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Acoustic wave propagation in austenitic stainless steel AISI 304L: Application examples

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ABSTRACT

Prior to the detection and monitoring by acoustic emission of defects in steel, this paper deals with the use of waveguide that avoids direct contact between the sensor and monitoring structure when working at high temperature. The study of the waveguide effect on elastic wave transmission shows that waveguide deforms the waveform but it does not affect its frequency. Waveguide length does not affect signal magnitude. An experimental example of compact tensile specimen monitoring by acoustic emission is given. The monitoring of the damage at low and high temperature "450 °C" by acoustic emission enables us to identify crack propagation stages and their acoustic signature.

1. Introduction

In many European countries, and particularly in France, regulations require that pressure vessels be subjected to pressure testing before use in the as-received state, and then every ten years to obtain requalification. These tests are performed to ensure the safety of industrial equipments and people. Under current regulations, these tests need the system to be stopped; and the vessel to be filled with water and subjected to a pressure reaching 1.5 times the operating pressure.

The new European regulation on pressure equipment (2002), allows replacing hydraulic testing by alternative methods using nondestructive testing (NDT) for requalification. The most common NDT techniques are ultrasonics, acoustic emission [1–3], radiography and eddy currents enabling preventive control by detecting the initiation of all types of defects. Among all these methods used for pressure vessels monitoring, acoustic emission has the largest coverage, since 100% of the structure can be monitored. Besides, various studies have been conducted to characterize the acoustic signature of crack propagation at room temperature [4,5]. But the use of acoustic emission method is not always possible because some pressure vessels are heated to temperatures that many acoustic emission sensors can not stand. Such vessels can be found in industries in the field of petrochemicals, chemicals, aerospace.

Acoustic emission monitoring of such systems is a real challenge, regarding the complexity of interpreting the signals emitted by the structure and cost of implementation. The high temperature sensors developed recently are not mature yet and their use leads to high maintenance costs. Using waveguides may be an alternative to the use of high temperature sensors. They provide sensor protection from aggressive environments (low and high temperatures, chemical solutions, gases, radiation, magnetism). But their design and influence on wave propagation have to be assessed.

In this context, we propose in this paper to present the design of the waveguide used in the study of the acoustic signature of crack propagation at high temperature and its influence on wave acoustic propagation.

2. Experimental procedure

The main goal of this study is to investigate acoustic signature of crack propagation at different temperatures. In order to do so we propose to perform tensile testing on CT (Compact Tensile) specimens and to monitor the crack propagation by acoustic emission technique at different temperatures. Specimens used for these tests

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are notched and fatigue pre-cracked in order to propagate a crack at the notch and work in confined plasticity. Tensile tests were conducted at high temperatures (up to 450 °C for material 304L) which require the use of a waveguide for acoustic emission monitoring. The choice of material was made after CODAP [6] (French design code for pressure vessels). Dimensions of test specimens are chosen to fit with furnace diameter and the waveguide size in order to work in good conditions.

2.1. Specimens dimensions (compact tensile specimens)

The Compact Tensile specimens dimensions are described in Fig. 1a. They have a thickness of 20 mm. The dimensions have been chosen to fit inside the furnace, which has a diameter of 130 mm. Particular attention was paid to the direction of sampling specimens which is shown in Fig. 1b.

2.2. Waveguide dimensions

The use of waveguides for acoustic emission monitoring of damage at high temperature is essential. The waveguide enables the transmission of acoustic waves detected at the hot surface of the specimen, toward the piezoelectric sensor placed at its end in a colder environment.

- Waveguide material

The waveguides are made of a material having an acoustic impedance similar to that of the specimen. In our case austenitic stainless steel AISI 304L is used.

- Waveguide diameter

Waveguides diameter is set to 8 mm, which is commonly used in industry

- Cone dimension

Waveguides used in this study have a cone at the tip in contact with the sensor. The cone will ensure better transmission of elastic waves to the sensor. In the case of resonant sensor, the cone should be sized so that the resonant frequency of the sensor corresponds to a resonant frequency of the cone.

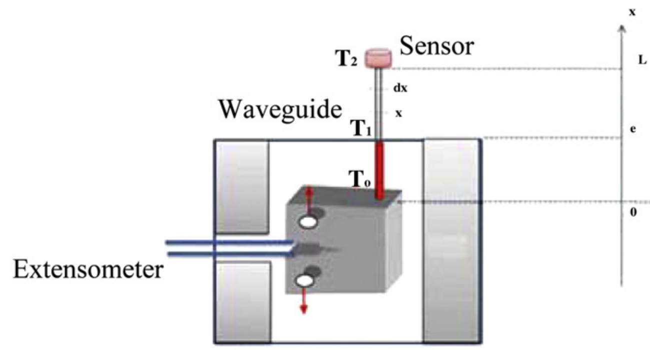

Fig. 2. Waveguide mounting condition.

- Waveguide length

The tolerance in operating temperatures for resonant sensors (200 kHz) makes it necessary to have waveguides of a minimal length to avoid damaging the sensors. In general, it is recommended not to exceed 60 °C on the waveguide end which is in contact with the sensor, in order to manipulate easily sensor and waveguide. Thermal calculations were undertaken to estimate the waveguide length required to reduce the temperature to an acceptable value for the sensor. These calculations take into account waveguide installation conditions, waveguide material, and furnace temperature (Figs. 2 and 3).

Considering that waveguide is a solid cylinder of section S, the calculation is to determine the length of the waveguide L so that the temperature $T2$ at the end of the waveguide does not exceed the permissible limit by the sensor (60 °C). In our study we calculate the length for $T2 = 25$ °C.

For x ranging from 0 to e (which is the part of the waveguide inside the furnace), it is considered that the temperature is constant in the waveguide, which gives $T0 = T1 = 450$ °C in the most harmful condition (highest temperature). In what follows we focus on temperature attenuation on waveguide part outside furnace.

The temperature drop in waveguide part outside furnace, which is due to conduction and transfer to the environment through natural convection, follows a negative exponential form:

$$T_2 - T_a = (T_1 - T_a)\exp\left(-\sqrt{\frac{4.h}{\lambda.D}}\cdot l\right) \quad (1)$$

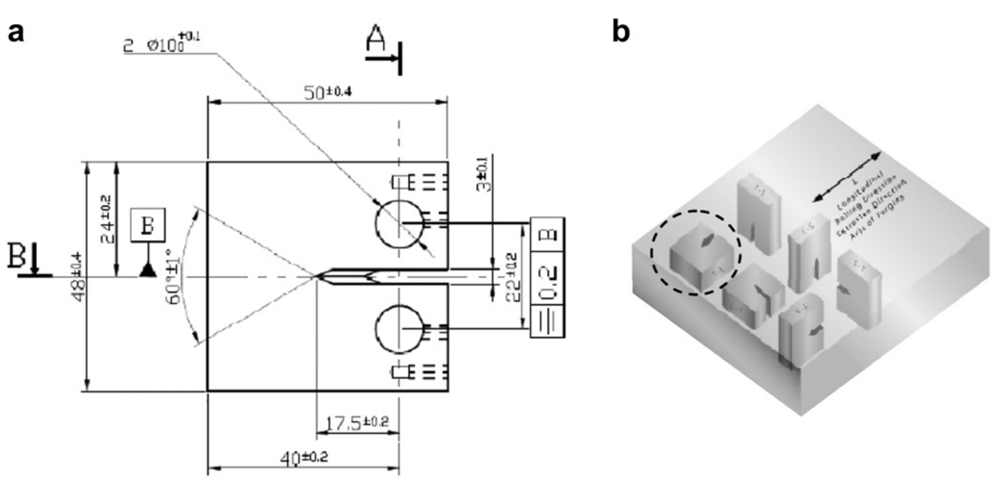

Fig. 1. a) Specimen CT20. b) Specimens direction sampling (T–L).