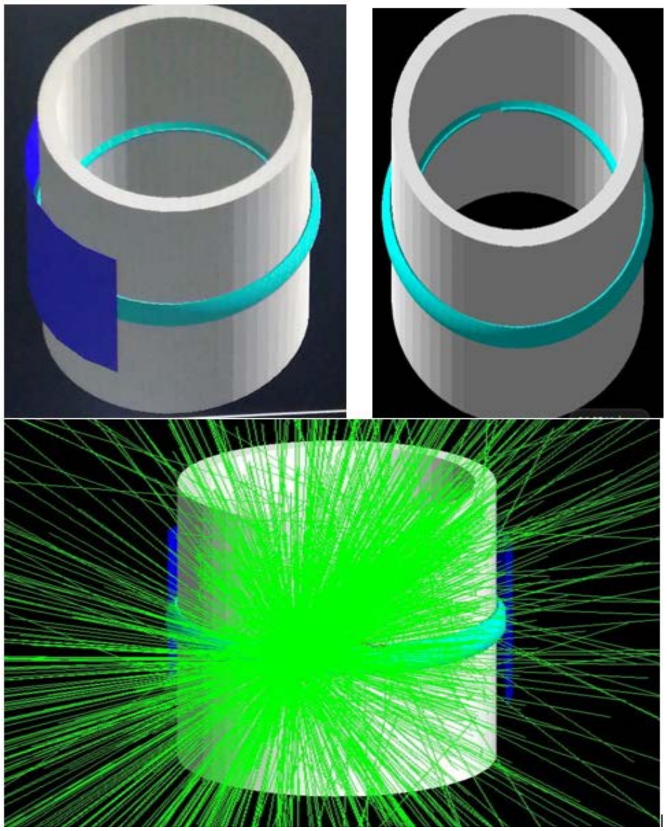


Fig. 5. The carbon steel pipe setup in GATE. The cyan region represents the weld, and the blue curved volume represents the film.

III. Result and Discussion

A. Flawed Carbon Steel Welded Plate

The radiographs obtained from the simulation displayed good-quality images. The achieved radiographic contrast and sharpness enabled a clear and precise definition of the defects, as well as the weld body and weld root. This is evident from the edge detection profile depicted in Figure 6, which demonstrates the accurate identification of the different features in the radiographic image.

The obtained results are promising and demonstrate the feasibility of creating diverse and reliable Radiographic Testing (RT) simulation scenarios.

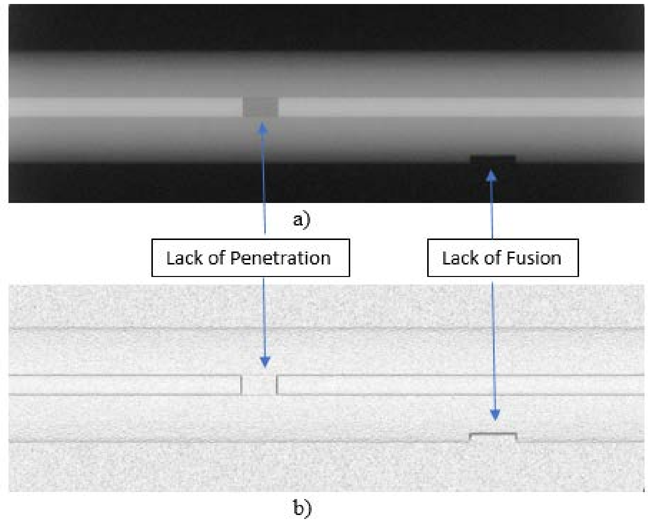
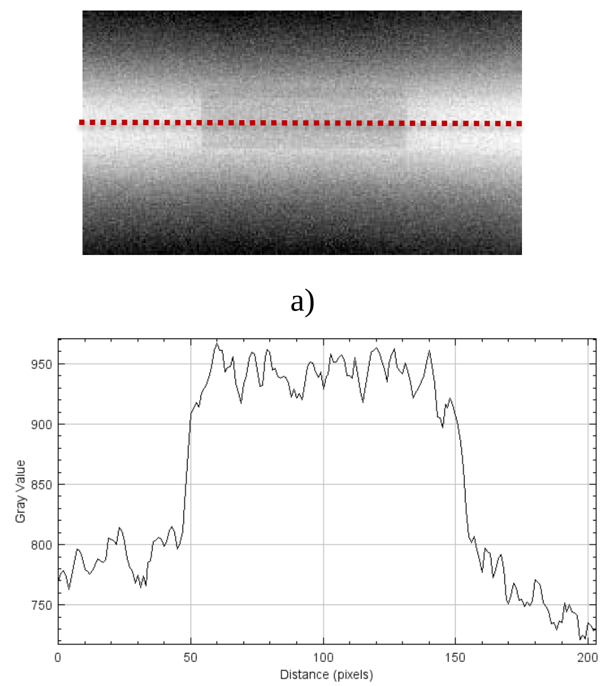


Fig.6. a) Welded plate radiograph using X-ray. b) Edge detection profile

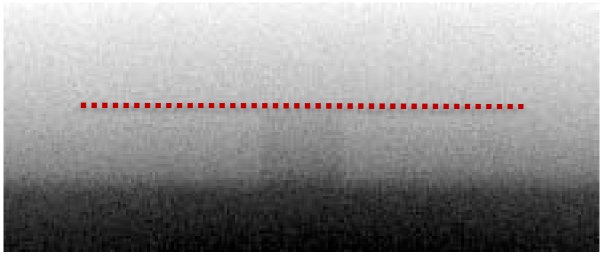
B. Flawed Carbon Steel Welded Pipe

Figures 7 and 8 are the radiographs obtained from the simulation, showing the weld defects, lack of penetration and lack of fusion, respectively.

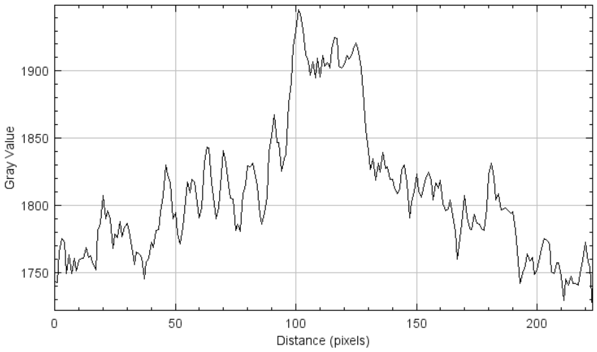


b)

Fig.7.a) The image produced by irradiating the 4-inch pipe lack of penetration region with 180 kVp X-rays. The red dotted line represents the region plotted in b)



a)



b)

Fig.8.a) The image produced by irradiating the 4-inch pipe lack of fusion region with 180 kVp X-rays. The red dotted line represents the region plotted in b)

The line profile within the area of interest exhibits a noticeable rise in radiation transmission at the location of the defects. Despite this observation, the radiographic image's contrast and definition remain below the desired standards. The initial analysis points towards the X-ray energy spectrum, X-ray intensity, and image receptor compositions as potential factors contributing to the substandard image quality.

Further investigations have been initiated to pinpoint the most influential parameters responsible for the poor image quality. The aim is to identify the specific aspects that require improvement to enhance the overall radiographic image quality.

IV. Conclusions

The present study has developed tools that allow for simulating radiographic inspections using GATE software. Once GATE is installed, users can integrate the developed resources, define the necessary material parameters, describe the item to be inspected, and run simulations.

The developed simulation environment provides an affordable option for Radiographic Testing specialists. However, it should be noted that the developed workspace is better suited for research and educational purposes. The Monte Carlo method used in GATE software can result in lengthy computation times, posing limitations on its practicality in industrial settings.

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