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A new approach to calculate the nodule density of ductile cast iron graphite using a Level Set

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A B S T R A C T

This paper proposes a new approach with digital image processing techniques to determine the number of graphite nodules on samples of nodular cast iron by following the NBR 6913 standard. Counting errors and excessive inspection time are common problems if the procedure is performed without the assistance of computational systems. To overcome these drawbacks, we propose here an algorithm for graphite nodule segmentation based on the Level Set technique. The proposed approach and two other computational methods, Watershed and Region Growing, are compared with the results given by experts using optical microscopy (OM). The results of the proposed method were closer to those of the experts using OM than the other two computational methods. The proposed method presented greater accuracy and faster execution time than the traditional method by visual inspection.

1. Introduction

Digital image processing techniques have been applied in various areas such as helping drivers in motor vehicles [1–5], supporting medical specialists [6–8], and assisting experts in materials analysis [9–11]. Optical microscopy studies are commonly used to assist experts in different mechanical fields, such as precipitate analysis [12], microstructural characterization [13–16], delamination analysis [17], drilling damage analysis [18–23], Brinell and Vickers hardness measurements [24,25], synthetic material porosity analysis [26–28], and cast iron analysis [29–32].

Nodular cast iron is one of the different types of caste irons that is analyzed by metallographic analysis. This analysis uses standard techniques to verify the quantity of graphite nodules on samples, and traditionally, it is performed visually using an optical microscope. However, this procedure is tedious and subjective. Therefore, this process needs to be automatized in order to minimize existing failures.

According to Chiaverini [33], cast iron is an iron-carbon-silicon alloy, with carbon content generally above 2.0%. However, it must be in an amount greater than can be retained in solid solution of austenite, in order to result in partially free carbon in the form of veins or graphite lamellas.

The main factors that influence the structure of cast iron, are the cooling rates and the chemical composition [34]. Other important factors are inoculation and overheating [35].

The quantity of graphite in the structure of cast iron is extremely important from a structural point of view. The larger the quantity of graphite present in the cast iron microstructure, the lower the mechanical resistance will be. This is due to empty effects, notches and distribution.

Cast iron is classified into different types according to the shape of the graphite, with an additional differentiation due to structure of the metallic matrix (which can be ferritic, pearlitic, ferritic-pearlitic, austenitic, martensitic), as seen in Fig. 1. Each matrix will originate different properties and distinct material classes [35]. Gray cast irons, white, mixed, malleable and nodular are some types of cast iron. The nodular cast iron, subject of this study, is defined as an Fe–C–Si alloy, where the carbon is in the form of spheroidal graphite in the as-cast condition. Nodular cast iron is an engineering material displaying high ductility, elastic modulus, mechanical strength and corrosion resistance. In addition, it has a low cost and is easy to produce, and is thus widely used as a structural material [36]. Some examples of nodular cast iron used in vehicles are Steering knuckles, hypoid rear axle gears, camshafts, crankshafts and disk-brake calipers [37,38].

To evaluate some of these properties, it is necessary to count the graphite nodules in the nodular cast iron, which can be done

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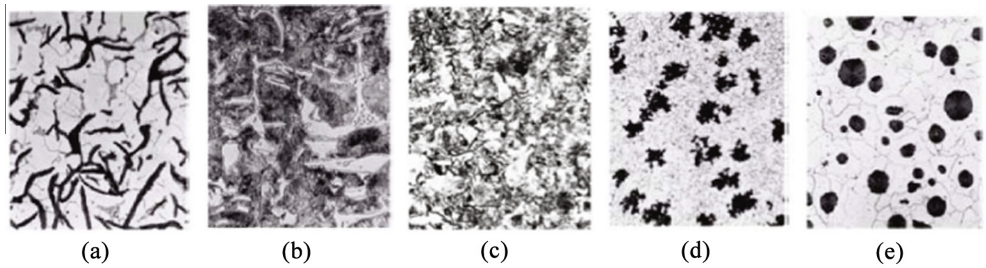

Fig. 1. Cast irons samples: (a) gray, (b) white, (c) mixed, (d) malleable, and (e) nodular.

following the Brazilian Standard (NBR) 6913 [39]. This Standard was used by Peixoto et al. [40] to automatically count the graphite nodules on metallographic images using the Watershed and Region Growing methods. In this paper, we propose a new approach based on the Level Set method to target graphite nodules. This method detects the graphite nodules using a Level Set approach based on a likelihood model. It uses the peak values found in the image histogram as the initial cluster information.

The results obtained by the proposed method are compared with Region Growing and Watershed methods as proposed in [40]. Moreover, the results are validated by experts in the field using OM. The remainder of the paper is organized as follows. The next section introduces the segmentation problem and the proposed methodology. In Section 3, we present the results of a comparative evaluation of the proposed approach and the methods in [40]. Section 4 draws the conclusions and suggests further work.

2. Materials and methods

In this section, we discuss the conventional counting methodology and the digital image processing techniques used for this purpose. Lastly, we will propose a method to calculate the density of the graphite nodules using the Level Set technique on metallographic images.

2.1. Graphite nodules count and density estimation

The number of graphite nodules in nodular or malleable cast iron is determined by the Standard in [39] with a microscope and a specimen that has preferably not been attacked chemically. The graphite nodule density is measured in $nodules/mm^2$, and it can be calculated by

$$Density = \frac{(NI + \frac{NP}{2})}{S \times n} \times A^2, \quad (1)$$

where S is the area of the reticle to be analyzed, A is the microscope resolution, n is the number of samples, NI is the number of full nodules in the region and NP is the number of nodules which are partially inside the analyzed region. It is worth mentioning that NI considers the nodules which are completely within the analyzed area, while NP considers the nodules on the border, i.e., those with some part inside and outside the region being analyzed. Fig. 2 shows a reticle model to determine the number of nodules.

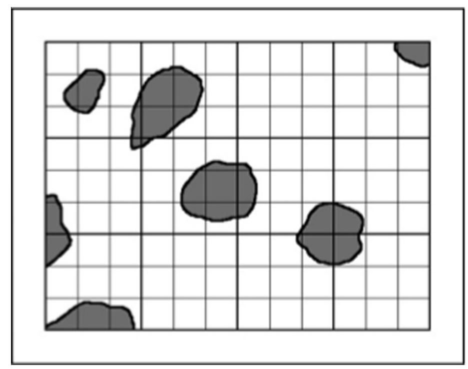

Fig. 2. Reticle model to estimate the number of projected nodules [39].

2.2. Count of graphite nodules using digital image processing

A Computer Vision System (CVS) is divided into five steps, namely: image acquisition, preprocessing, segmentation, extraction of attributes and pattern recognition [41]. The digital image is obtained in the image acquisition step from a capture device, which in this application is the optical microscope. The preprocessing is intended to improve image quality using such methods or techniques as: reduction of noise or artifacts, in addition to the brightness and contrast equalization; edge sharpening of the image objects; and reduction of undesired tones or distortions [41]. The segmentation step is intended to recognize and isolate Regions of Interest (ROI) in the digital image [41]. The last step is the extraction of attributes. This step is characterized by extracting attributes of objects selected in the previous step.

The segmentation step is one of the most important to automate the count of graphite nodules. In this step the position of the nodules is sought, since the nodules should be classified as *partial* or *fully* observed in the image. The Region Growing and Watershed methods are classical approaches for image region-based segmentation, and in [40] these methods are used for graphite nodule segmentations. In this paper, we used the Region Growing and Watershed, as proposed in [40], to perform a comparative assessment of the proposed method.

2.2.1. Watershed Transform

The Watershed Transform is based on the natural phenomenon of topographic flood mapping [41]. It considers the image as a topographic relief viewed from above, as if it had been captured by a satellite. If an area is flooded, the regions of minimum values will be the first to be affected. with a flooded area increases steadily, stopping only when it finds another growing region. This transformation gets watersheds from image gradients, which must correspond to homogeneous gray level areas of this image. Gradients are used as a background to find the topographic objects.

In this paper Otsu thresholding is used in a pre-processing step to minimize errors of metallographic processes, such as alcohol spots and errors in the grinding process or polishing [40]. The result of thresholding is used to identify the river basins, which are the graphite nodules in this application. Fig. 3 shows a segmentation result by this approach.

2.2.2. Region Growing

The Region Growing algorithm starts with a set of *seed* pixels. The regions grow from seeds by appending the neighboring pixels