Raw data based image processing algorithm for fast detection of surface breaking cracks

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Raw Data Based Image Processing Algorithm for Fast Detection of Surface Breaking Cracks

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Abstract. The aim of this work is to illustrate the contribution of signal processing techniques in the field of Non-Destructive Evaluation. A component's life evaluation is inevitably related to the presence of flaws in it. The detection and characterization of cracks prior to damage is a technologically and economically significant task and is of very importance when it comes to safety-relevant measures. The Laser Thermography is the most effective and advanced thermography method for Non-Destructive Evaluation. High capability for the detection of surface cracks and for the characterization of the geometry of artificial surface flaws in metallic samples of laser thermography is particularly encouraging. This is one of the non- contacting, fast and real time detection method. The presence of a vertical surface breaking crack will disturb the thermal footprint. The data processing method plays vital role in fast detection of the surface and sub-surface cracks. Currently in laser thermographic inspection lacks a compromising data processing algorithm which is necessary for the fast crack detection and also the analysis of data is done as part of post processing. In this work we introduced a raw data based image processing algorithm which results precise, better and fast crack detection. The algorithm we developed gives better results in both experimental and modeling data. By applying this algorithm we carried out a detailed investigation variation of thermal contrast with crack parameters like depth and width. The algorithm we developed is applied for various surface temperature data from the 2D scanning model and also validated credibility of algorithm with experimental data.

INTRODUCTION

Recent technological advances facilitated the next generation Non Destructive Testing techniques which are capable of automatic inspection. In this context the requirement of an efficient processing algorithm is crucial for Non Destructive Evaluation. Surface breaking cracks are the most critical issue in most of the metal steel manufacturing industries. The life of the component is closely related to the presence of cracks in it. Laser thermography technique with crack detection capability has been chosen as the most important thermographic technique. It has the capability of characterization of geometry of surface flaws. Crack detection in metallic samples at high temperature is highly significant in present manufacturing scenario. During the casting process billets are already at high temperature, the cracks presence in the billet reduce value of the component and must be removed using machining process after cooling. This secondary process increases cost and time of production. Only a few NDT methods have inspection and crack detection capabilities in hazardous and remote environments. Laser thermography method can be used for high speed data collection, 2D imaging, 3D quantitative measurements, non-contact remote capabilities and can be employed for measurement of defects, process and product parameters. It also has capability for the detection of

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surface cracks and for the characterization of the geometry of artificial surface flaws in metallic samples in room temperature.

Kubaik *et al*. suggested the idea of flying spot thermography [1], further for few decades this technique was extensively developed [2-4]. Also advancements in IR detector and laser technology add scope to this inspection technique [5-8]. In laser thermography metal surface is heated locally. Surface and sub-surface cracks are identified from perturbations detected by the IR camera. The crack detection capability of a particular inspection technique depends on various factors. In case of laser thermography it depends on crack parameters and laser scanning parameters.

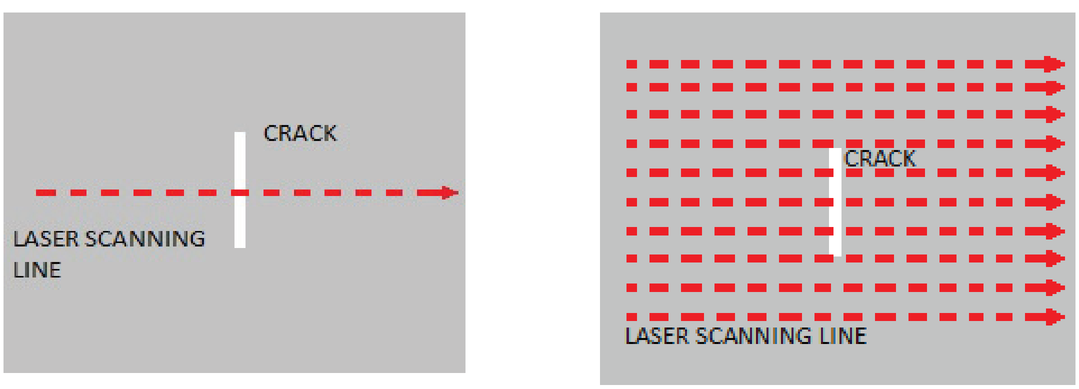
In this work we are mainly focusing on the capability of the proposed image processing algorithm for the valid detection of surface and subsurface cracks. Here we are checking the flexibility of algorithm by varying the crack parameters and laser scanning speed. For this developed a promising model for 2D laser scanning across surface breaking cracks which were in varying parameters. Thus checked the flexibility of algorithm and also the credibility of algorithm was validated using experimental data.

PRINCIPLE

A focused laser beam is used to heat the metal surface locally. This results in a spherical manner of diffusion. But in the case of flash thermography it will be in planar fashion, homogenous distribution of heating occurs over the surface. Heat flows in axial as well as radial directions, thus perpendicularly oriented surface and sub-surface cracks are highlighted due to heat diffusion. IR-camera helps in acquisition of thermal image of surface and from which the identification of cracks can be done. Cracks are acting like a black body where heat energy efficiently absorbed also functions as a good IR emitter. Due to these two main factors IR camera records higher temperature from surface with crack [9-10].

Modeling and Simulation Parameters

The simulations using COMSOL Multiphysics v 5.2, focused on a 3-dimensional model of the steel material of size (100×100×40) mm and a 20W continuous laser beam is used to scan over the surface at a speed of 20mm per second like local heat source, an artificial crack having 200 micron opening and 30mm length and 2.2 depth is introduced the middle of the block. And 2mm is laser having diameter is used to carry out a 2D laser scanning across the crack whereas the initial temperature of the steel block was set to room temperature [9]. 1D and 2D laser scanning schematic is shown in fig1.



(a) (b)

FIGURE 1. (a) 1D Laser scanning schematic and (b) 2D Laser scanning schematic

Sample metal surface generates a temperature gradient by illuminating the surface. Due to which an energy transfer will exists from the high-temperature to the low-temperature region. The heat transfer rate due to conduction per unit area is proportional to the normal temperature gradient:

$$\frac{q}{A} = -k\frac{\partial T}{\partial n}$$

where q is the heat transfer rate, $\frac{\partial T}{\partial n}$ is the temperature gradient in the direction of the heat flow, and the constant k is the thermal conductivity of the material (W/m. K). The negative sign is indicate that heat flows from a higher to a lower temperature value. Considering the energy balance in three dimensions the heat conduction equation in a concise form can be written as:

$$\rho C_p \mathrm{u}.\nabla T + \nabla.(k\nabla T) + \rho C_p\frac{\partial T}{\partial t} = \dot{Q} + Q_{ted}$$

where $\dot{Q}$ is the heat generation, ρ is the density of the material, and C_p is the specific heat of the material. The ambient temperature is taken room temperature (T_0=298 K) for all domains.

A surface laser heat source assumes that the beam energy is absorbed over a very small distance into the material (absorption length) compared to the size of the object heated. The finite element mesh only needs to be fine to resolve the temperature fields and the laser spot size. The laser source itself is not explicitly modeled, and it is assumed that the fraction of laser radiation reflected from the surface is not reflected back. The deposited beam power option in heat transfer module is used to model the CW laser beam and a Gaussian laser beam profile is defined as the heat source, written as

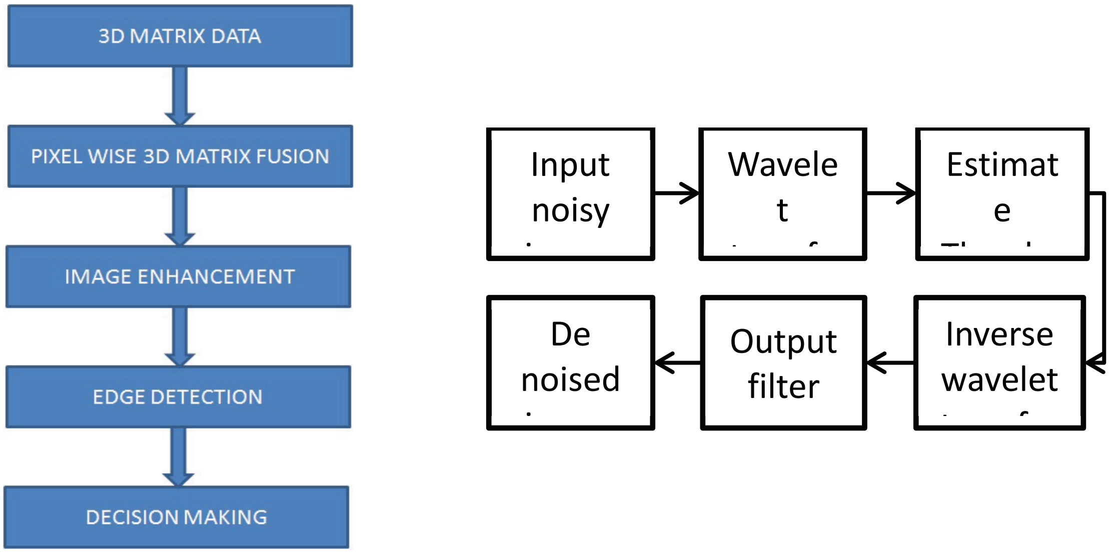
$$\mathrm{f(0,e)} = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{\mathrm{d}^2}{2\sigma^2}\right)$$

where $d = \frac{||e\times(x-O)||}{||e||}$, σ =Standard deviation.

RAW DATA BASED IMAGE PROCESSING ALGORITHM

Raw data based image processing algorithm is an image processing method which mainly emphasizing on the fusion of the 3D matrix raw data which is obtained directly from the experiment or simulation. In sense the whole scanning record in every instance during 1D or 2D scanning is getting back in the single image. Here fusions of images were not done, but the fusion of matrix itself is done. The main reason is because fusion of images will lead to loss of information, but the direct raw matrix fusion leads no information loss [11]. Thus can conveniently convert the fused 2D matrix to the image and can process and analyze it. This method gives far better results compared to existing algorithms. Figure 2(a) shows the flow chart of the proposed algorithm. First 3D matrix is fused to 2D matrix in pixel wise. From all matrices corresponding positioned pixels are fused. Image obtained by this method is of high quality, without any information loss. Image obtained is undergone enhancement process to filter out the noise and enhance image from the degradations caused due to noises from the experiment environment. Also image enhancement is not required to simulation data. Image denoising done using wavelet transform. Then edge detection was done to highlight the crack.

Figure 2(b) shows the block diagram of image denoising using wavelet transform. The wavelet transform has become an important tool for this problem due to its energy compaction property. Indeed, wavelets provide a framework for signal decomposition in the form of a sequence of signals known as approximation signals with decreasing resolution supplemented by a sequence of additional touches called details [12]. Denoising or estimation of functions, involves reconstituting the signal as well as possible on the basis of the observations of a useful signal corrupted by noise. The methods based on wavelet representations yield very simple algorithms that are often more powerful and easy to work with than traditional methods of function estimation [13]. It consists of decomposing the observed signal into wavelets and using thresholds to select the coefficients, from which a signal is synthesized. Image denoising algorithm consists of few steps; consider an input signal and noisy signal. Add these components to get noisy data. After applying wavelet transform, wavelet coefficients are modified using different threshold algorithm and done inverse wavelet transform [14-15]. Daubechies wavelet filter is used to obtain denoised fused image.



(a) (b)

FIGURE 2. (a) Flow chart of proposed algorithm and (b) Block diagram of Image denoising Using wavelet transform

RESULTS AND DISCUSSION

Our main objective of this work is to ensconce the crack detection capability of the proposed algorithm with respect to variations in crack parameters and laser scanning speed. First we are analyzing the simulation result from the dedicated model corresponds to the steel material and then analyze the experiment data. Also processed the experiment data obtained from experiments using brass plate as specimen having inbuilt vertical cracks.

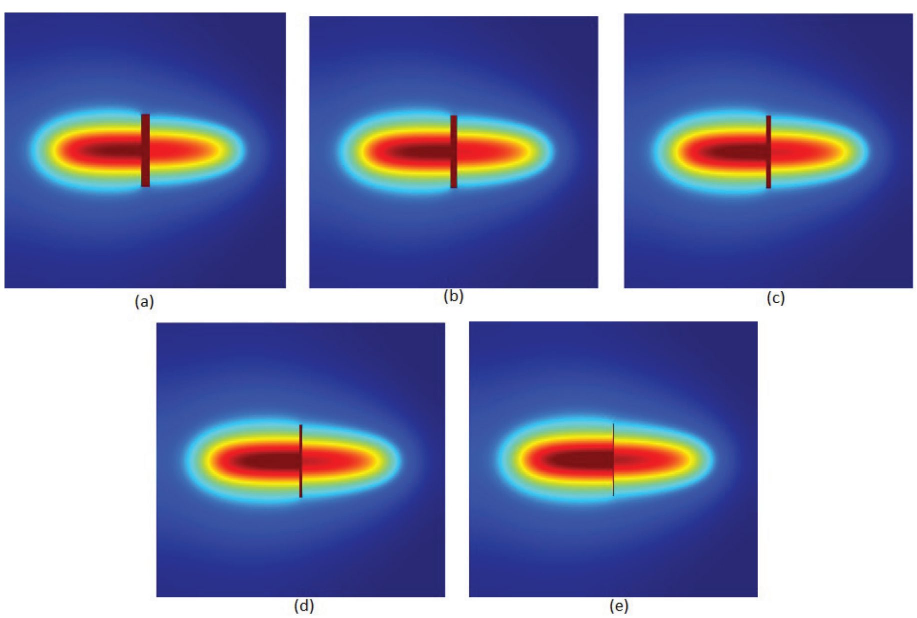


FIGURE 3. Fused images for crack width: (a) 1mm, (b) 0.8mm, (c) 0.6mm, (d) 0.4mm and (e) 0.2mm

The algorithm is applied both in experiment and simulation data. 1D scanning for different crack width was modeled. The crack width ranges from 1mm to 0.2mm. Figure.3 shows fused images obtained for crack widths 1mm, 0.8mm, 0.6mm, 0.4mm and 0.2mm. The heat distribution pattern differs as the crack width differs. Figure 4 shows the crack highlighted images. From those figures it is clear that the crack indication capability varies accordingly with the crack parameter, here which is width. As the crack width is increased, the heat blockage will be higher. Thus heat distribution also varies, which effects the crack indication also.

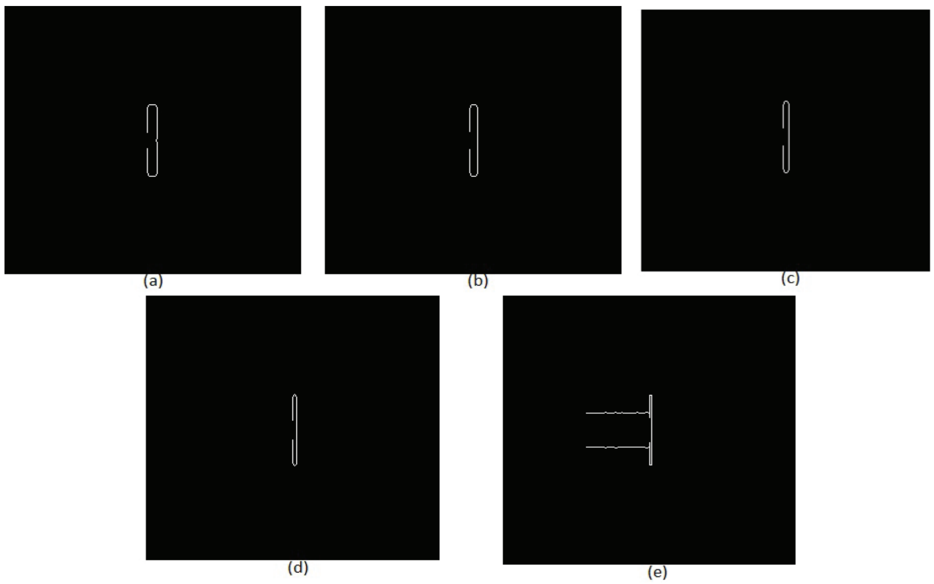


FIGURE 4. Crack highlighted images for crack width size (a) 1mm, (b) 0.8mm, (c) 0.6mm, (d) 0.4mm and (e) 0.2mm

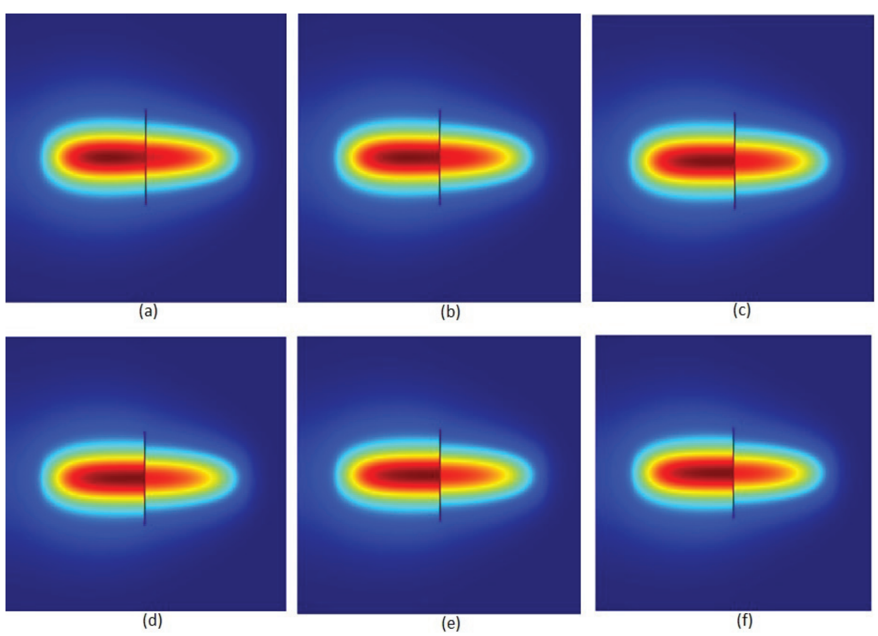


FIGURE 5. Fused images for crack depth size (a) 1mm, (b) 2mm, (c) 3mm, (d) 5mm, (e) 8mm and (f) 10mm

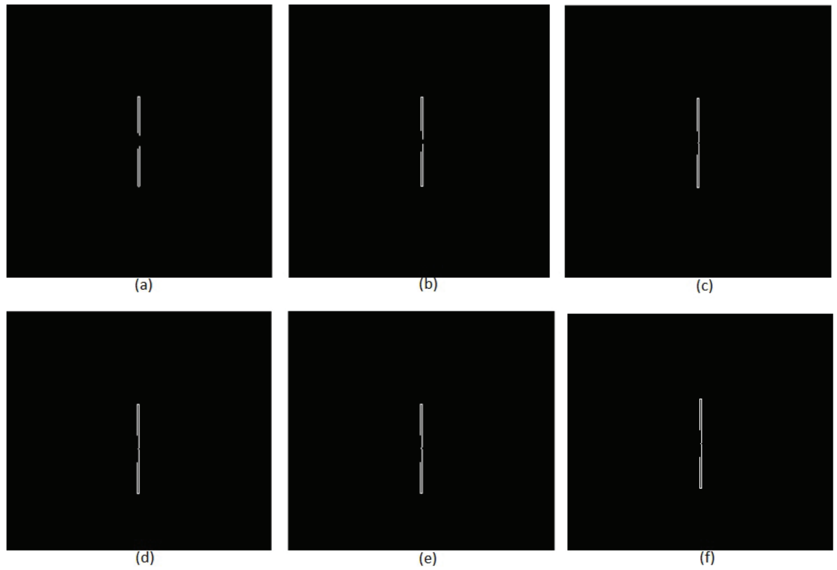


FIGURE 6. Crack highlighted images for crack depth size (a) 1mm, (b) 2mm, (c) 3mm, (d) 5mm, (e) 8mm and (f) 10mm

Credibility of Algorithm with Experimental Data

The credibility of our algorithm was checked by applying the same algorithm in experimental data. The investigated sample was a block made of ST37 steel, (100 x 100 x 40) mm in size containing notches of different dimensions as depicted in Fig. 8. The experiments presented in this paper focus on the notch with 2.2 mm depth. A 20W laser beam is used to scan over the notch and the thermal distribution on the surface is captured by an IR camera. We did two set of experiments with same laser power but different scanning speed 1mm/s and 10mm/s. In both cases experiments where done with metal surface in room temperature. Figure 7 shows the schematic representation of laser spot thermographic technique.

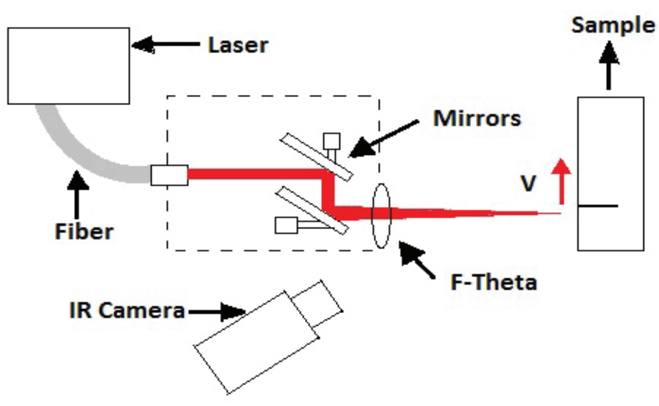


FIGURE 7. Schematic representation of laser spot thermographic technique

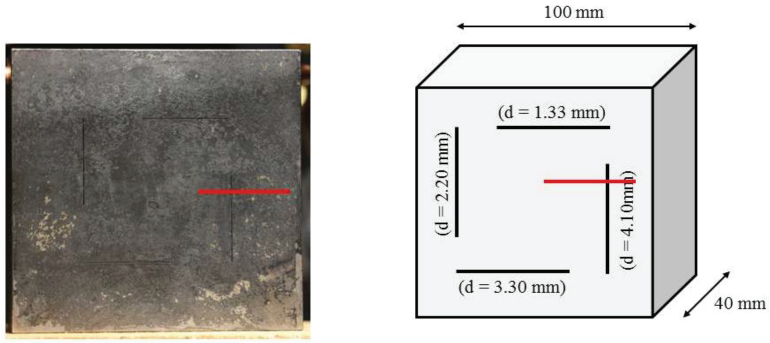
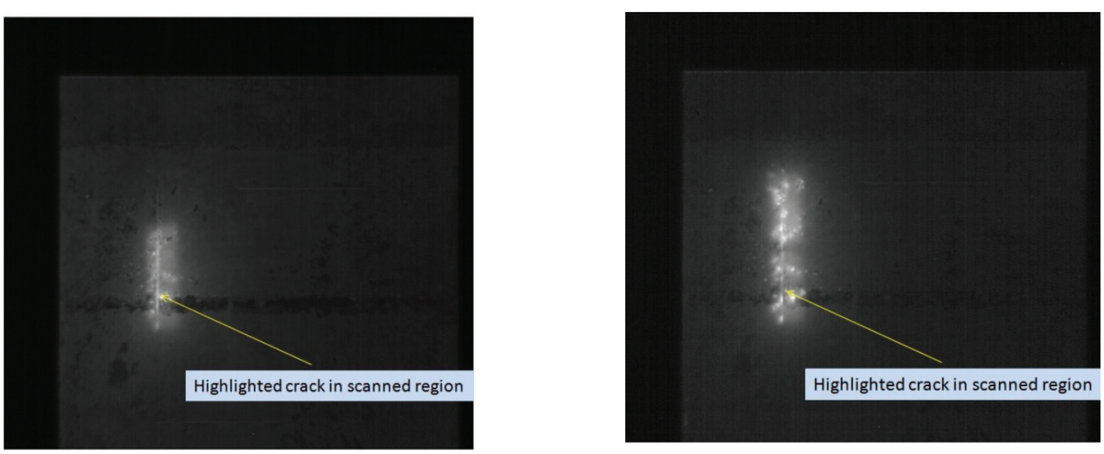


FIGURE 8. (a) Photograph of the specimen made of ST37 steel and (b) Scheme of the specimen 0.2 mm in width

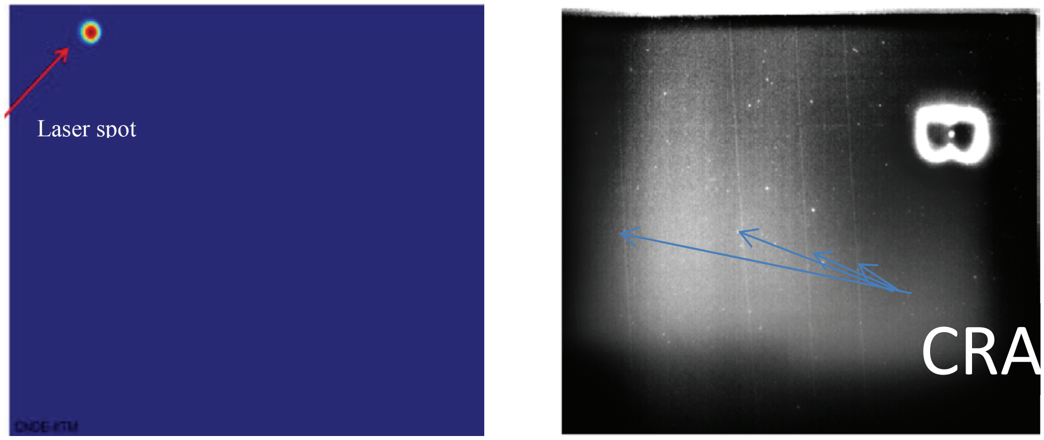
Figure 9 (a) and (b) shows processed results from raw data based image processing method. There are four in built cracks with various depths in the specimen. In that a 2D scanning was done on the single crack with depth 2.20mm. The scanning is done in 1mmps and 10mmps speeds with 20W laser. This result highlights the effect of laser scanning speeds on the delamination detection. As the speed is reduced, the crack detection capability will be higher. From below shown figures, cracks are clearly highlighted from the 2D scanning. In that 1mmps scanning speed results the clear and better indication of crack. The processed image of the experimental data having the clear identification of notch due to heat blockage is obtained. But in case of experimental data have to consider some difficulties like emissivity variation, surface irregularities, micro level material removal due to high power laser use and production of fumes etc., all of this will affect the thermogram obtained. So it is necessary to consider all these factors while processing to get better visibility of cracks. Depends on the nature of data, methods chosen for the analysis differs.

Figure 10(a) shows a single frame 2D laser line scanning of Brass plate which was captured by the IR camera. The whole brass plate is scanned using flying laser spot. Brass plate is having four vertical cracks which were not visible by camera while scanning, only slight variation in the heat distribution noticed at some points where crack depth is comparatively high. Since data were obtained from the experiment environment presence of noise was also considerably high and this lead the processing task a crucial one. The resultant processed image highlights all cracks and image quality also enhanced which eliminates degradation caused due to noise.



(a) (b)

FIGURE 9. Processed experimental data (a) 20W and 1mmps and (b) 20W and 10mmps



(a) (b)

FIGURE 10. (a) Single Frame with laser spot from the experiment and (b) Crack highlighted resultant image

CONCLUSION

A Simple 3D numerical scanning laser thermography using flying laser spot is modeled and simulated using Comsol Multiphysics v5.2. In case of variation in crack depth and width, the surface temperature distribution also varies. This change in temperature distribution specifically notifies the crack parameter. Proposed algorithm is effective for the qualitative analysis of cracks and quality of the crack image is improved far better from the existing methods. Also studied effects of crack parameters and laser speed on detectability of crack. Since algorithms gave compromising crack detection in both experimental data and FEM simulations, which justifies proposed algorithms, it can be applicable in future applications for online testing and quantitative analysis of surface breaking cracks. The potential of this algorithm can be efficiently examined and allows developing laser thermographic inspection to a powerful and reliable NDT technique.

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