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EVALUATION OF FATIGUE CRACKS IN WELDED PARTS OF CLAD PIPELINES BY MEANS OF EDDY CURRENT TESTING

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ABSTRACT

Eddy current testing (ECT) with sensing coils placed orthogonally and connected in differential mode was applied to evaluate fatigue cracks in girth welds of clad pipelines. In the laboratory experiments, an automated inspection was performed with the goal to evaluate transducer's detectability, and different scanning speed was tested to reproduce in service situation. Three samples of clad material with a 45° bevel weld were tested in a three-point bend fatigue machine, resulting in a fatigue crack located in the weld root of the clad sample. The results have confirmed that the introduced eddy current transducer is a potential solution for fatigue crack detection in clad circumferential weld root.

Keywords: fatigue cracks, welded parts, clad pipes, eddy current testing

NOMENCLATURE

ECT	Eddy Current Testing
EC	Eddy Current
MFL	Magnetic Flux Leakage
EMAT	Electromagnetic Acoustic Transducer
CRA	Corrosion Resistance Alloy
GTAW	Gas Tungsten Arc Welding
CT	Computed Tomography

1. INTRODUCTION

The application of clad material to subsea pipelines is gaining ground in deep water oil exploration. Its bimetallic configuration presents an attractive combination of mechanical strength and corrosion resistance, ensuring the safety and integrity of pipelines that connect the reservoir to oil rig. The clad material for oil exploration consists of a base material, usually carbon steel, inner coated with a thin layer of corrosion resistance alloy (CRA), turning into an attractive economical solution for deep water exploration, since only a small portion of the noble anti-corrosive alloy is required. Clad material has a metallurgical bond between the CRA and the base material attained by carbon diffusion during the hot rolling process [1].

The potential for fatigue cracks to occur in pipeline structures due to cycling loads inherent of offshore oil production (such as, tide variation, waves, ocean current, platform movements, etc.) makes it necessary to have an inspection tool to carry out periodic nondestructive inspection in the inner pipe surface. In case of clad material, it is crucial to detect fatigue crack on its initial stage, because if the crack propagates through the layer of the CRA and reaches the carbon steel, a strong galvanic couple is completed, accelerating, exponentially, the fatigue corrosion process [2]. The most critical point of pipeline structures is the circumferential weld [3], and demands special attention during inspection. Figure 1 presents a section of clad pipeline with a base material of carbon steel API X65 coated with Inconel 625, and highlights the inspection region with the crack positioning.

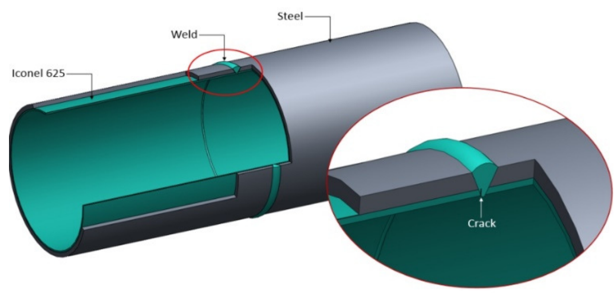

FIGURE 1: CLAD PIPE WITH THE INSPECTION REGION HIGHLIGHTED.

This scenario, detection of fatigue crack in Inconel (according to its electromagnetic properties), encouraged the development of an EC system for inner inspection of clad pipelines. The main challenges are the circumferential weld root

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geometry, the sharpness of the fatigue cracks and the fact that, generally, in-line inspection tools operate in a speed range between 0.5–4.0 m/s [4], which affects, directly, the transducer detection capability and the tool longitudinal resolution.

The techniques instrumented in the commercial in-line inspection tool, such as, MFL (magnetic flux leakage), ultrasound, EMAT (electromagnetic acoustic transducer), are very effective in inspection of generalized corrosion or micro cracks in the base metal of carbon steel pipelines [5–7]. However, because of some practical limitation, such techniques are not efficient for detecting micro cracks in welded parts. Reber et al. [8] have shown an ultrasonic configuration for crack detection in carbon steel pipeline girth welds, and presented relevant experimental results demonstrating the technique capability. Nevertheless, the authors highlighted, in their conclusions, that the application of such a technique in in-line inspection tools is still a challenge. Such challenge gets even more complex in the case of clad material inspection, where the anti-corrosive layer results in an additional interface for the ultrasonic wave propagation, interfering directly in the incident and refracted wave. Moreover, Cheng et al. [9] pointed out that ultrasonic testing is not effective for inspections of Inconel welds, because of its strong inhomogeneity and anisotropy. Once the ultrasound wave is sensitive to grain structures [10], Inconel welds significantly scatter the waves so that clear echoes due to defects cannot always be noticed.

Such challenges motivate the feasibility study of an in-line inspect tool development to detect fatigue cracks in the circumferential welds of clad pipelines based on eddy current concept. Yusa et al. [11,12] and Todorov et al. [13] presented the capability of the EC transducer for fatigue crack detection in welded joints. Among the publications analyzed [11–15], it was verified that the EC transducer with orthogonal configuration of coils exhibits the most significant inspection results. Its differential configuration, and the fact that the coils are located close to each other, minimizes the influence of the weld root profile in the inspection signal. Besides the relevant results completed with the orthogonal transducer, none of the authors have evaluated its behavior and performance when operating at high-speed condition, relevant for field application considering pipeline inspection, neither with welded parts with real fatigue cracks (the authors used mainly notches). In addition, the tests performed in the examined studies used commercial or lab EC equipment, which restricts the application in tools that demand embedded electronic hardware.

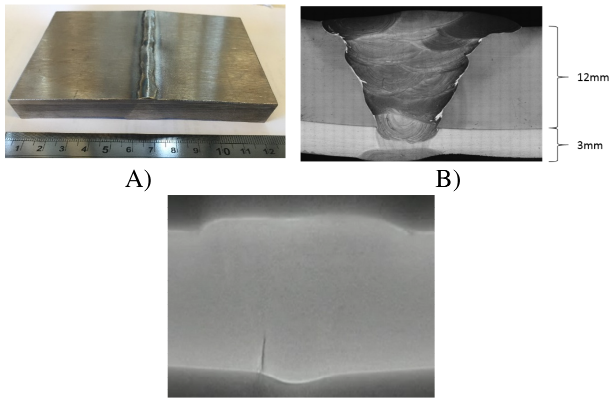
The goal of the present work is evaluating the capability of an EC transducer to successfully meet the previously described requirements: detect fatigue cracks in the circumferential weld root of clad pipelines when operating at different inspection speed. An orthogonal coils EC-based transducer was manufactured and tested, and a specific electronic hardware was developed to drive the transducer and measure the testing coils electrical complex impedance.

In-line inspection tool, commonly called PIG, is a type of tool widely employed to inner inspect metallic pipelines in different engineering fields. The tool is autonomous and designed to inspect long pipelines, in a range of several kilometers. Normally propelled by the fluid under production, the tool requires a sensor matrix to cover the pipe perimeter, a dedicated electronic hardware to drive, process, and save the sensor data during the inspection process, and a battery module to source the system.

In the experimental tests, an array of orthogonal coils, representing the sensor module in a typical in-line inspection tool, scanned a clad samples with fatigue cracks nucleated in the weld root. A CT testing was performed to check the morphological details of the fatigue cracks. The results achieved demonstrated that the orthogonal EC configuration is a potential solution for fatigue crack detection on circumferential weld root of clad pipelines.

2. MATERIALS AND METHODS

Three clad plates with substrate of carbon steel high strength low alloy, API 5L X65, and clad layer of Inconel 625, with dimensions 120 × 80 × 15 mm, were manufactured with a 45° bevel to receive a weld bead from GTAW (gas tungsten arc welding) weld process. A three-point bend fatigue test oscillating in 4 Hertz was performed with a payload of 90% of the material yield strength. Figure 3a presents a photo of one the samples with the fatigue crack, while 3b, a metallography image of one of the weld cross section, and 3c a CT cross section image of the sample where the fatigue crack can be noticed besides the weld root. One may observe the thickness of the carbon steel layer, 12 mm, and the Inconel 625 clad of 3 mm.



A) B)

C)

FIGURE 2: A) PHOTO OF THE SAMPLE WITH THE FATIGUE CRACK; B) METALLOGRAPHY IMAGE OF THE WELD CROSS SECTION; C) CT CROSS SECTION IMAGE OF THE SAMPLE WHERE THE FATIGUE CRACK CAN BE NOTICED BESIDES THE WELD ROOT.

3. RESULTS AND DISCUSSION

All three testing sample was scanned with different scan speed using the orthogonal EC transducer operating at 260 kHz. Figure 3a presents the C-scan of one of the clad samples with the

ECT results, while 3b the CT image of the sample where the red dot line indicates the fatigue crack positioning.

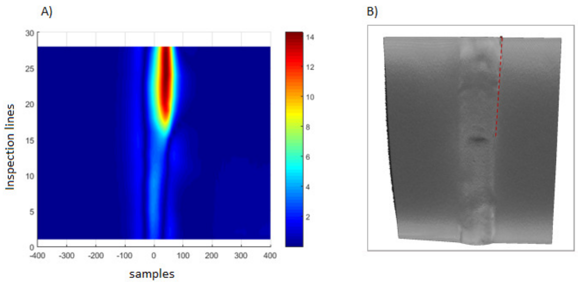


FIGURE 3: A) C-SCAN OF THE FATIGUE CRACK; B) 3D CT IMAGE OF THE SAMPLE.

Figure 4 presents the inspection results of the three clad samples combined. Tests from 0.2 m/s to 1.0 m/s were performed and in all situation the fatigue cracks were well ientified in the weld root.

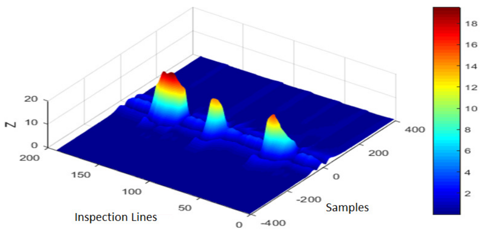


FIGURE 4: A) C-SCAN OF THE FATIGUE CRACKS INSPECTION.

4. CONCLUSION

The weld root of a clad sample was inspected with an orthogonal EC transducer and the fatigue was clearly identified, corroborating the excellent results reported in the referred bibliography.

Different inspection conditions were tested and as the speed is increased, the notch identification starts to merge in the weld signal, requiring, though, a higher data streaming from the electronic hardware to perform inspections above 1.0 m/s.

The suggested EC system using the transducer with orthogonal configuration presented the possibility to implement an in-line inspection tool to detect fatigue cracks in clad pipelines.

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