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OSM-Classic: An optical imaging technique for accurately determining strain

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ABSTRACT

OSM-Classic is a program designed in MATLAB® to provide a method of accurately determining strain in a test sample using an optical imaging technique. Measuring strain for the mechanical characterization of materials is most commonly performed with extensometers, LVDT (linear variable differential transistors), and strain gauges; however, these strain measurement methods suffer from their fragile nature and it is not particularly easy to attach these devices to the material for testing. To alleviate these potential problems, an optical approach that does not require contact with the specimen can be implemented to measure the strain. *OSM-Classic* is a software that interrogates a series of images to determine elongation in a test sample and hence, strain of the specimen. It was designed to provide a graphical user interface that includes image processing with a dynamic region of interest. Additionally, the stain is calculated directly while providing active feedback during the processing.

Code metadata

Nr.	Code metadata description	Please fill in this column
C1	Current code version	V5.1.1
C2	Permanent link to code/repository used of this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-16-00091
C3	Legal Code License	MIT License
C4	Code versioning system used	None
C5	Software code languages, tools, and services used	Matlab [10] (*.m, & *.fig)
C6	Compilation requirements, operating environments & dependencies	MatLab, & Image Processing and Optimization Toolboxes
C7	If available Link to developer documentation/manual	
C8	Support email for questions	draldric@ualberta.ca (Subject: OSM Support)

1. Motivation and significance

Important information that can be used to characterize the material and help predict its behavior under different loading conditions can be provided by testing samples for their material properties. Strain gauges are typically used to measure the strain experienced by the material during testing and assist in determining these properties The two main types of strain measurement devices that are commonly use are the resistive strain gauges (RSG), and the linear variable differential transformers (LVDT) [1]. However, these approaches have limitations in many testing applications.

RSG's are made from a resistive element; the resistive element is either made from a small diameter wire or from an etched pattern in metal foil. When the material experiences a strain, the strain is transferred to the device by mechanical means (cantilevers or adhesives) and this causes a change in the length and width of a resistive element. The change in dimension causes an overall change in the electrical resistance of the element that allows the calculation of strain experienced by the material. LVDTs are made of three coils, one primary and two secondary, wrapped around a single core. As the core is displaced, a change in the self-induction in the secondary coils is observed that is linearly related to the displacement of the core [2]. With the core and shell of the LVDT fixed to the specimen, the change in the displacement can be measured and thus the strain can be determined by knowing the original length of the material between the contact points.

Both devices provide an indirect measurement of the change in the length of the test sample. This change in length is determined from the electrical response of their components and is represented by a single voltage. Changes in the sample, such as crack

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propagation and necking, are masked by the single output voltage leading to poor interpretation of results. The measurement of the strain of small samples can be challenging when using physical extensometers that rely on RSG's and conventional resistive strain gauges. The sharp knife-edges of extensometers, used to prevent slipping on the sample, can dig into the samples causing unwanted stress concentrations that can lead to premature failure. The effects of temperature on resistive strain gauges requires the use of two or more strain gauges to compensate for the changes in temperature changing the resistivity of the strain gauge, as well as, the thermal expansion of the gauge material [3]. Additionally, the measurement devices are quite fragile and require that the extensometer/strain gauge be removed before or when the sample starts to yield to avoid damaging it.

Many of these problems can be addressed by using a non-intrusive optical imaging method for strain measurement. The strain on a specimen can be determined using a camera in conjunction with high contrast markings on the sample providing a 2D view of the sample for later interpretation. The strain is measured by either using marks at the edge (1D strain measurement) or speckles spread over the gauge length (2D strain measurement). While digital image correlation (DIC) or individual point tracking to determine a strain field can be implemented by applying a speckle pattern to the gauge length, it can be difficult to apply an appropriate pattern to the samples [4]. Video extensometry (VE) can be implemented in the form of an edge tracking algorithm by marking the edges of the gauge length with a line or dots, allowing for simpler and less computationally heavy algorithms [5]. The *OSM-Classic* software provides a low-cost alternative to VE that is able to provide fast, yet accurate strain determination with consumer available cameras. The software, additionally, provides the user with a greater understanding of the strain results by providing the user with necessary feedback that is not available with traditional contact extensometry.

2. Software description

Practical implementations of the DIC and VE techniques to measure strain have been developed by commercial test machine manufacturers including MTS' Advantage Video Extensometer [6] and Electroforce's Digital Video Extensometer [7]. These implementations require the purchase of software and the associated hardware. However, the cost associated with purchasing these systems and additional equipment is prohibitively expensive. An optical imaging method of measuring strain, *OSM-Classic*, was developed to alleviate this and problems associated with contact extensometers/strain gauges. *OSM-Classic*, operates on sequential images that can be acquired with inexpensive hardware. Similar to Optical Strain Measurement by Digital Image Analysis [5], both programs use error functions to determine the locations of two parallel edges, defining the length on the sample, in a sequence of images. However, *OSM-Classic* has been designed to require no preprocessing of the images to decrease the time required to provide results, a six-point curvefit to increase the accuracy of the edge tracking and more visual feedback during strain determination for a better understanding of the results.

Preprocessing the images can take large amounts of time depending on the number of tests, images per test and the file size of the image. *OSM-Classic* was designed to reduce or eliminate the required preprocessing of images, by providing various adjustments in the program, (See Section 2.2). The adjustments in the program allowed the use of boundaries on the image, as well as a limit on the intensity, to ensure optimal strain measurements are achieved without preprocessing. While the program is able to achieve results with the adjustments included in the program, steps need to be taken to ensure the images are suitable for strain determination.

Adjustments before the images are captured consist of making sure the gauge length fills the frame, applying strong contrast marks, and lighting the sample properly. The gauge length of the material needs to fill as much of the frame as possible, while still allowing enough room for the specimen to elongate. The contrasting marks need to provide enough contrast to be distinguished from the sample and to ensure the edges will be detected. Finally, the camera needs enough light to provide the high contrast in the image while maintaining a consistent frame rate. Fig. 1 shows an example of applying high contrast marks to ensure optimum images will be captured. It can be seen that the high contrast marks (black) on the sample were applied from the gauge length to the gripping area of the sample leaving the gauge length to appear in high contrast (white) in the image. Although this is not always necessary and alternative marking approaches can be used, this provides a much more stable detection of the edges and lessens the likelihood of "losing" gauge length edges.

The algorithm used to determine the locations of the high contrast marks, in *OSM-Classic*, starts by taking the average intensity, perpendicular to the strain direction. The intensity profile is fit with the six-parameter function,

$$f(x) = (A - F) * [erf(B(x - C)) - erf(D(x - E))] + 2F, \tag{1}$$

where A, B, C, D, E, F are the parameters used in the least squares fit, and x is the position along the intensity profile where the error function (erf) is being fitted. After the location of the edges (C and E) are determined from the curve-fit above, strain can be determined using the general one dimensional definition of strain (ε) as:

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{(C - E) - (C_0 - E_0)}{C_0 - E_0}, \tag{2}$$

where ΔL is the change in gauge length compared to the original length, L_0. This is determined from the location of the left edge of the gauge length, C, compared to its the original location of the left edge, C_0; and the location of the right edge, E, compared to the original location of the right edge, E_0. Since strain is defined as the ratio of change in length to original length, it is dimensionless and can be determined in the pixel space of the image.

2.1. Software architecture

The software was written for MATLAB®, using the GUI development environment (GUIDE). It is coupled with a video conversion program, that can be used to convert captured videos into the required sequential images for processing. The main menu provides a single access point to all the functions of the software and allows switching between the different programs (*OSM-Classic* and *Video Converter*), while allowing future software inclusions to be easily implemented. The main menu is accessible through the *m*-file, `OSM_Suite`, that provides an intuitive point and click style interface.

2.2. Software functionalities

The software can rotate the image so that it is orientated in the same direction the strain will be determined. The program provides functionality for inverting the image to allow the auto guessing, which automatically locates the edges for the initial guess of the curvefit, to detect their locations. Fig. 2(a) shows the original orientation of the image and the result of rotating to the required orientation in Fig. 2(b). The camera orientation can be made to maximize the available resolution for determining strain and time spent rotating individual or batch images can be eliminated, by allowing the orientation of the images to be selected in the program.

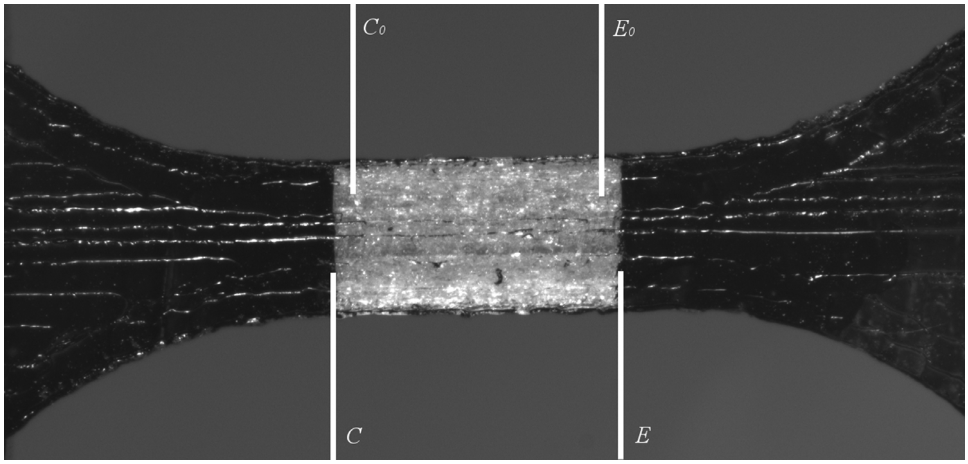

Fig. 1. Image showing an example gauge length for a specimen (white); the high contrast marks (black) serve to create the edges to be tracked by the program. C and E represent the current edges, and C_0 and E_0 represent the initial position of the edges.

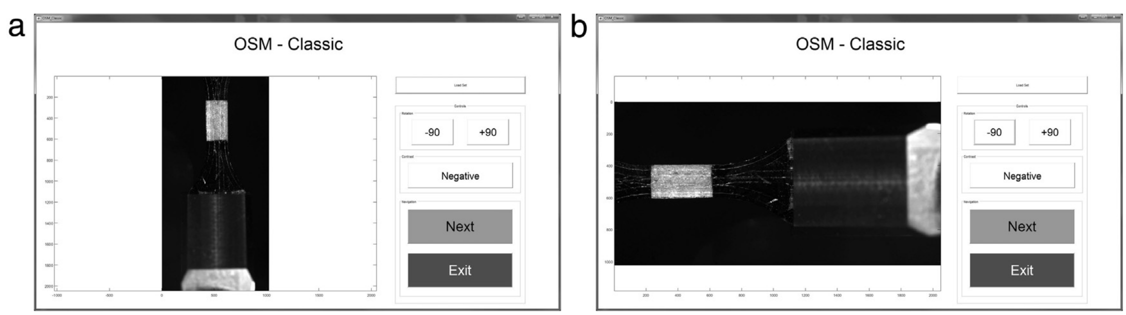

Fig. 2. Example showing the original orientation of the image (a) and the corrected orientation (b).

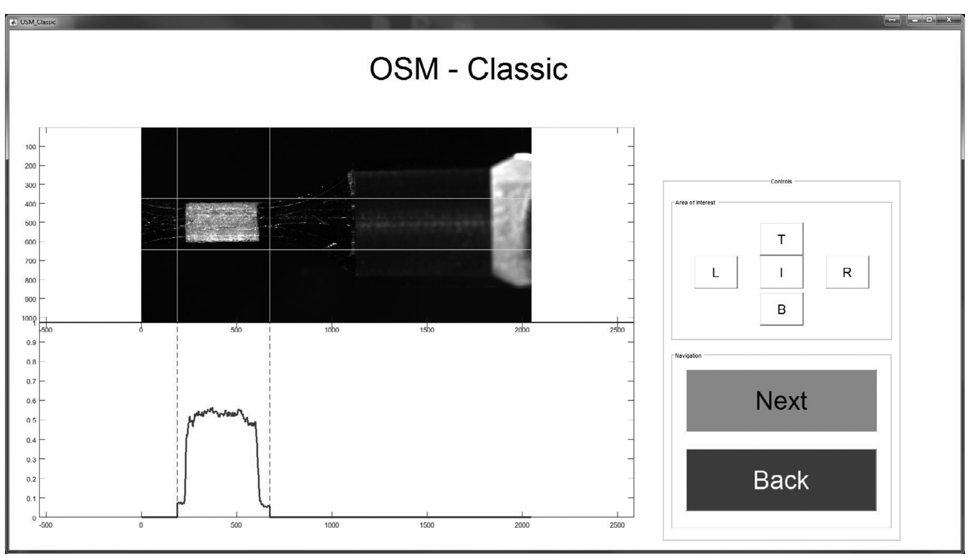

Fig. 3. Image of the software displaying the application of a Region of Interest.

In addition, a region of interest (ROI), shown in Fig. 3, can be set around the gauge length and moving boundaries can be enabled. Setting the ROI in the image removes the noise that is not located close to the gauge length. This can be observed in Fig. 3 as the sudden drop to zero in the plot display at the bottom of the GUI. In addition, a moving boundary can be enabled to remove more background interference throughout the measurement while keeping a constant region between the detected edge and the boundary of the ROI. The ROI's boundaries can be displaced by the same amounts by determining the displacement of the detected edges in one frame. This allows the program to dynamically remove the background, while always keeping the ROI close to the ends of the gauge length.

A limit can also be applied to the intensity profile as demonstrated in Fig. 4, to remove the noise associated with the surface of the material to provide sharper changes in intensity close to

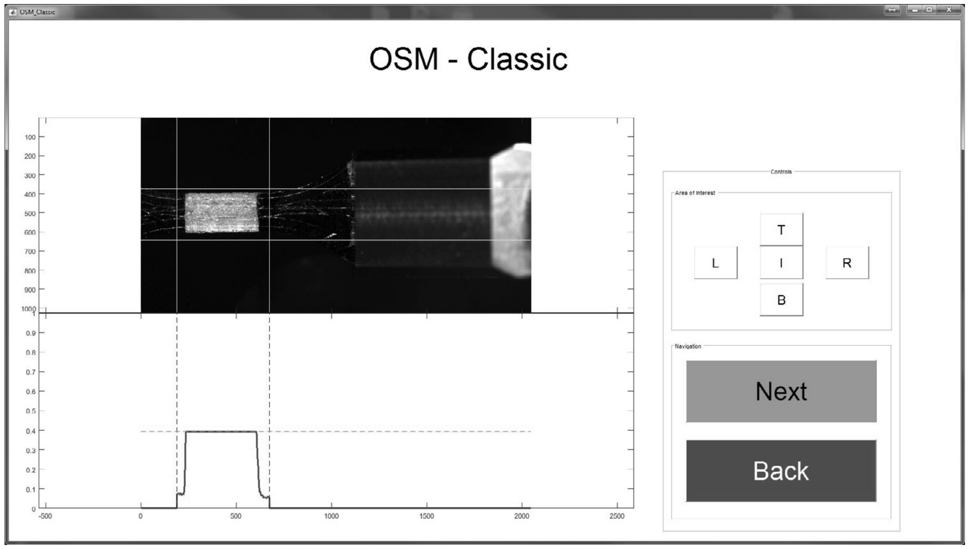

Fig. 4. Image of the software showing the removal of noise between the to edges, by application of an intensity limit.

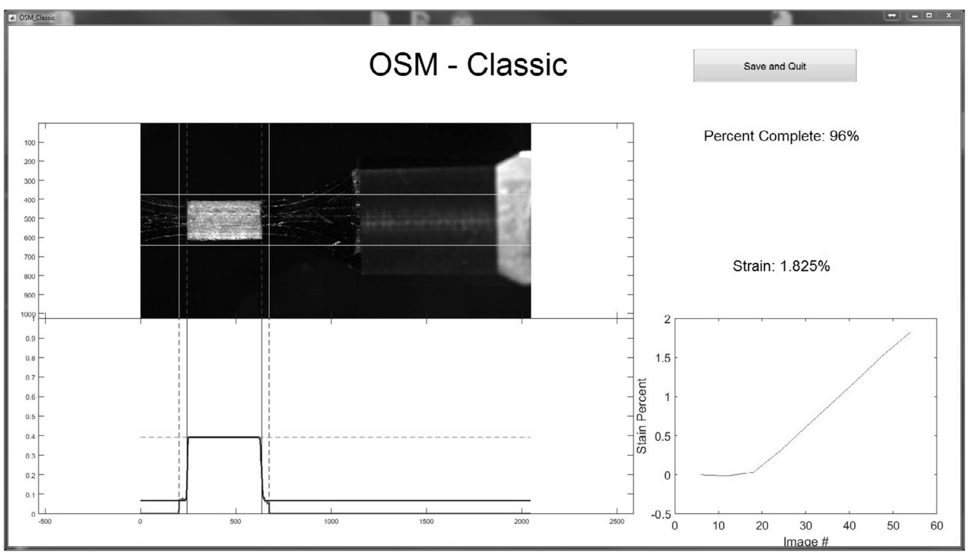

Fig. 5. Image of the software showing the different types of feedback available during the strain processing.

the edges. By creating sharper edges in the intensity function there is an apparent high contrast that makes the edges easier to be accurately detected. The limit for the intensity provides less drifting of the detected edges, and increases the reliability of the program.

The software also provides feedback on the sample and the measurement determination that is not possible with traditional methods for measuring strain. As shown in Fig. 5, the program displays the current image that is being processed, as well as the ROI and detected edges used to determine the strain. Additionally, below this is the intensity profile of the current image; plotted over top of the intensity profile is the least squares approximation of the curve, with the centers of the two error functions highlighted by the solid vertical lines. There is also an online display to show a quantitative measure of the current strain, in percent, along with a graph displaying the strain as a function of image number. If the time between each image is a constant, the slope of this graph can be interpreted as the rate of strain. The additional feedback the software provides gives a better understanding of the material's behaviors and anomalies during testing.

3. Implementation and empirical results

An empirical study was performed to provide validation of the results obtained by the software. This validation was performed by simultaneously measuring the strain with an extensometer and capturing the test with a camera. After the images were processed with the software, the strains were plotted against each other and the linearity was determined by fitting a linear function to the data.

For the data to be validated, the result would require a slope of one, which suggests the strain values for the two methods are the same. In addition to the slope, the correlation coefficient would also require a value of one, which is a metric used to determine how deviant the data is from the linear trend. Fig. 6 displays one of the results from the tests performed; it is shown that there is a strong linear trend (slope of 1.023 and correlation coefficient of 0.9999). From the total test sample size of ten presented here, the average slope was determined to be 1.011 ± 0.090 and the average correlation coefficient, R^2, was determined to be 0.998 ± 0.003. With the average slope and correlation coefficient close to one, and relatively low deviations, it can be concluded that the

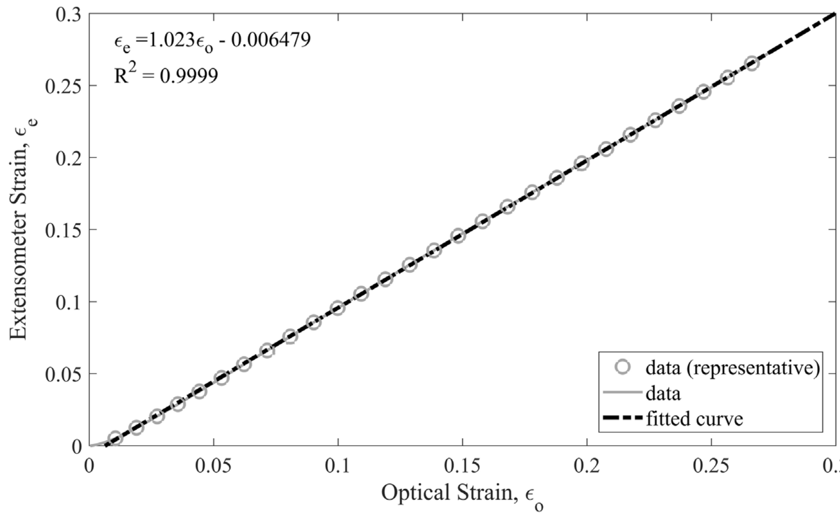

Fig. 6. Comparison between MTS Extensometer and *OSM-Classic*. The graph shows a linear trend and strong correlation of the data. The line (data) consists of 1450 data points, with representative data shown by circles.

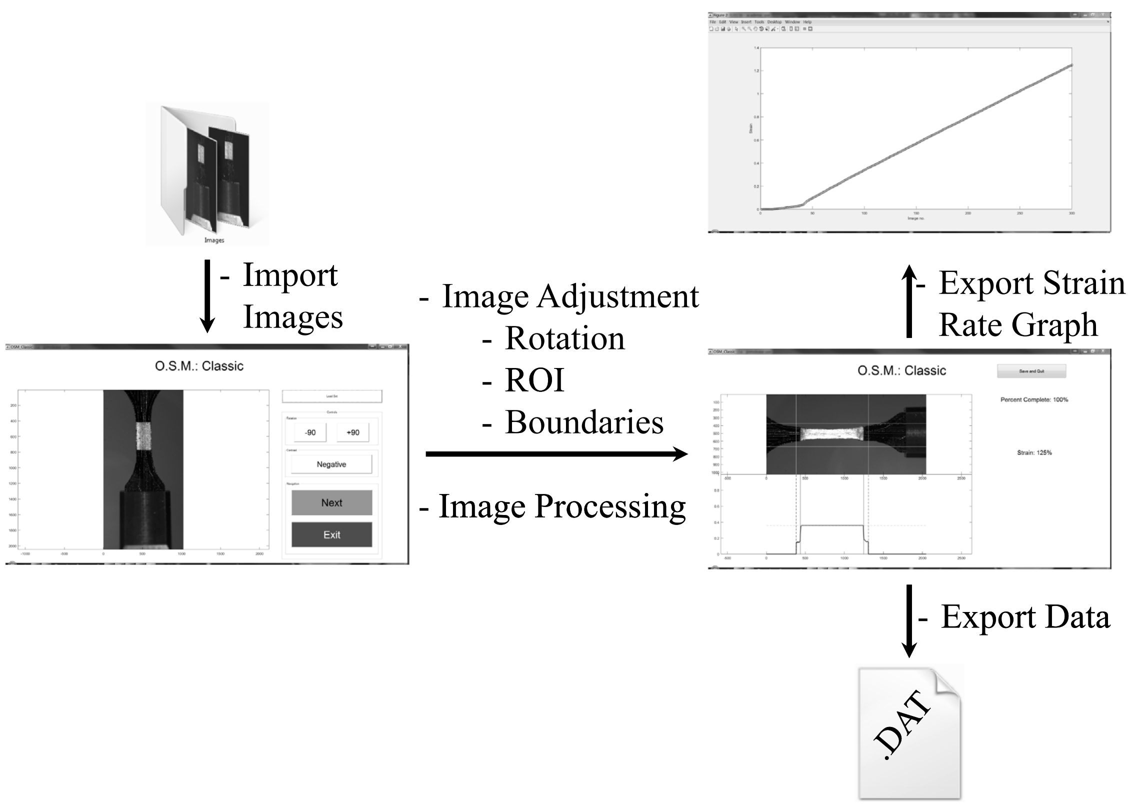

Fig. 7. Illustration of the workflow for determining the strain of a specimen.

results obtained from the software are accurate in comparison with a traditional strain measurement device.

4. Illustrative examples

Fig. 7 shows the workflow associated with *OSM-Classic*. A folder of images is imported into the GUI, where the orientation of the image can be rotated to ensure the strain is occurring in the horizontal direction. The ROI can be set around the gauge length, as well as, an intensity cap can be set to remove noise within the gauge length. Moving boundaries can be set to allow a smaller ROI around the sample and the initial guesses for the locations of the high contrast marks can be set. The processing can be started with or without visuals and the results, including the image number, position of the two edges and the strain are output to data files in csv format.

5. Impact

Material science is an ever expanding field. With the increase in popularity of additive manufacturing and textile composites, the ability to measure the strain of smaller samples, samples at different temperature, or samples that experience large strains becomes critical. *OSM-Classic* provides material scientists and researchers with the ability to measure the strain after testing, without the need to purchase the expensive hardware and software from test machine manufactures. Additionally, the software allows the use of consumer available cameras. *OSM-Classic* does not require the timely preprocessing that is required by previous software. The software has been utilized to determine the strain on small 3D printed samples tested at various temperatures [8] and tubular braided composite rebar [9].

6. Conclusions

The optical strain measurement program, *OSM-Classic*, has been presented. This program allows for the determining of strain on a sample that cannot be fitted with a strain gauge or extensometer; it can also be used where remote strain measurement is required, such as through transparent windows of a temperature/environmental chamber. By extension, this further allows the measurement of strain in environments too harsh or ill-suited for other strain measurement devices. The software only requires a video, or sequence of images be captured of the sample during testing to accurately determine the strain while providing useful feedback to the user.

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