Overview of module

Introduction

'Experimental mechanics' can be defined as the investigation by experimental means of the mechanical behaviour of engineering systems subjected to load. The system can be a structure, a material, soft matter such as human tissue, a fluid-structure coupling; the list is practically endless. Implicit in the definition is that some kind of measurement system is used to capture a quantity that describes the system's behaviour. The main attributes conventionally associated with experimental mechanics are the deformation and the mechanical strain. These can then be related to a failure parameter by deriving the stresses from the strains and by using the material constitutive relationships. Experimental mechanics approaches that provide a measure related to the strain are therefore very important design tools. Many of these techniques have been available for decades but recently have been gaining popularity because of the advances in computing power and decreasing hardware costs. More importantly from the design perspective, the necessity for experimental data to validate numerical models of systems manufactured from complex nonlinear inhomogeneous materials, such as fibre reinforced polymer composites, is ever increasing. Experimental mechanics approaches have much to offer and it is the purpose of this module to provide an overview of the range of the techniques, their operation and applications.

The aim of this module is:

- to provide an in-depth understanding of experimental mechanics approaches
- to introduce students to testing procedures
- to provide detailed knowledge of the application of point measurement techniques such as electrical resistance strain gauges and optical fibre sensors
- to provide a detailed knowledge of modern full-field techniques such as Thermoelastic Stress Analysis (TSA), Digital Image Correlation (DIC), Electronic Speckle Pattern Interferometry (ESPI)
- to understand how the data from experimental techniques are manipulated to validate numerical models.

Test machines

The basic equipment required to conduct experimental assessment of structures is a test machine. To understand the load-carrying ability of a material and to determine the amount of deformation it can withstand before failure, the first step is to determine the properties of the material. To obtain these, a sample of material (i.e. a *test specimen* or *coupon*) is tested by loading in tension, i.e. stretching the material until failure occurs. To conduct the tensile test and apply the load in a controlled manner a specialist machine is used. A schematic of a typical test machine is shown in Figure 1.

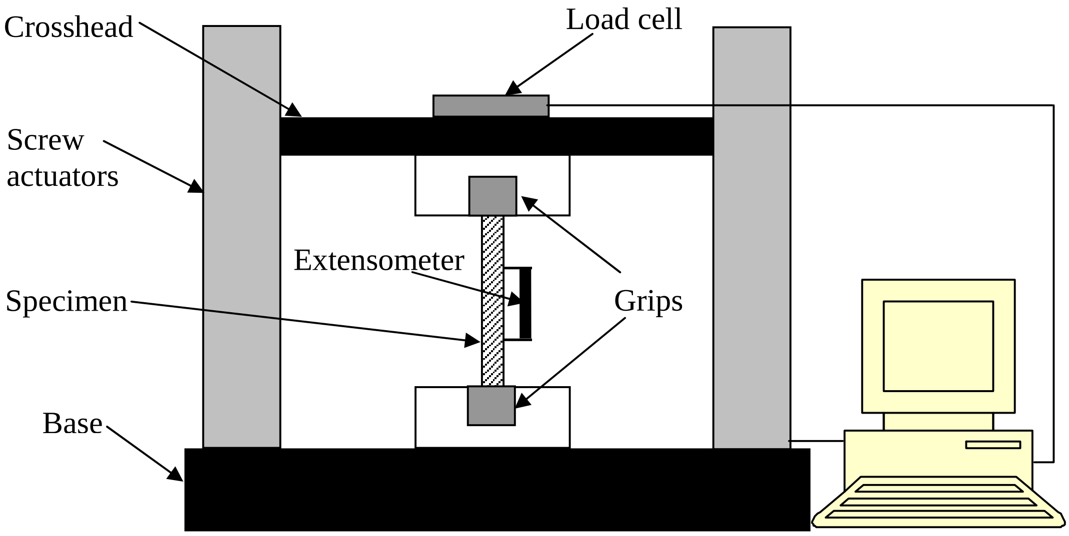

Figure 1 Schematic representation of a typical test machine

A typical test machine's main components are the *frame*, *load cell*, *grips* and an *actuator*. The frame is equipped with two metal columns, a *base* and a moving *crosshead*. The crosshead is a rigid metal block located on the columns that connect to a piston and slides up and down. It can be positioned according to length of the specimen and can move to any position within the available range of the column length. Two grips, one mounted on the base the other on the crosshead, are equipped with jaws that are used to mount the specimen and designed to retain the specimen even after fracture. While the lower grip is fixed, the moveable upper grip is controlled by an actuator providing a constant rate of motion hence loading the specimen. The load cell is mounted on the crosshead and measures the magnitude of the applied load (i.e. *force*) building up as the specimen is stretched. Finally, all control operations are carried out via a separate control panel installed in the environs of the testing machine.

Test machines can be categorised on the basis of the load generating mechanisms; hydraulic, mechanical and electrodynamic. The hydraulic test machine is capable of applying dynamic tension or compression loads *via* a hydraulic piston at static or very slow loading rates. A mechanical test machine uses a screw jack system, which is controlled by motors that drive the crosshead up and down and is more suited to *quasi*-static testing. In both cases a servo system can be introduced that utilises a feedback control system. This servo control system allows the amount of displacement to be controlled accurately. In the module all types of test machine are described along with hands-on experience in the laboratory.

Electrical resistance strain gauges

An electrical resistance strain gauge is the most well defined method of obtaining the surface strains from a component under load. A strain gauge is shown in Figure 2 and comprises a thin film with a metallic conducting element etched on it. The gauge is attached to the structure in such a manner that any strain changes in the structure are transmitted fully into the gauge; hence the gauge copies the surface strain in the structure. The gauge is normally bonded to the structure using a cement or adhesive. Clearly, the quality of the measurement is dependent on the quality of the bond. A range of adhesives is available for use with strain gauges. These have been designed to optimise the strain transmission and to match the material properties of the object under investigation. The strain is measured by passing an electric current through the conducting element. As the structure, and hence the gauge, deforms the conducting element will deform and its resistance will change. The change in resistance results in a change in measured voltage across the gauge (indicated on the voltmeter-see Figure 2) that can be directly related to the strain. Gauges are available as simple single sensors or as multiple sensors known as *rosettes*. A single gauge will provide the strain in the gauge direction, which may or may not be the maximum or *principal* strain. To obtain the principal strains (i.e. the maximum and the minimum) it is necessary to use a three-gauge rosette. During the module student will take part in lectures and laboratory classes on the practical application of strain gauges to specimens and on obtaining measurements from single gauges and rosettes.

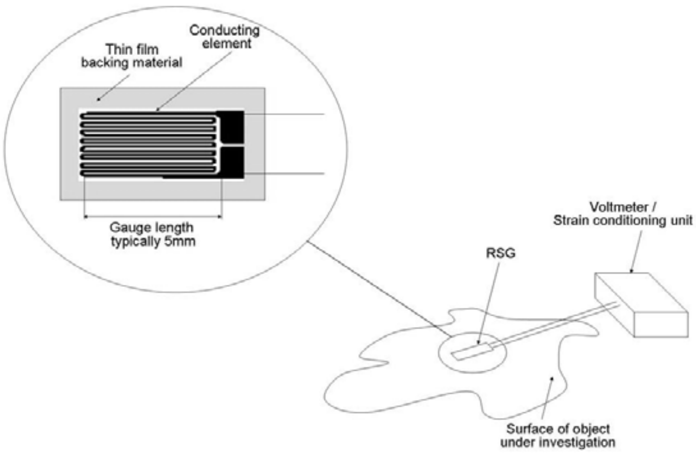

Figure 2 Resistance strain gauge (RSG)

Full-field techniques for strain measurement

Full-field techniques describe a category of approaches where a field of data is collected as opposed to the single point reading extracted from a strain gauge. The techniques can be broadly divided into three categories:

1. White light techniques
2. Coherent light techniques
3. Infra-red techniques

In this module two white light techniques will be covered: Digital Image Correlation (DIC) and the Grid Technique. Both techniques use digital cameras (i.e. CCD (charged coupled device)) to capture images of a component both before and after deformation. In DIC a random pattern is tracked and the deformation extracted from the movement of the random pattern. In the Grid Technique a well defined grid is attached to the specimen and the phase of the light from the deformed and undeformed images is used to obtain the displacement. To obtain the strain, the displacements are differentiated and a full-field image of the strain is obtained. At present the Grid Technique cannot accommodate out-of-plane displacements. In DIC out-of-plane displacements are obtained by employing two cameras. A typical set-up is shown in Figure 3.

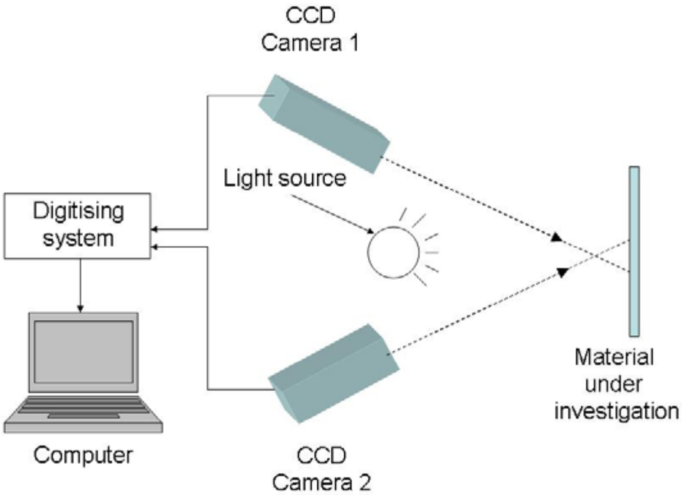

Figure 3 Typical set-up for stereo DIC

In coherent light techniques the specimen surface is illuminated by laser light. Interference occurs between the source and the reflected light, causing a speckle pattern. The size of the speckles result from the nature of the light and the aperture it passes through. In Digital Speckle Pattern Interferometry (DSPI), a CCD digital camera records two light patterns: one from the undeformed condition and the second from the deformed condition. In Figure 4 a schematic of a simple DSPI set-up for measuring out-of-plane deformation is shown. Essentially there are two components in the system. A laser is used to illuminate the material under investigation and provide the speckle on the surface of the object. The laser also provides a reference beam to the CCD camera via the beam splitter. The other component is the interferometer, which is shown in Figure 4 as a prism and lenses. Data from the deformed and undeformed condition are combined arithmetically by subtracting two speckle patterns. This results in a series of closely spaced lines appearing in the image that is displayed on the monitor, which are known as fringes. This representation is sufficient for a qualitative representation of the deformations. In order to process the data into quantitative information, multiple data sets are required for the deformed condition; these are obtained using the phase shifting device (see Figure 4) that changes the optical characteristics of the ESPI system. A sequence of a minimum of three positions of the phase shifting device allows the data to be processed into digitised data maps of the out-of-plane displacement field in terms of the phase of the light. These can be analysed directly or processed further to provide strain. To obtain in-plane deformation data it is necessary to illuminate the object from at least two directions (to provide deformation data in one direction). Commercial systems are available that allow both in-plane and out-of-plane deformations to be measured; these usually contain four-laser illumination systems.

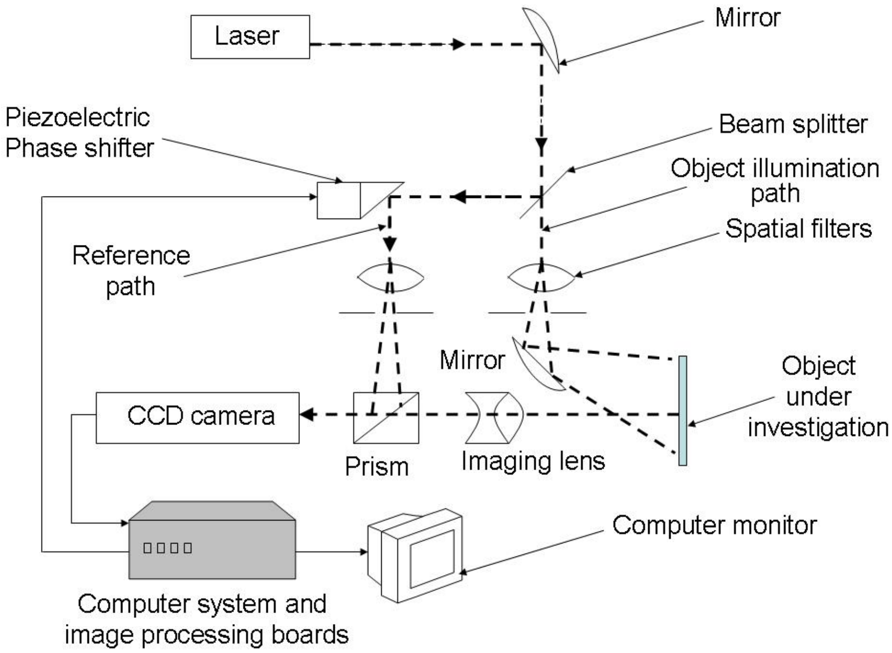

Figure 4 Typical DSPI set-up

Photoelasticity is one of the oldest and most useful forms of full field measurement techniques. It involves the observation of fringe patterns caused by stress-induced birefringence. The instrument that is used for photoelasticity is called a polariscope. A schematic of a conventional plane polariscope is shown in Figure 5. Essentially a replica of the artefact under investigation is produced in a transparent plastic material. This is loaded and placed in the polariscope as shown. Polarised light passes through the replica and is observed through a further polarising plate known as an analyser. The refractive index of the material is stress dependent and causes retardation (or interference) in the light passage, which produces fringes in the replica that can be directly related to stress. Digital photoelasticity utilises CCD digital cameras and collects images with the analyser in a number of positions to automatically generate data that is proportional to the difference in the principal stresses. The technique utilises white light but relies on the interference of the passage of light through the specimen to obtain the measurement. Therefore it sits between the interferometric techniques based on coherent light and the simple white light techniques.

Infra-red techniques for strain measurement centre on the ‘thermoelastic effect’. The fundamental basis is that when a specimen is subjected to stress there is an instantaneous change in temperature. This temperature change can be directly related to the sum of the principal stresses in the structure. In practice, as the temperature change is of the order of mK the temperature change is measured using a highly sensitive infra red detector. The approach is known as Thermoelastic Stress Analysis (TSA). A schematic of the typical TSA equipment arrangement is shown in Fig. 6. As a single transient load would result in a temperature change that would quickly dissipate. The test specimen is therefore cyclically loaded within its elastic range to minimise heat transfer in the specimen sufficiently to obtain an adiabatic response. This can be achieved for most applications at frequencies around 10 Hz.

Temperature measurements are obtained from the specimen surface and correlated with the loading using a reference signal from the test machine. The voltage output from the infra-red detector is converted to a digital output and plotted as a full-field map on the computer monitor. Calibration techniques are used to convert the temperature change data into stress values.

During the module students will receive lectures on each of the techniques described above. The lectures start with the background to the fundamental physics of white and coherent light and infra-red technology. Each technique is described in detail with examples and plentiful references. Laboratory classes covering the white light techniques, photoelasticity and TSA are conducted subsequently.

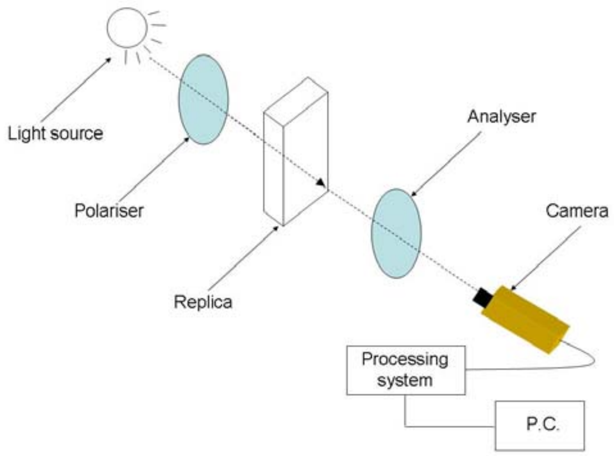

Figure 5 Set-up for digital photoelasticity

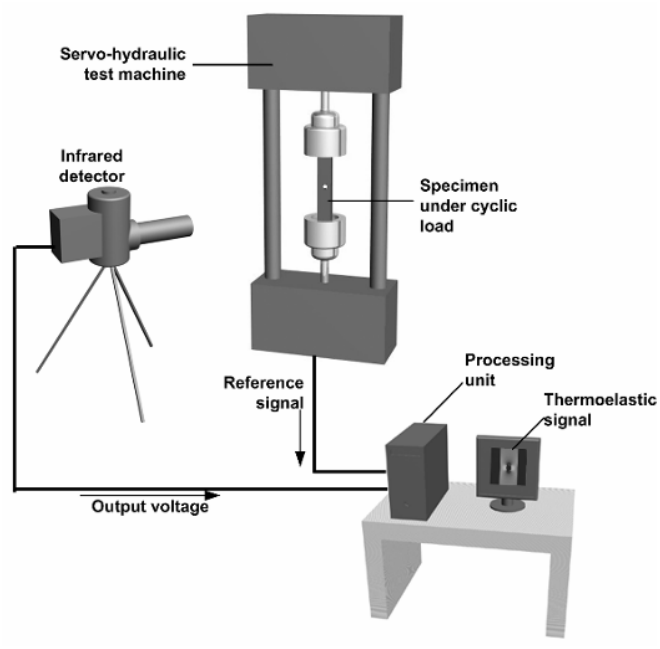

Figure 6 Typical set-up for TSA

Laboratory classes and analysis of data

The details for each laboratory class are provided on a separate sheet. During each laboratory session you will collect data using each of the techniques described. The data will be uploaded to \\soton\ude\courses\SESG6031. Your data will be stored with your group number. All software necessary for this module is also stored in the same space. To access this space please type the link into **windows explorer**. If accessing from a home PC through a VPN connection, you may be asked for your Southampton user name and password.

In the module you will be expected to analyse the data using various techniques and extract information such as Young's modulus, Poisson's ratio, calibration constants and stresses. Full instructions are provided in the laboratory sheets.

Assessment

Aim: In the course work assignment a detailed analysis of the data collected in the laboratory classes will be carried out. The mechanical properties of the aluminium alloy material that was tested will be derived from the different experimental mechanics procedures. The stresses and strains in the disc will be derived using each technique and the values from each technique compared. The virtual fields method will be used extract the material properties from the data from the discs obtained using the white light techniques.

The module will be assessed purely by coursework. There are six coursework activities in the assignment. Full details and instructions are given on separate handouts. The table below gives the coursework activity and its overall percentage for the module.

Coursework title	**Weighting**
Brazilian disc analysis	10%
Dog bone tensile test	15%
Camera set up	15%
DIC, Grid and VFM on Brazilian disc	25%
TSA	15%
Comparison of derived stresses	10%
Conclusions	10%

- The findings from the above should be written-up into a formal technical report of no longer than 3000 words (not including tables and figures).
- Descriptions of the experiments should be given along with clear discussion.
- Marks will be allocated for presentation as well as for technical content, all graphs need gridlines, legend, axes need to be labelled and units must be provided.
- In the discussion section each technique must be compared this means you need to present the data in a way that it can be compared. Convert the DIC and Grid technique data to stress sum data and compare with the TSA data and the theory.
- The report must finish with at **least 10 strong conclusions** about the accuracy, precision and applicability of the experimental techniques.

The coursework is worth 100% of the module marks and you will have until **Friday 11th May 2018** to complete the coursework. The coursework is to be up loaded into on the blackboard site as a single .pdf and the file name should be firstname_lastname_EM.

Useful Background Reading

Rastogi P. and Hack E., *Optical Methods for Solid Mechanics – A Full-Field Approach*, Wiley-VCH (2012).
Sutton, M.A., Orteu, J-J. and Schreier, H.W., *Image Correlation for Shape, Motion and Deformation Measurements,* Springer, New York, (2009).
Rastogi, P.K., *Digital Speckle Pattern Interferometry and Related Techniques*, John Wiley and Sons, Chichester (2001).
Steinchen, W., and Yang, L., *Digital Shearography: Theory and Application of Digital Speckle Pattern Shearing Interferometry,* SPIE Press, Washington (2003).
Patterson, E.A., "Digital photoelasticity: principles, practice and potential", *Strain* **38** (2002) 27–39.
Dulieu-Barton, J.M. and Stanley, P., "Development and applications of thermoelastic stress analysis", *Journal of Strain Analysis for Engineering Design*, 1998, **33**(2): 93-104.
Pitarresi, G. and Patterson E.A., "A review of the general theory of thermoelastic stress analysis". *Journal of Strain Analysis for Engineering Design*, 2003 **38**(5): 405-417.
Stanley, P. and Chan, W.K., "Quantitative stress analysis by means of the thermoelastic effect. *Journal of Strain Analysis for Engineering Design*, 1985 **20**(3): p. 129-137.
Pierron, F. and Grediac, M., *The Virtual Fields Method* Springer (2011).