A Digital Image Processing Tool for size and number density distribution of precipitates in creep exposed material

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Abstract:

Present paper deals with developing an advanced digital image processing tool for determination of size and number density of precipitates present in creep exposed P92 steel. The image processing tool box in MATLAB is usually employed for noise detection and removal, edge detection, cropping, histogram of region of interest as well as size wise distribution of the desired objects from the micrograph. This tool helps in fast and accurate acquisition of information. In this investigation, creep testing has been carried out on two P92 steel specimens at temperature of 650°C and stress of 120MPa till rupture. Scanning electron microscopy was used to capture images of the specimen in as-tempered condition and in the near rupture gage region after creep rupture. The developed software has been used to analyze the micrographs for quantification of precipitates in terms of area fraction, size and number density. The use of edge detection technique in the developed software helps in avoiding human intervention during image thresholding thereby increasing accuracy in precipitate sizing. Findings from this investigation have been used to evaluate the role of precipitation morphology for specimen failure due to creep especially in precipitate strengthened steel like P92 steel.

Keywords: *Image processing toolbox; GUI; MATLAB; P92 steel; Precipitates*

1. Introduction:

Generally, images contain different types of objects and structures which convey information about the material [1, 2]. Detection followed by subsequent counting estimates the number of objects in an image. Counting arises in many real time application such as counting grains in agriculture industry, counting cells in microscopic images, counting of number diamonds in industry etc. Existing methods for counting involves a large amount of hardware which also adds to the cost or manual counting which is time consuming and may give erroneous results. The rapid development of computer vision and pattern recognition technology has been used in quality assessment, detecting and counting object details using image processing tool[3, 4]. Automatic counting of objects is a subject that has shown its application with objects as varied as cells [3], RBCs [4], fish [5], eggs [6] etc. Because automatic counting is objective, reliable and reproducible, comparison of different objects in a specimen, it gives more accurate results with automatic programs than with manual counting.

Components operating in extreme environment are prone to several damage mechanisms like creep, fatigue, corrosion and thermal ageing. Damage induced in the material is mainly due to microstructural changes in terms of grains and precipitation morphology leading to voids and crack formation, followed by material failure. So microstructural property evaluation is needed to know the material status. All the microstructural properties has been evaluated previously either through manual scaling or with some software which can mark the boundary irregularly in which the targeted object detection is obscured or eliminated by the program as they are not clearly expressed or may be overlapped. Using color processing, lighting intensity also affects original image[7-10]. In the existing software for microstructural analysis, calibration of scale provided in the microstructure is calibrated manually. As the microstructure is the major strength of any components, their measurement needs a higher accuracy level of access. To address this issue, we have proposed a Matlab graphical user interface (GUI) based method capable of quantifying all the microstructural features like grain size, precipitate size and number density, voids, crack sizing from the micrograph of a specimen. We have applied the software to quantify microstructure of creep ruptured P92 steel specimen, where the material has under gone high temperature deformation at 650°C and stress of 120MPa. This method is based on morphologic operations used in digital image processing in order to make its implementation simple obtaining result accuracy. Development of a method to characterize the distribution of precipitate particles and study the impact of these particles on change of material properties by taking their microstructure is the prime objective of the present research. Effectiveness of this developed tool was analyzed by using the micrographs of creep damaged P92 steel.

2. Experimental:

Steel plates of P92 steel specimen were collected in as-tempered condition. Samples were prepared for creep testing machine. Creep testing was carried out on two P92 steel specimens at temperature of 650°C and stress of 120MPa till rupture. This test condition was chosen according to the operating condition in power plants where this material is used. After creep rupture, failed specimen were cut near the rupture region for microstructural analysis. Micrographs of specimen were taken in as-received condition and near the rupture region of gage length of creep failed specimen using scanning electron microscopy (SEM). A Matlab based GUI was developed (in-house) for microstructural analysis using the image processing toolbox. The SEM images were then analyzed using the proposed software. Brightness and contrast thresholds were adjusted automatically for better separation of the precipitates from the surrounding grain structure. The SEM scale bar on the image was used to calibrate the number of pixels per micrometer to accurately measure particle size. Depending on the size of the object. The software then measured the number of particles (count), average particle size (average size), and area fraction of particles (% area) for each image. Each sample was examined to determine the effectiveness of this technique in analyzing the correlation between precipitates and creep damage parameters in P92 steel.

The fundamental steps of image processing and analysis in the proposed algorithm showing steps are presented in Figure 1. Brightness and contrast thresholds were adjusted automatically for better separation of the precipitates from the surrounding matrix grain structure. The scale bar on the image was used to calibrate the number of pixels per micrometer for accurate particle size measurement. The software then used to measure the number of precipitated particles (count), their actual size, and area fraction (% area) for each image. But, the output result has the capability to output statistics for each individual particle, providing an exhaustive study of precipitate size and distribution for future research. Averaging of data were carried out considering 10 micrographs for each specimen.

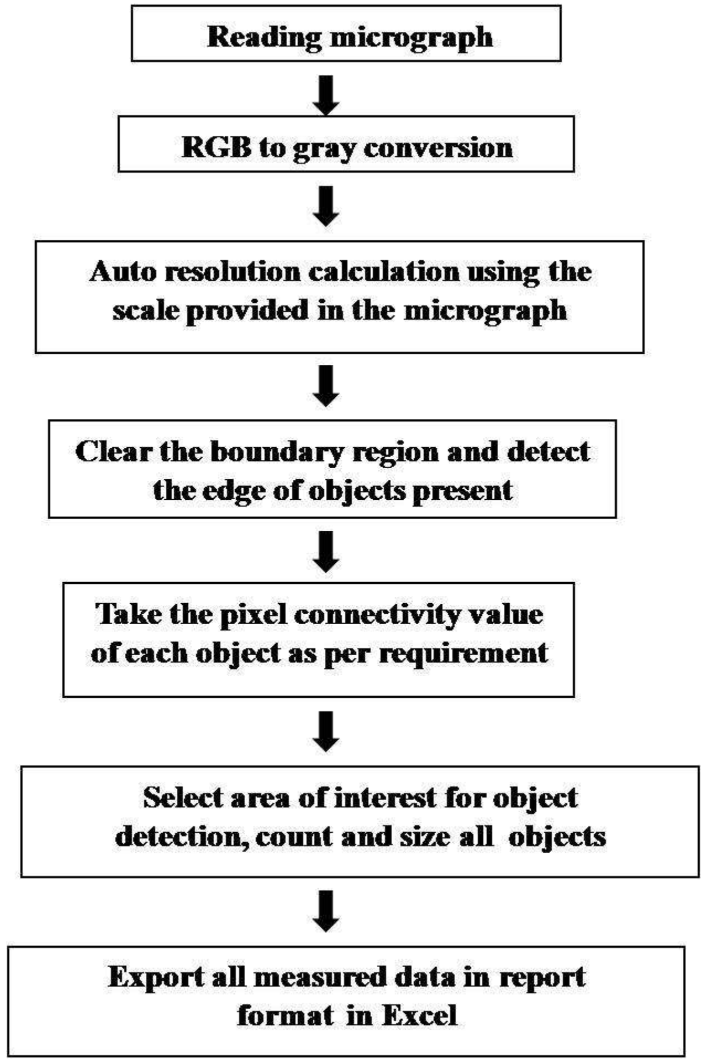

Figure 1: Proposed algorithm for operation of the GUI

3. Results and Discussion:

The microstructure of P92 steel specimen in as-tempered condition and after creep is shown in figure 2. From the microstructure it is revealed that there is a change in size of precipitates (in terms of growth and coarsening) as moving from as-tempered condition towards creep rupture. So, evaluation of precipitation morphology is the major determining parameter for creep life evaluation of this precipitate strengthened material. Using the developed software number density and size distribution of precipitates(with both minimum and maximum size), area fraction were determined. Image thresholding was done in each image using edge detection technique for background noise reduction. Figure 3 shows the steps followed for precipitate counting using the developed software.

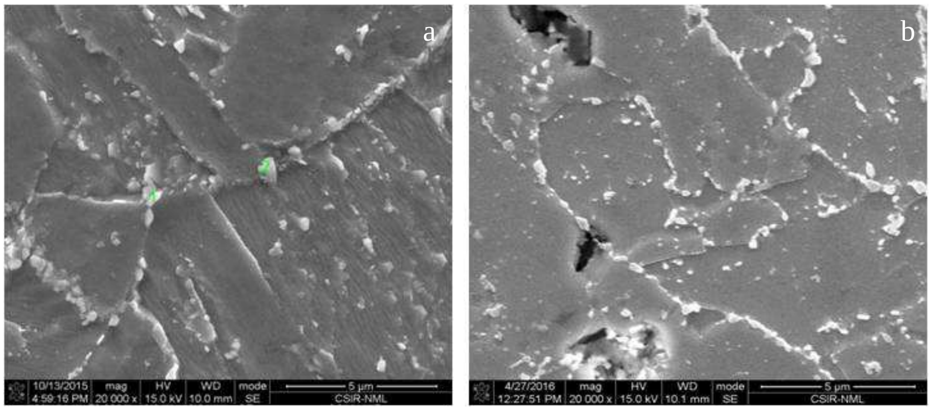

Figure 2: SEM micrographs of P92 specimen in (a) as-tempered condition, (b) near rupture region across the gage length after creep failure

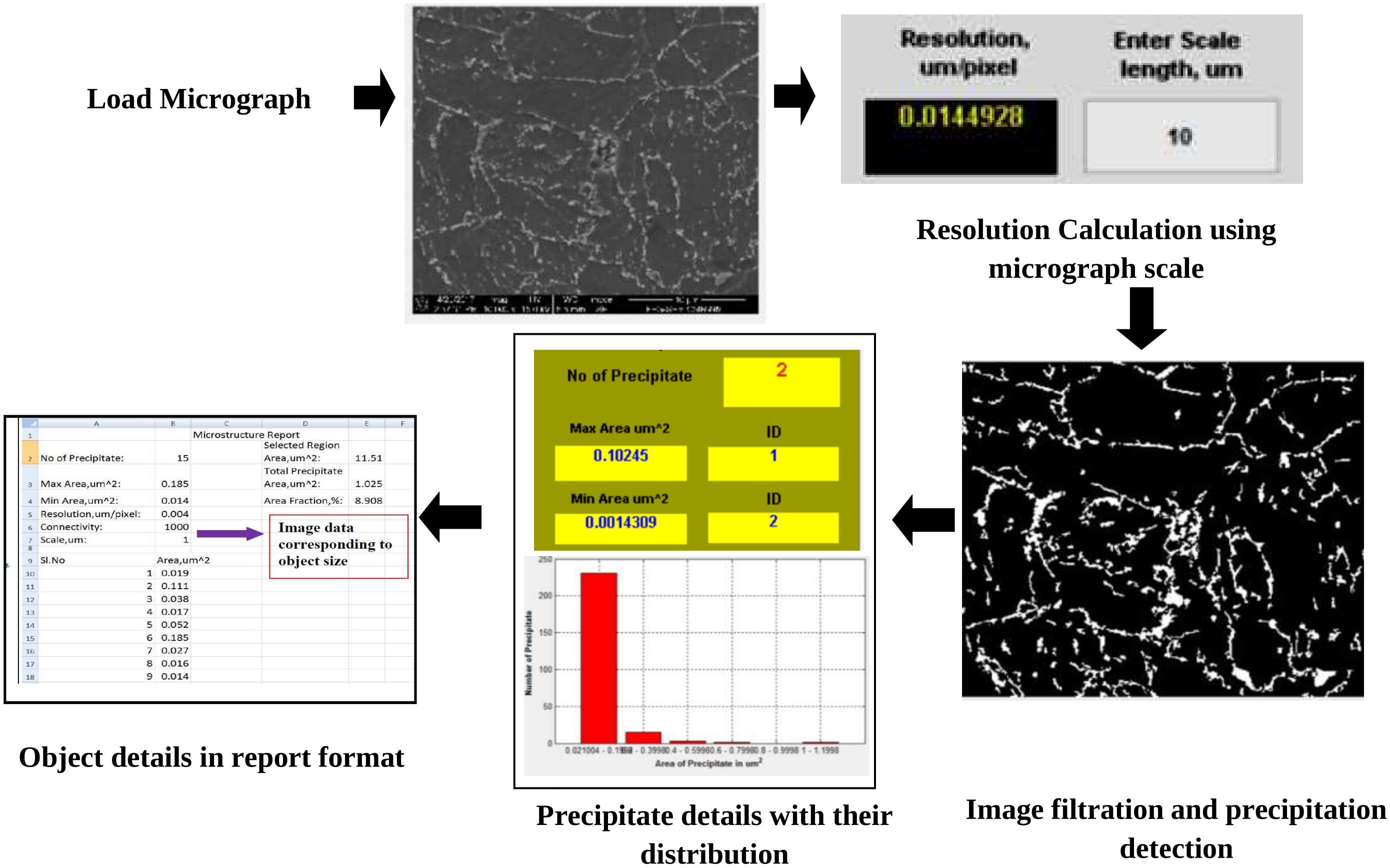

Figure 3: Steps for Object counting from a micrograph using the indigenously developed software in Matlab interface

After loading the micrograph, pixel size was calibrated using the provided micrograph scale length. In the next step, background noise reduction was done by edge detection technique which reveals only the precipitates present in the matrix. The image processed through the software was able to identify the pixels of precipitated particles (white) against the surrounding matrix (black). The precipitates in each image were evaluated using the "count precipitate" function. Size wise distribution was carried out on these particles depending on the requirement. The report generation module was used for saving data for future reference.

It was observed that the number of precipitates ranged from approximately 200 to 800 moving from as-received specimen towards crept specimen. The average area of each precipitate was found between 0.3 to 0.9 μm^2. Area fractions which is calculated taking the percentage of ratio of total area of precipitate to the total area of the image, ranged approximately from 1% to 8% . The precipitates were divided in to 4 different categories i.e. fine, finer, coarse and coarser based on size ranges. Figure 4 shows the area fraction of all the four category of precipitates according to their size range in as received and crept specimen. It is observed that area occupied by coarser precipitates in crept specimen were maximum as compared to coarse, finer and fine category. This distribution study was possible to perform only after developing the indigenously developed software. This study helped to quantify the precipitate effect on creep ruptured specimen.

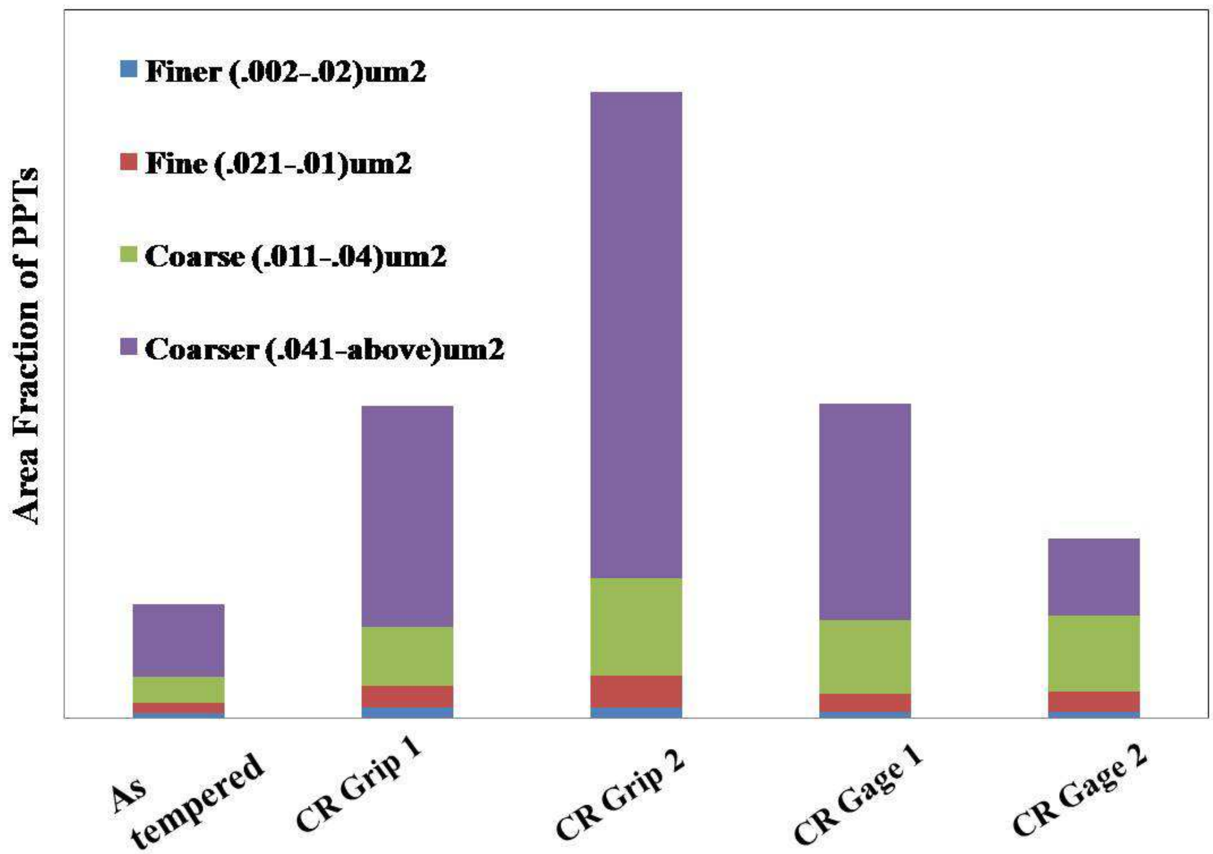

Figure 4: Area fraction of precipitates in as-received and creep ruptured(CR) specimen

4. Summary:

In this study, digital image processing based on Matlab is effectively used for distribution and counting of different objects of any micrograph with enhanced accuracy. The developed program is fast, low cost and user friendly software which can be helpful for counting of object details. Through this study, an analytical technique was developed to quantify precipitate population and distribution by measuring their count, size, and area fraction. This technique will be helpful for analyzing effect of precipitation morphology in P92 steel during creep.

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