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Thermographic test for the geometric characterization of cracks in welding using IR image rectification

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ABSTRACT

This paper presents a novel Infrared (IR) thermographic method based on IR image rectification and extraction of isotherms which allows the detection of cracks in welds, as well as the geometric characterization and orientation of the crack to assist the prediction of the direction of propagation of the crack through the material. The technique has been validated through its application to two specimens with different types of cracks, and the quality of the results obtained has been analyzed with respect to the real measurements of the cracks.

1. Introduction

The study of welded elements is particularly relevant because of their function as safety guarantors in structures and machine elements. For this reason, international quality standards [1,2] are very demanding regarding geometry of welds and presence and characteristics of imperfections or flaws. The application of non-destructive testing (NDT) to these elements has been the object of numerous investigations in the last 30 years. However, the latest research shows the need of finding a technique for the detection of faults in welding that can be easily applied on site without causing any damage or malfunction [3]. Among the defects commonly present in welds, the study of the cracking process has high importance regarding safety and integrity of structures, vehicles, and machines that work under high demands. The greatest innovation in the analysis of cracks happened during World War I [4], when Alan Arnold Griffith created a new discipline within the mechanical engineering called Fracture Mechanics [5]. Apart from the detection of the crack itself, the assessment and characterization of the type of crack is important, predicting the direction of propagation and measuring: *Depending on the geometry of cracks, these can be devastating to a weld because the sharp edges cause stress concentrations and cracks can grow under load* [6]. Thus, the knowledge of the size, morphology, and orientation of the cracks presents enormous importance from the point of view of failure prediction.

Some defects in welds such as large and well-defined cracks are possible to detect by the human eye, but other defects with small dimensions are difficult to detect through a visual inspection, and their orientation is not simple to define without using complementary techniques. Infrared thermography (IRT) appears as an alternative technique for non-destructive inspection of materials due to its reliability, portability and its capacity for detecting, with high speed and efficiency, not only superficial defects but also subsurface defects if active thermographic methods are approached. Nonetheless, the main professional utility to this day of IRT like NDT has been the detection of defects in composite materials [7,8]. Nevertheless, active infrared thermography can be used to detect defects in the subsurface of the welding and inside the metal, and even to measure its depth. Different thermographic techniques can be applied mainly depending on the following aspects: type of heating, the arrangement of the sample and heating or excitation source, and the size and shape of the excitation source [9]. Excitation sources (continue or pulsed) are tasked to induce an artificial excitation of the electrons of the atoms of the material in order to show surface or subsurface defects, imperfections or discontinuities. The sources can be optical or non-optical; the first usually present the highest power density, being frequently provided by lasers [10] or halogen lamps [11]. However, using a simpler excitation source is also possible for the study of metals on some cases [12]. On the other hand, research towards the use of simple excitation sources can provide useful progress because the most potent sources such as lasers can damage the surface of the metal. In addition, the reflections of the laser if applied on low emissivity surfaces can be a limitation to the application of the technique

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[13]. Non-optical excitation sources like vibrothermography [8], eddy current [14] or ultrasounds [15] are frequently used and also present an enormous interest for metal testing. Nowadays, microwaves are also being applied like an efficient non-optical excitation source [16] but they could present serious disadvantages in safety and versatility for outdoor applications. When the excitation source is pulsed, results can be analyzed either in the frequency domain (pulse-phase thermography (PPT)) or in the time domain (thermographic signal reconstruction (TSR)) [9]. When the excitation source is continuous, results can be analyzed by contrast (relative difference between a pixel of the image and its closest pixels) [17] or by time domain (cooling or heating rate) [12].

The image nature of the thermographic product allows its combination with other non-destructive techniques that provide geometric information, such as laser scanning point clouds [18] and photogrammetry [19]. This sensor integration is useful even when active thermography is applied [20], using the temperatures measured and the computed parameters as descriptive data of the elements under study.

Photogrammetry could be a non-destructive technique that provides geometric information of the elements under study using only one camera. Given that this technique uses a photographic camera as its only device, the principles of the technique are adequate for their application with IR Cameras, maximizing the information gathered from each image. Among the different photogrammetric techniques, image rectification is one of the most efficient, providing geometric information easily with little economic investment: the equipment requirements consist on the camera and a geometric reference or scale [21]. Image rectification is based on the correction of the distortion introduced in the image by the camera lens [22] and on the posterior removal of the perspective distortion present in the original image using a geometric (vanishing points) or mathematical (projective transformation) approach.

The main advantage of the combination of photogrammetric techniques with infrared thermography is that the second removes the need of using additional lighting equipment, since its measurement is based on temperature differences rather than visual characteristics. This is the reason for the development of the present research, consisting on the performance of a thermographic test using a simple excitation source for the detection of superficial and subsurface cracks in welding, followed by the rectification of the IR images for the geometric characterization of the defects detected. In particular, length and width of their head, and global orientation of the crack.

The procedure allows the characterization and measurement of two types of cracks in welded steel according to the international standards [1,2]. Measures over IR image usually present bad precision results, mainly due to the great size of the pixel and the diffusivity parameters. This paper proposes a process based on contour lines for giving more accuracy to the thermographic geometrical measures and to plot a symmetry edge for the cracks, which could be used for the study of the dangers of cracks based on their pattern of propagation.

This paper is organized as follows: Section 2 presents the equipment used, and the testing methodology; Section 3 analyses the results obtained, and the information gathered from the combined thermographic and geometric knowledge of the detected defects. Last, Section 4 explains the conclusions drawn from the presented study.

2. Materials and methods

2.1. Materials

Two plaques of low carbon with a thickness of 7.5 mm were used. The plaques have been welded with tungsten inert gas welding (TIG), presenting butt-welding with edge preparation in V. Their geometry is shown in Figs. 1 and 2. The first weld (Fig. 1) has a crack in which little notch is oriented parallel to the longitudinal axis of the weld, denominated as toe crack according to the quality standard [1,2]. The second weld (Fig. 2) has the weld cap removed and presents a longitudinal crack. The two plates have been chosen by the very different morphology their cracks present: the toe crack has a peculiar shape because it penetrates into the material, whereas the longitudinal crack is placed on the surface propagated through it.

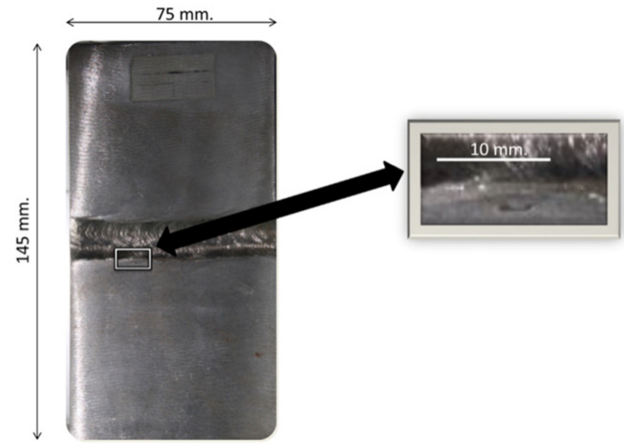

Fig. 1. Image and dimensions of the first plaque, which presents a toe crack (detail in the right image).

The thermal excitation of the material is performed with an electric heater (Joule effect heating) with 2500 W of active power. The superficial temperature is controlled with a contact thermometer TESTO720 with Pt-100, resolution 0.1 °C, and accuracy 0.2 °C. The thermometer is held in its position on the surface of the plaques with black tape in order to ensure total contact with the plaque and avoid the interference of the ambient conditions in the measurement.

The IR camera used for this work is an NEC TH9260 with 640 x 480 Uncooled Focal Plane Array Detector (UFPA), with a resolution of 0.06 °C and a measurement range from −40 °C to 500 °C. The camera is geometrically calibrated prior data acquisition using a calibration grid based on the emissivity difference between the background and the targets, presented in [23]. The grid and the corresponding IR images are shown in Fig. 3. The calibration parameters of the IR camera in the focus position used for data acquisition during the thermographic essays are shown in Table 1.

During data acquisition, the camera is controlled via PC regarding the establishment of the acquisition interval and duration, as well as the introduction of the ambient parameters (distance camera-plaque, ambient temperature and relative humidity) for the correction of the environment effect.

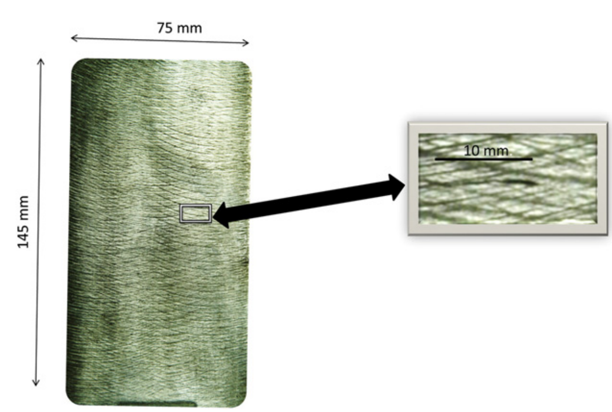

Fig. 2. Image and dimensions of the second plaque tested, which presents a longitudinal crack, nearly visible thanks to the removal of the weld cap (detail in the right image).