MATRIX | MATERIALS

POLARISCOPE

CP5220

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Laboratory Technique

Safety in the Laboratory

The principal hazards in using apparatus that demonstrates the static and dynamic performance of associated theorems and the assumptions involved are where rotary or linear motion occurs and where the handling of loose heavy items, for example weights, is part of the procedure.

Of the loose items the heavier weights must be regarded as the most dangerous objects. Should one of these fall onto the feet of those around the apparatus the potential for damage is present. Hence it is recommended that cast iron weights be handled carefully and when moving and placing the heavier ones (say 10 N upward) on load hangers this should be regarded as a two handed operation. It is surprisingly easy to spill a complete stack of weights off a hanger when adding a further one.

In addition to weights there are some heavy parts that have to be interchanged during some experiments and a similar approach using two hands where required is suggested. It may also be both sensible and necessary for two people to take part in changes to the apparatus.

Success in the Laboratory

Work in the laboratory depends on understanding, observation and skill. In the first place a good understanding of the performance, and limitations, of experimental models is needed. To know about the theory involved is useful but not essential. In the second place keen observation leads to better results and avoidance of mechanical mistakes. Lastly, the way in which students handle the apparatus can influence the accuracy and speed of the work.

To help students gain experience and improve their experimental technique a range of information is offered in the following notes. Bear in mind that in the world of real engineering it is often necessary to check the performance of new designs using the methods and instruments of laboratory experiments.

Design of Experimental Models

The purpose of each experiment is to illustrate an item of structural theory, or to show how well simplifying assumptions in the applied mathematics correspond to actual behaviour. This often requires the model to exaggerate the behaviour of a real structure.

In order to achieve specific objectives each experiment has a particular arrangement best suited to the theoretical requirement. These arrangements of the apparatus are described in the Construction Appendix, where included, of each experimental Instruction Manual. Before starting an experiment students should read through the Instruction Manual and be prepared to follow the recommended procedure.

Laboratory Technique

Increased deflections are usually achieved by using very flexible models. The stiffness depends on ***EI*** or ***EA*** so a change of material from steel (**E** = 205 kN/mm2) to aluminium (**E** about 1/3 **E** for steel) or a plastic (**E** about 1/80 **E** for steel) is a solution. The alternative is to use thin steel beams with a low ***I***.

One disadvantage experimentally is that friction in bearings may affect displacements and force measurements. The other is that large changes in dimension (geometry) of models must be accommodated if possible.

Results can be improved by using stiffer models and larger loads, but this reduces visual effects such as curvature of beams.

Sources of Resistance

A knife-edge can simulate a frictionless pin or bearing, but horizontal and rotational movements demand ball bearings. These are packed with grease and fitted with shields to keep out dust and grit. Hence ball bearings have some torsional restraint, which affects forces in the order of magnitude 1 N. This shows up as a difference in readings for loading and unloading.

Pin joints in trusses are also subject to friction, which increases in proportion to the loading.

Repeatability of Readings

The ability to obtain accurate and repeatable experimental results is generally a matter of care and technique. Of course it helps to know the sources of error and to recognise when the apparatus contributes to the variability of readings.

Frictional variation can be minimised by using vibration. The extent of the friction can be observed by first increasing and then decreasing an applied load by hand to get the difference in readings. Tapping the frame on which the experiment is mounted will reduce the variation.

Cast iron weights for loading must always be applied gently. A load suddenly added will instantaneously apply twice its static value. Although weights are hand finished there is a manufacturing tolerance of ± ½%. This may affect linearity in experimental readings.

Introduction

Photoelastic stress analysis is an extremely powerful technique which enables a complete stress analysis to be carried out on engineering components or structures even at the design stage. It is capable of supplying solutions to both two dimensional and three dimensional stress problems and for the purpose of introducing the technique, two dimensional stress systems will be considered.

The technique of photoelastic stress analysis involves making of a scale model in a suitable transparent plastic and placing the model in a beam of polarised light using an instrument called a polariscope. If loads are applied to the model in a similar direction to those applied in service to the actual component, then an interference pattern will be visible in the model. The interference pattern will consist of coloured fringes called isochromatics if white light is used as the illuminant or black fringes on a self-coloured background id monochromatic light is employed.

These fringe patterns can be interpreted to give information on the magnitudes of the principal stresses which area present in the model and then, by using a simple formula, the stresses in the actual component can be determined even though the component material may be steel, aluminium, cast iron, glass, ceramic, or even plastics itself.

For the model to be compatible it is essential, of course, that the plastics from which the model is made should be elastic and stressed within its elastic limit and that the prototype material should also be elastic and stressed within the elastic limit.

APPARATUS

Apparatus Description

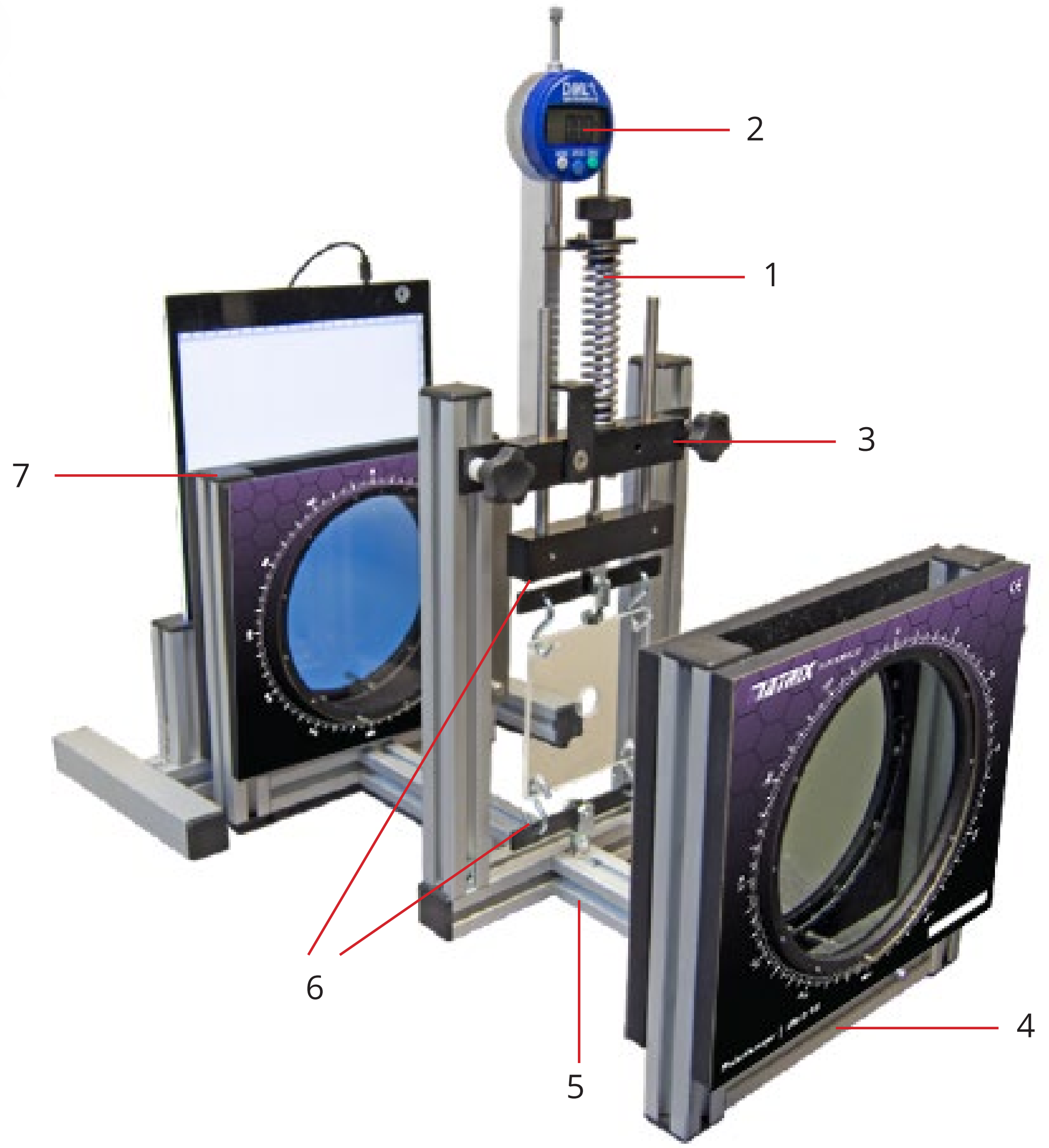


Diagram Key

1	Load Spring	5	Frame
2	Dial Gauge	6	Adjusters
3	Cross Bar	7	Lower Plates
4	Upper Plates		

The apparatus consists of a two tiered bench top frame into which all component parts are fitted.

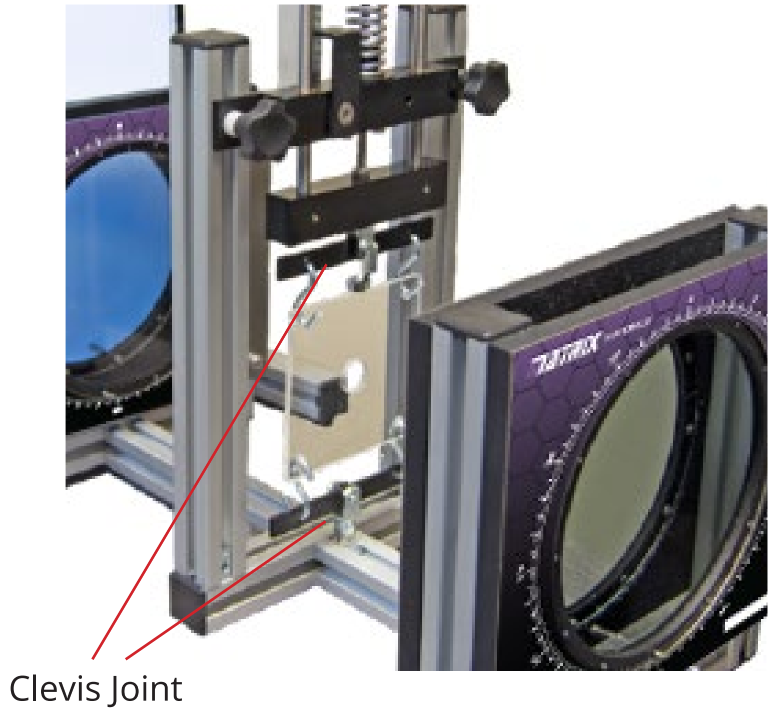
APPARATUS

Apparatus Description

The lower frame is longer than the upper frame. All frame elements have central grooves running along their length. Rubber mounting feet underneath the lower frame allow for soft resting on the bench top or light box apparatus.

The grooves of the lower and upper frame are used to fit in and secure the square clamping plates which hold the wave plates and respective polariser and analyser filters. The upper and lower quarter wave plates as well as the (analyser and polariser) can be turned via the clamping plates.

On top of the lower frame is a mounted loading mechanism. This is held in position by two twist knobs, one on either side, and has a long piece of studding running through the middle of it. This frame has a clevis joint at one end and an opposite facing clevis joint in the upright part of the frame.



These clevis joints support the specimens over the wave plates. The right hand clevis is attached to the load frame. The pin in the middle of the clevis can be unclipped and removed in order to load a different specimen or load plate.

The load frame is pulled through the cross bar, with the cross bar rigidly fixed to the top face of the lower members. A spring on the other side of the cross bar is compressed as the load frame is pulled towards the cross bar. The adjuster on the end of the spring causes the compression. This adjuster is a knob which is twisted by hand.

APPARATUS

Apparatus Description

The amount of compression of the spring is monitored using the load gauge. The spring is calibrated to have a spring rate of 10N/mm. Thus each millimetre moved by the dial gauge, the load frame is applying a 10 Newton force to the specimen. The dial gauge has increments of 0.01mm, thus a resolution of 0.1N is achievable on this apparatus. The specimen is put under tensile loading during testing.

DO NOT OVER STRESS SPECIMENS-THIS UNIT IS NOT DESIGNED FOR DESTRUCTIVE TESTING.

Due to the various specimens and fixings supplied the cross bar can be moved along the lower members of the frame by releasing the knobs and sliding the cross bar into position. This should be aligned opposite each other to ensure an even starting test position.

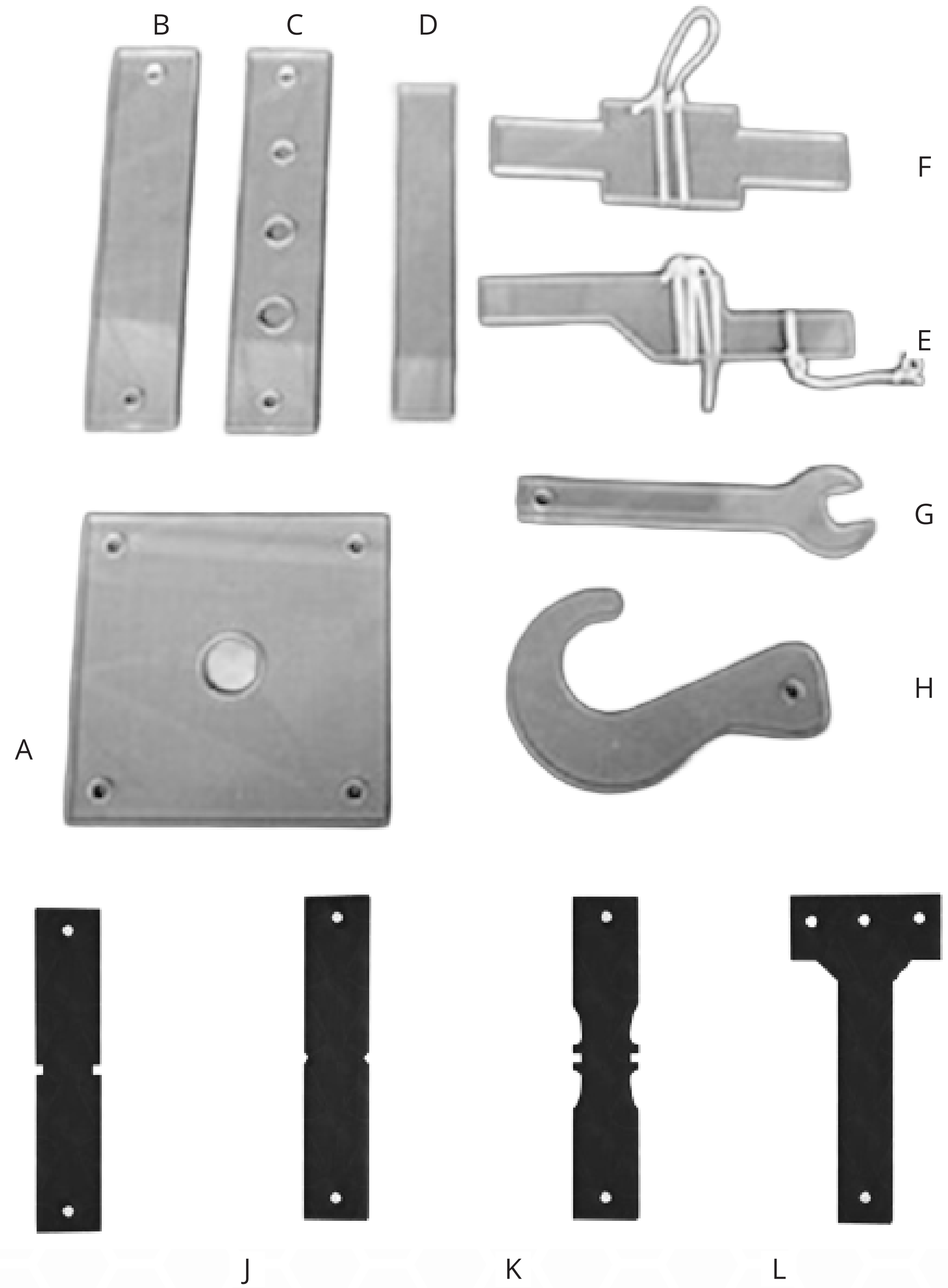
The top element of the frame houses the upper plates. The plates fit in the centre grooves of the upper tier of the frame, these are set in position and should not be moved. They can however be turned easily by undoing the locking knob at the front and then using the knobs on the top edges be turned through 360º. The plates have clear markings of 180 º so that this measurement can be recorded for reference. This is the same for the lower plates also.

The rotation of the filters change the optical axis of the light waves which display the isochromatic fringe pattern mentioned in the theory, the orientation of the filters depict whether the isochromatic fringe pattern is displayed in colour or in black spots called an isoclinic line which tends to show the direction of the principle stresses rather than the magnitude of them. In this experiment however we are only interested in the isochromatic fringe patterns.

APPARATUS

Apparatus Description

Specimens available:



APPARATUS

Apparatus Description

Specimen Letter	Specimen Description
A	Square Plate Specimen
B	Rod Specimen
C	Perforated Beam specimen
D	Bar specimen
E	Bending Element Overlap Specimen
F	Shaft specimen
G	Spanner Specimen
H	Crane Hook Specimen
I	Rod N Notch Specimen
J	Rod V Notch Specimen
K	Rod Scallop N Notch Specimen
L	Welded Seams Specimen

Each specimen has either holes or no holes in for mounting into the frame. Each specimen is then shaped, some with holes internally to allow excellent visual aid to stress concentrations.

Filters And Wave Plates

With each MH7915 comes supplied a kit of filters and wave plates these should be installed prior to delivery:

APPARATUS

Apparatus Description

The details of each are in the following table:

Label Reference	Critical Load (N)
'A' or 'AN'	Analyser (Polarising Filter)
'TQ' or 'Q2'	Top Quarter Wave Plate
'BQ' or 'Q1'	Bottom Quarter Wave plate
'POL' or 'P'	Polariser (Polarising Filter)

Each label is placed on the bottom of the plate when viewed for correct reading orientation.

In the lower tier of the frame, place the Bottom Quarter Wave Plate into the frames and then place the Polariser on top of the wave plate and secure into the frame with the twist knobs.

In the top tier, place the Top Quarter Wave Plate into the square frame, then place the Analyser on top of the wave plate and secure with the circular plate on top of the filter and tighten the twist knobs to secure this part of the unit into the frame.

Ensure all labels are at the bottom when the plates and filters are fitted and that the 0 position is in line with the groove on the top of the frame.

Filters And Wave Plates

Each specimen is manufactured to a known shape and from a material called Columbian resin (CR39).

It is a colourless material with good clarity and a popular choice for two-dimensional photoelastic demonstration models. It has moderate mechanical strength, displays a moderate amount of creep, but exhibits minimal time-edge effect. At oblique incidence, it will exhibit pronounced birefringence.

Material	Tensile Strength MN/m2	Modulus of Elasticity MN/m2	Poissons Ratio	Fringe Value of Material at 5893 x 10-6 cm kN/m.fr
CR39	48	1700-2400	0.44	14.9-17.5

This material is also used for application such as specialist lenses.

APPARATUS

Apparatus Assembly

*Light Box Not Supplied With Standard Unit.

The main MH7915 unit assembly is placed on top of a monochromatic (white) light source. This could be a standard projector or accessories purchased from Matrix. It comes with a universal power supply that can be plugged into any mains socket. The power lead is connected into the light box unit where there is an on/ off switch along the power cable.

APPARATUS

Apparatus Description

Light box (D Module)

The quarter wave plates and filters should come fitted as described in the previous section.

Each specimen mounts into the frame as shown using cord, hooks and the load plates supplied with the apparatus:

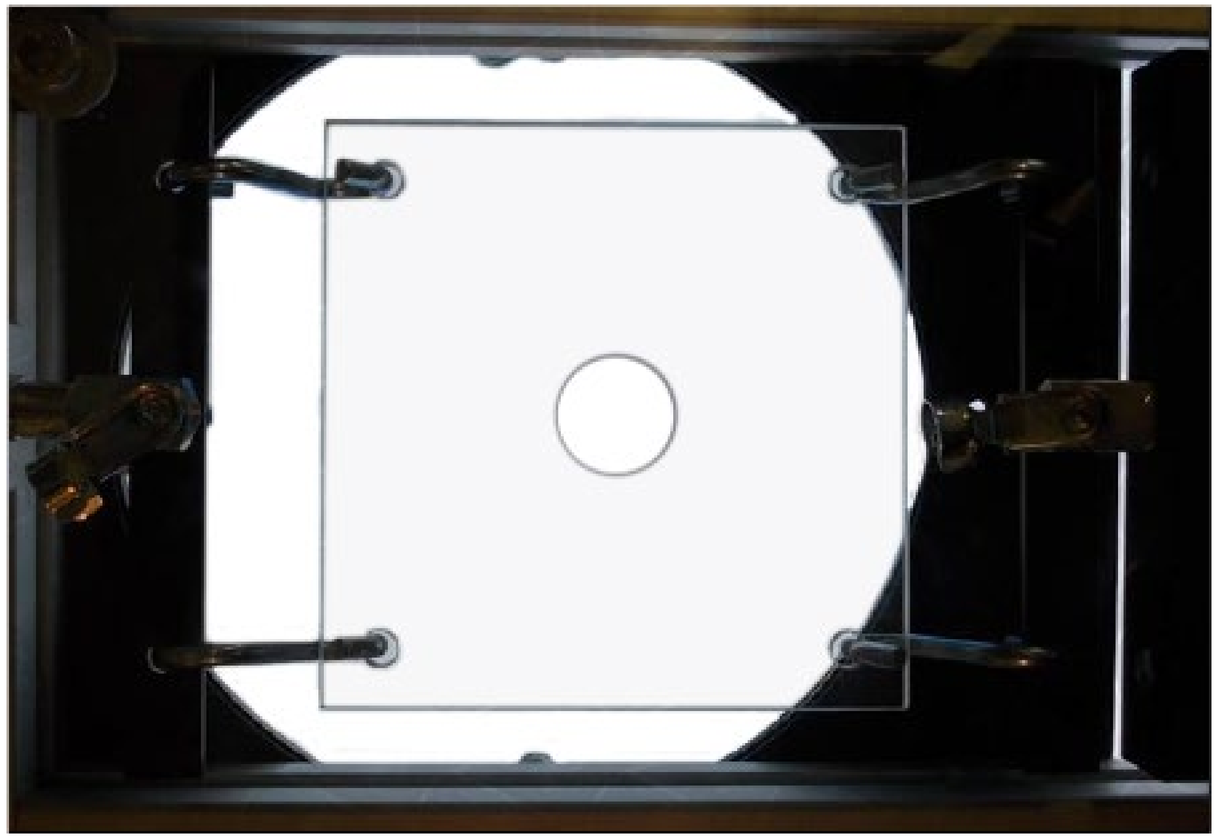


Figure 1: Square Plate Specimen

The square plate requires both load plates and all four hooks in order to carry out testing. NOTE: Ensure the studding is against the front load plate.

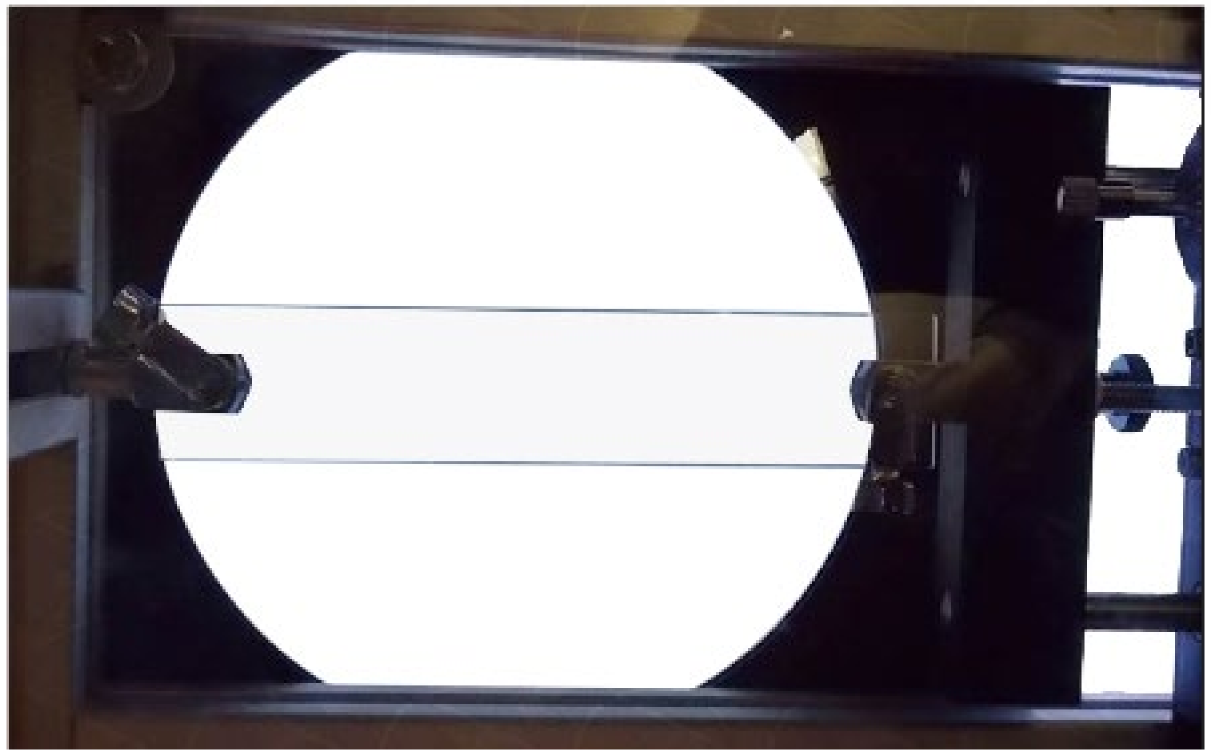


Figure 2: Rod Specimen

The rod specimen needs to be attached only via the two clevis joints, ensure that the clevis inside of the frame pillar is relatively level before tensioning and locking the load frame in place.

The bending overlap sample requires a unique setup due to its shape, long and short loops of cord are required because of the step in the specimen. Two 'S' hooks and a load plate at the front are also required, as well as a loop to hold the middle of the sample. This is similar to the setup of the Shaft specimen displayed below.

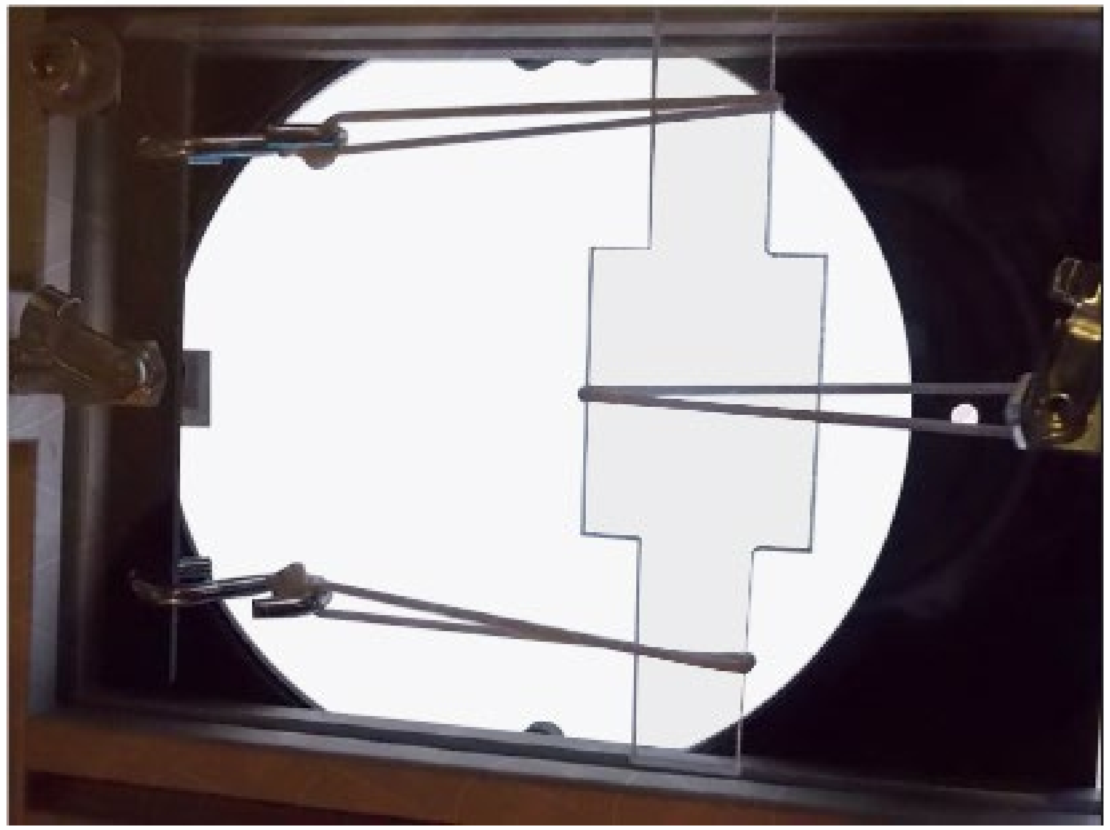


Figure 3: Shaft Specimen

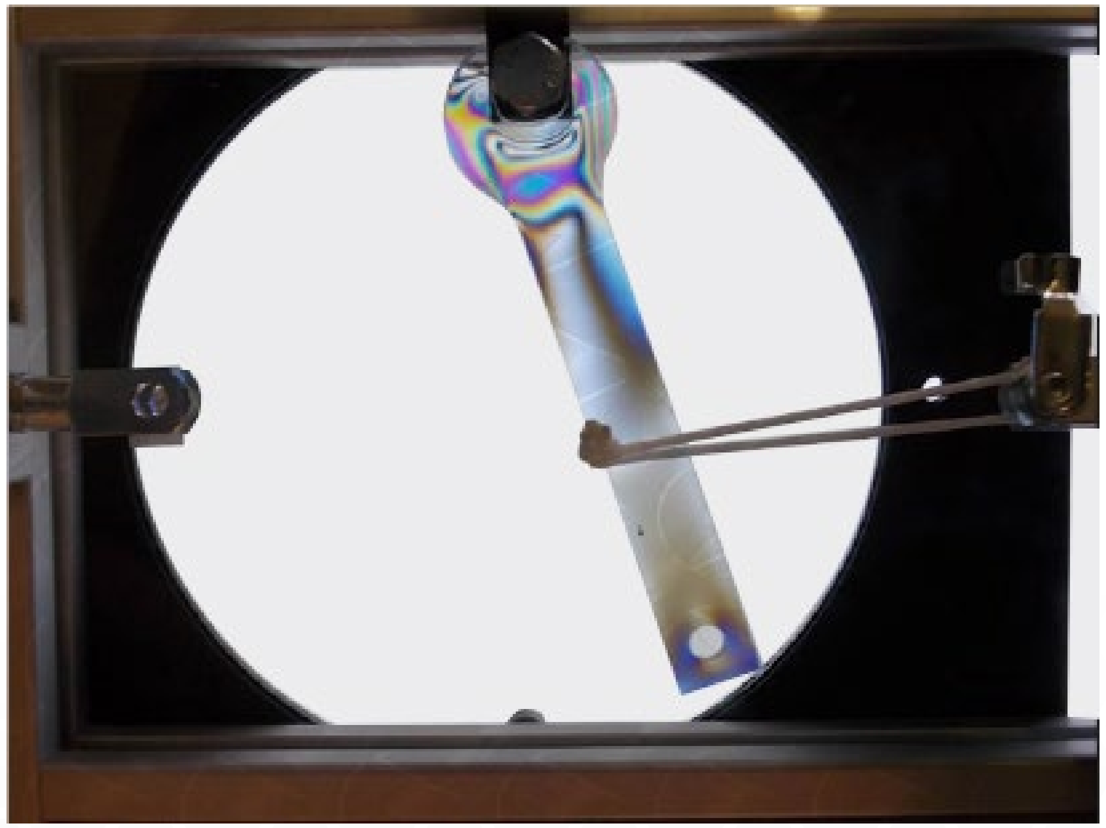


Figure 4: Spanner Specimen

APPARATUS

Apparatus Description

The spanner specimen uses the side attachment as shown above, to act as a pivot point and also a cord hoop to apply the stress onto the specimen.

It may be necessary to bring the load frame and cross bar closer to the specimens to ensure that the clevis attached to these parts will reach the specimen.

When moving the cross bar release the knobs at either side and re-tighten fully when moved and in the correct position. Ensure the T-nuts that hold the load frame to the bottom frame are installed correctly when tightening.

Remove any slack in the system by turning the adjuster against the spring. Ensure the dial gauge bracket rests on the inner face of the dial gauge washer.

Place the unit onto a light source (e.g. overhead projector or light box, not supplied).

Keep rotating the adjuster until all slack is removed and the specimen starts to become tensioned. You will also see the dial gauge move in small increments. Ensure the sample is as level as possible by moving the clevis on the load frame as the sample is tensioned.

Turn the light source on and look down through the whole unit from the top tier of the frame. You should be able to see the specimen in position.

Load the specimen by turning the adjuster knob. You should observe a change in colouring of the specimen in certain areas where the stress is highest.

Unload and load the specimen a number of times to get a feel for the operation of the unit and what you can see.

EXPERIMENTS

Object / Procedure / Observations

Objects

To observe the stress concentrations and colourings of model test specimens.

Procedure

Place a specimen into the apparatus and remove any slack in the loading mechanism.

Ensure the filters and quarter wave plates are in position at 0°.

Turn on the light source and check you can view the specimen down through all filters and wave plates.

Load the specimen and observe what you see.

Record and draw the colours observed and the fringes created during loading.

Loosen the twist knobs of the top quarter wave plate and analyser and rotate them around 180° .

Observe what effect you see by doing this.

Observe the effects of rotating different plates/ filters and varying angles.

Observations

For each specimen describe what you saw when loading the specimen.

What changed when turning the top quarter wave plate and analyser?

Were the stress concentrations what you would have expected to see for the specimen under test?

What would happen if you removed the analyser plate and rotated it through 5° increments? Does it make a difference which plates are rotated?

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For an understanding of what happens when plane polarised light passes through a loaded plastic model, please refer to the image below.

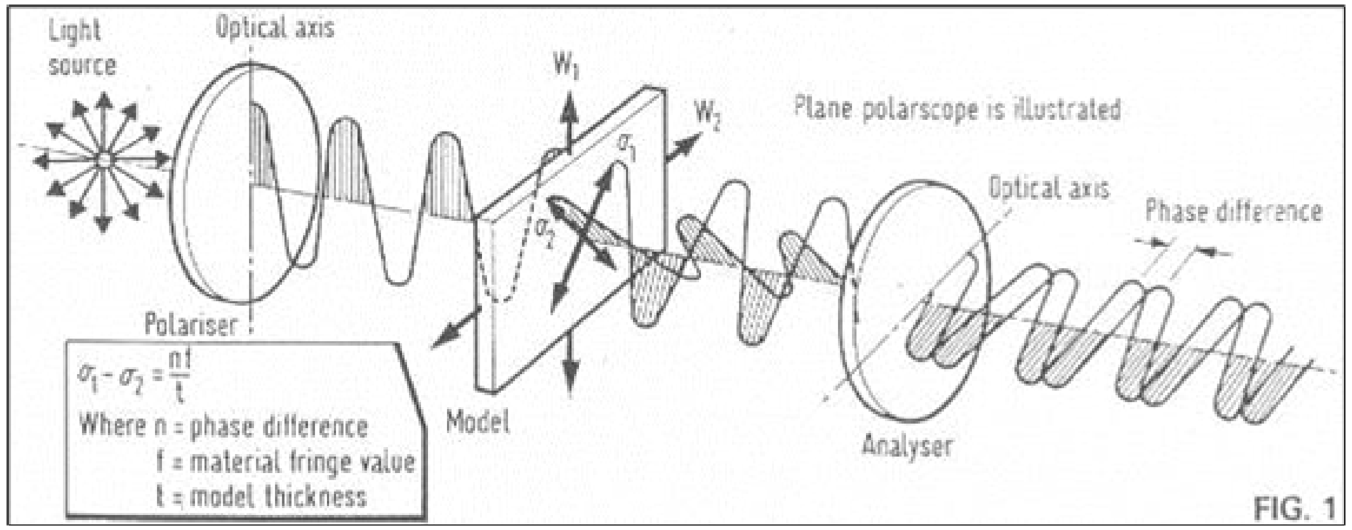


FIG. 1

The image above show a loaded plastic model placed between two Polaroid filters, respectively called a polariser and analyser, through which a single ray of monochromatic light (that is, light of a single wavelength) is passing. At the point where the ray passes through the model the two principal stress $\sigma 1$ and $\sigma 2$ are inclined as indicated. (At any point in a two-dimensional model there will be two mutually perpendicular stresses which may be tensile or compressive and which act on planes which are free of shear stresses. Such planes are termed principal planes and the stresses acting upon them are consequently known as principal stresses and photoelastic work are generally designated 'P' and 'Q' respectively. Please note that P and/or Q may be zero at a point, it is important to remember that at any point on a 'free' or 'unloaded' point on the boundary of a two-dimensional model P and Q are always zero.

The magnitudes and directions of these principal stresses are of paramount importance in deciding whether or not the design of a component is 'safe' and not liable of failure, as all criteria of failure equations are based upon the magnitudes of P and Q.

Reverting back to figure 1 above it will be instructive t trace the path if the single ray of light, commencing from the light source.

A ray of ordinary monochromatic light can be imagined to consist of a series of transverse wave vibrations in random planes and some of these planes are represented by the direction vectors. As this ray passes through the polariser, the optical axis of which is in the vertical plane, only the vertical vibration of the ray will pass through. This vibration is known as a polarised light wave and it is sinusoidal in character. As this plane polarised light wave passes through the thickness of the model two remarkable things happen:

The wave splits up into two separate components, one of which vibrates in the direction of the algebraic maximum principal stress P and the other in the direction of the algebraic minimum principal stress Q. This is because the plastics become birefringent or double refracting under strain.

Secondly, each component wave will pass through the thickness of the plastic model at a velocity which will depend upon the magnitude of the particular stress along whose axis each component passes and upon the optical properties of the plastic itself. (This effect is produced by the fact that the refractive indices are proportional to stress levels in the plastic).

If P has a larger magnitude than Q then there will be phase difference in the emerging component wave which can be used as a measure of the magnitude of (P-Q). When these two component waves arrive at the analyser position their horizontal components will pass through and the effect will be to produce two component waves of similar amplitudes and retain the phase difference.

Here then are the essential ingredients for optical interference which gives rise to the isochromatics fringe pattern already mentioned. If white light is passed through the model then a coloured isochromatics pattern will result.

Another effect will be observed if one of the principal stresses is parallel with the optical axis of the polariser and reference should be made to figure 2 below.

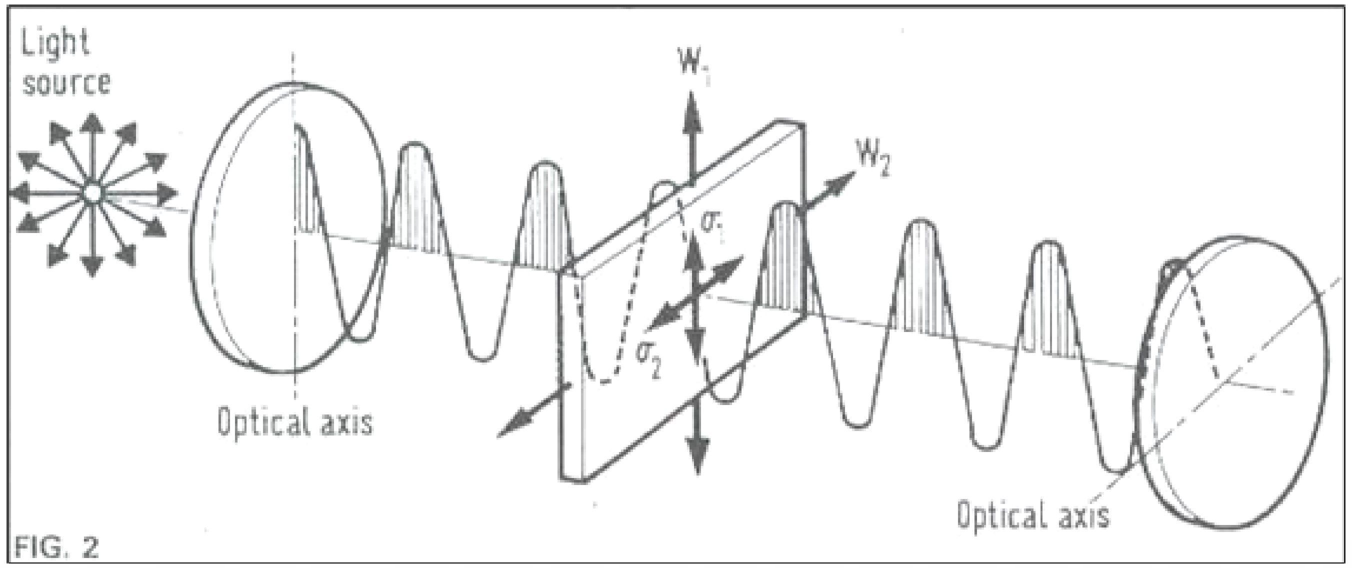


FIG. 2

In this case, the emerging plane polarised light wave enters the model in a direction parallel to a principal stress, namely the P stress. Since there is no horizontal component in the Q stress direction, the plane polarised light wave passes through the model unchanged and, in meeting the analyser, it is vibrating perpendicularly to the optical axis of this filter.

THEORY

Theory

Consequently, no light can pass through and, to the observer looking into the polariscope; a black spot would be present at the point under consideration. This black spot would tend to lie with other black spots to form a continuous fringe, termed an isoclinic. The definition of an isoclinic is that it is the locus of points at which there is a constant inclination of principal stress directions.

Isoclinic lines cannot give any information on the magnitudes of the principal stresses but in fact give valuable information on the principal stress directions. It is outside of the scope of this instruction manual to deal with isoclinics and principal stress directions.

In using a plane polariscope this can be illustrated diagrammatically in figure 1 and 2, the isoclinic lines will be superimposed upon the ischromatic pattern, as has already been mentioned, and this can be very confusing when information of stress magnitudes alone are required. Extremely rapid rotation of the polariser and analyser synchronously would eliminate the isoclinic lines from the isochromatics fringe pattern but a more practical arrangement is to insert what are termed quarter wave plates into the optical system as illustrated in figure 3 below.

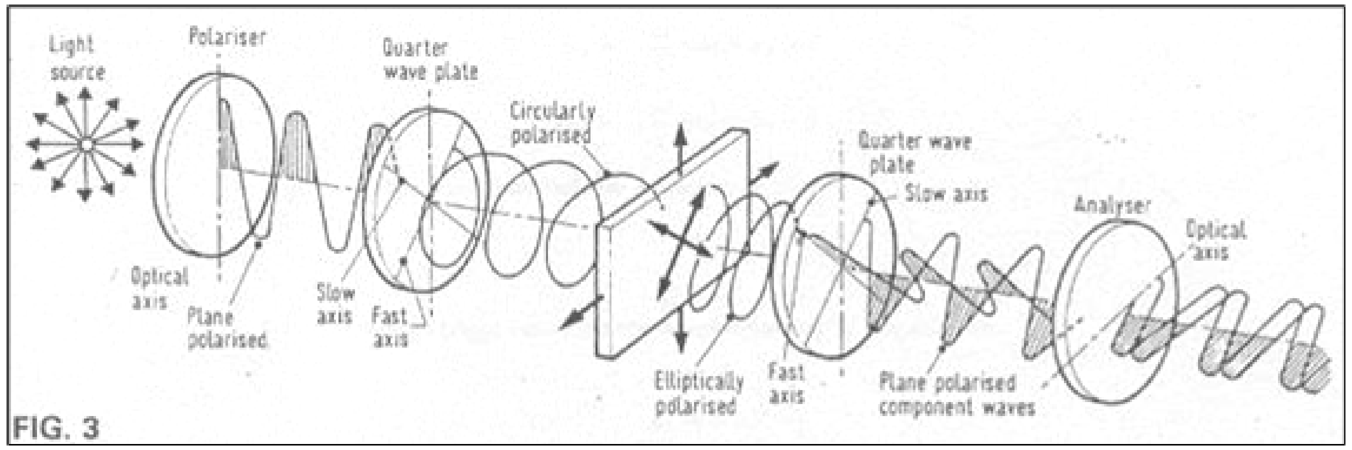


FIG. 3

It has already been seen that light emerging from the polariser will be plane polarised light but, on passing through the first quarter wave plate it will be transformed into circularly polarised light which does not have any directional property. This circularly polarised light entering the model will emerge from it as elliptically polarised light. The second quarter wave plate will convert it back into two separate plane polarised component waves. Because of the non-directional character of circularly polarised light, the isoclinic fringes will not be produced in the model and all the observer will see under these conditions are the isochromatics fringes which give information on the stress magnitudes.

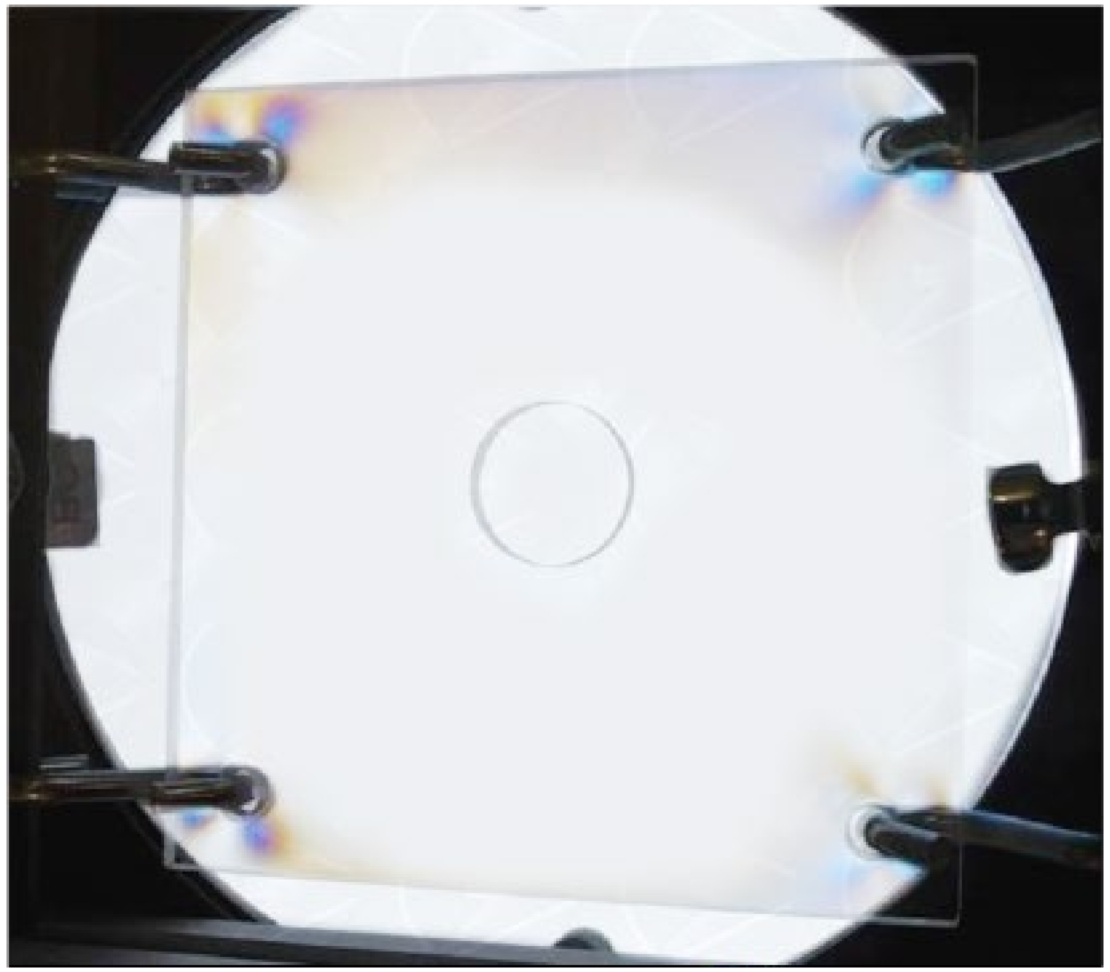
The quarter wave plates, when placed inwards as shown in the figure 3, will produce circularly polarised light within the sample area. When the sheets are flipped over, the quarter wave plates are outside the polarising field and have no detectable effect. In this case plane polarised light passes through the sample.

RESULTS

Example Results

The following results were obtained by an average student.
DO NOT OVER LOAD SPECIMENS, COLOUR SPECTRUM CAN BE OBVSERVED WITHOUT THE NEED OF DAMAGE TO SPECIMENS.

The stress concentrations, fringes and colourings for the specimens supplied is as follows although there will be variations between tests. Note that subtle differences between specimens will incur different visual results, this along with screen/ resolution and camera image settings.



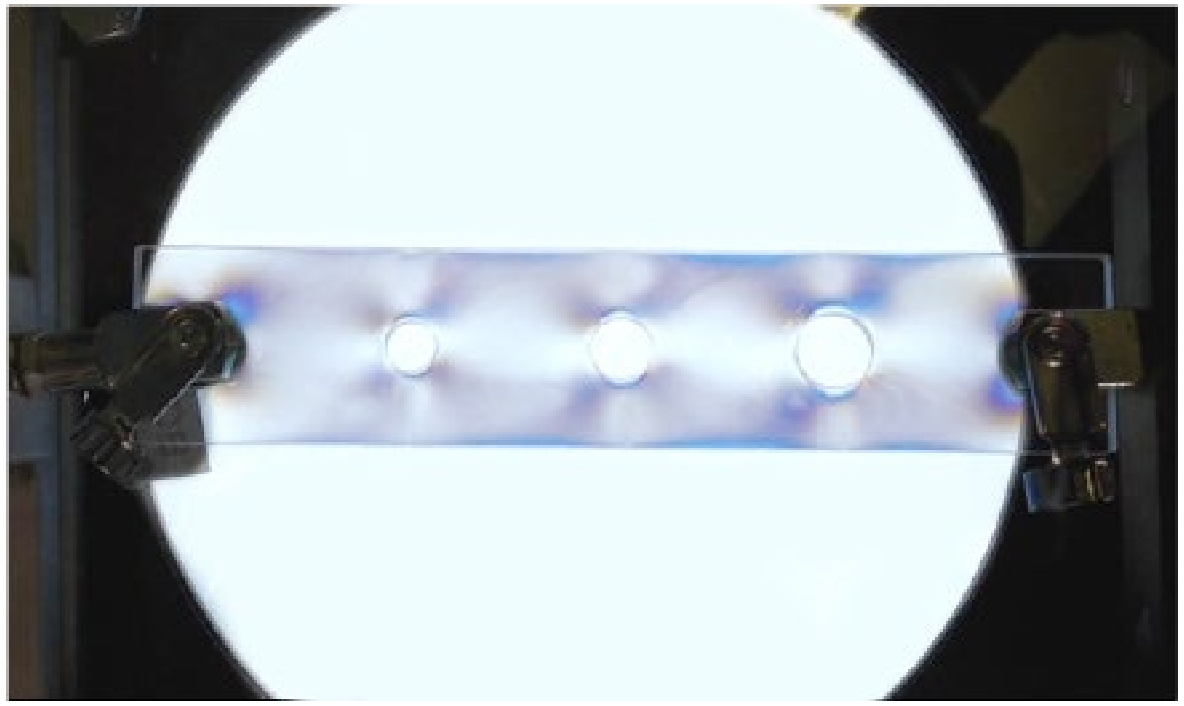
Square Plate at 208.5N

A) Square: These colours are a display of placing stress on the square plate specimen and achieving a relative retardation of 0-620nm. The applied stress of 208.50N appears to be acting at the corners and fixing points of the specimen with a display of stress in between these points also in the direction and planes that the stress is being applied through. The left point of the specimen does appear to be under more stress as they are the anchor points where as the right points are attached to the cross beam that moves with the spring and dial gauge.

RESULTS
Example Results

Rod at 151.2N

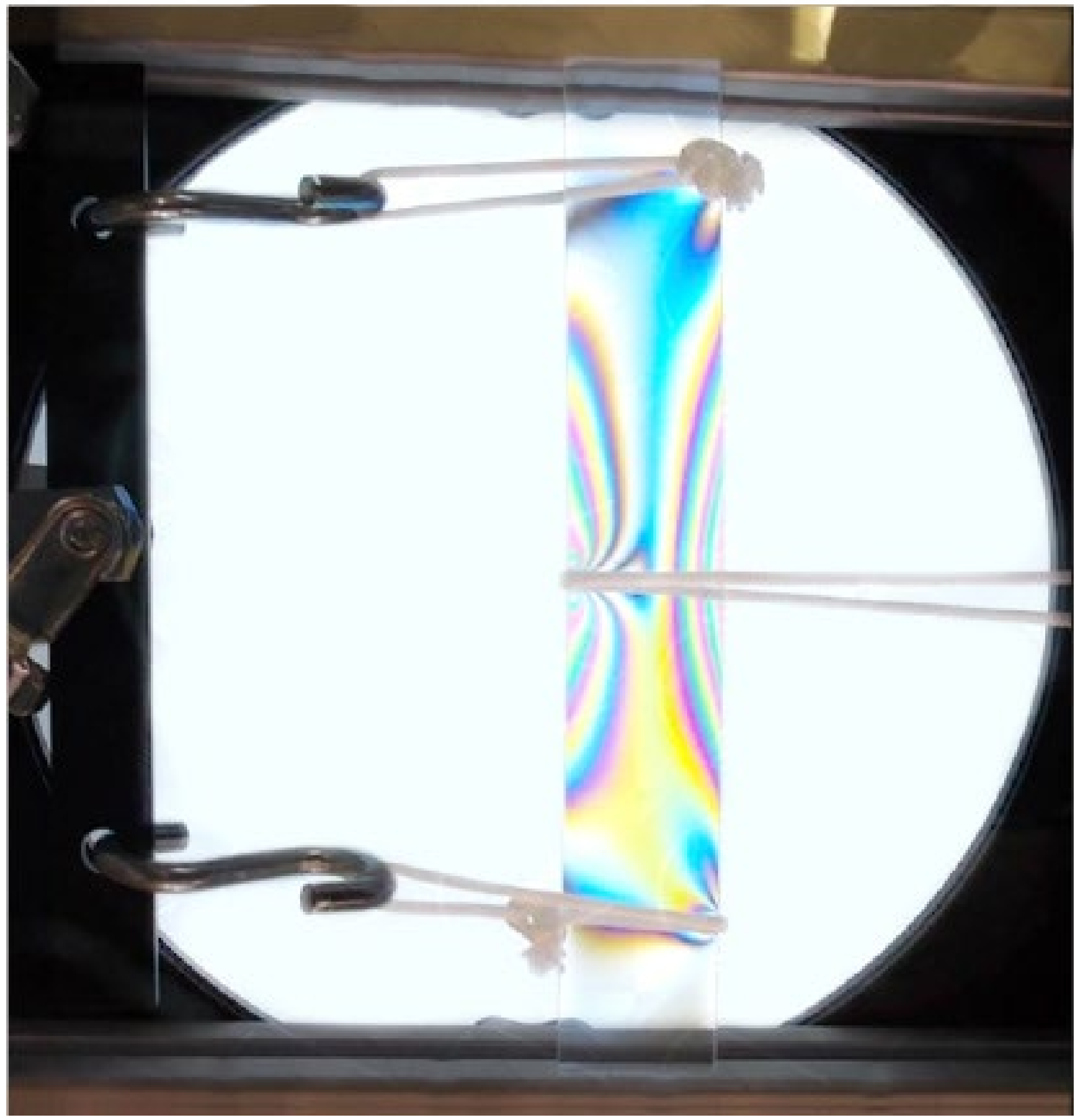
B) Rod: These colours are a display of placing stress on the Rod specimen and achieving a relative retardation of 0-460nm. The stresses of 151.20N in this specimen are displayed at the fixing points attaching it to the apparatus as well as a slight display on the edges of the sample showing the stress that the edges are being place under despite the centre of the specimens appearing to be unaffected by the applied stresses.



Perforated Beam at 173N

C) Perforated Beam: These colours are a display of placing stress on the Perforated Beam Specimen and achieving a relative retardation of 0-460nm. There isn't a great deal of stresses present from 173N applied to the sample, but considering the low force applied there is still some visible stress present. This is mainly around the holes placed in the material and on the edges in the gaps of the holes at either side showing the tension of these holes and the stress that the material is placed under because of the holes included in the specimen.

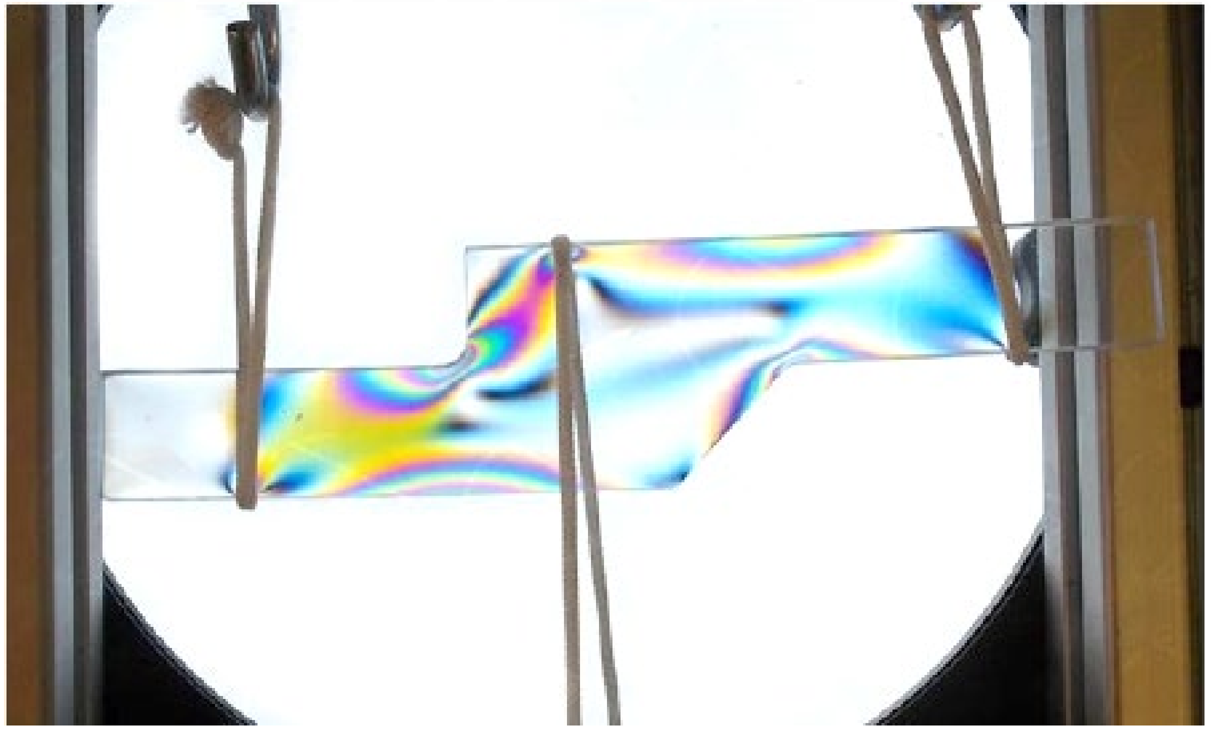
RESULTS
Example Results



Bar at 235N

D) Bar: These colours are a display of placing stress on the Bar Specimen and achieving a relative retardation of 0-1550nm. There are a lot of stresses displayed in this specimen from a force of 235.10N which are displayed at the anchor points of the cord hoops but mostly in between two of the cord hoops which displays the tension in between the forces acting upon the sample when placed in this experiment.

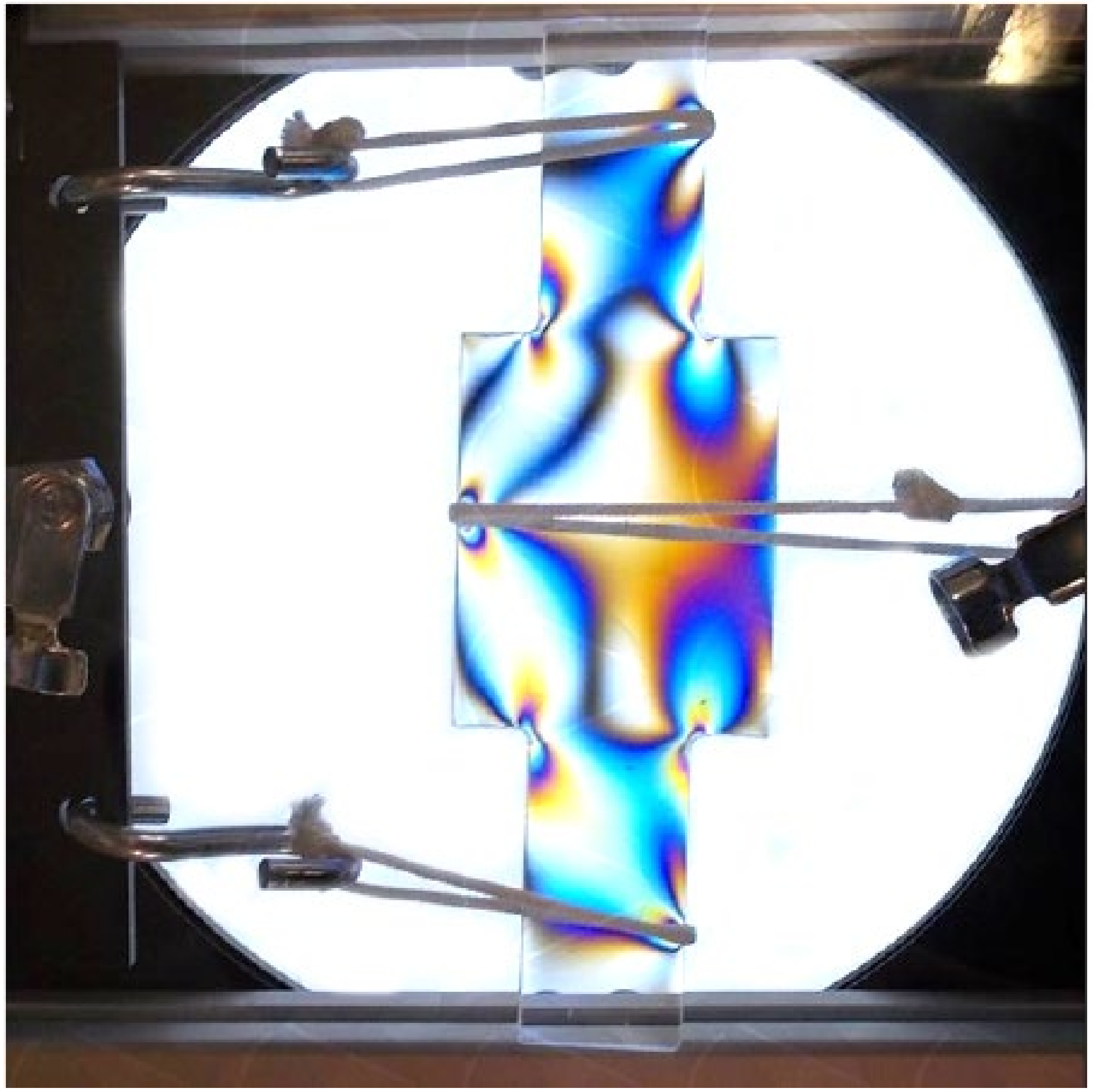
RESULTS
Example Results



Bending Overlap at 173.7N

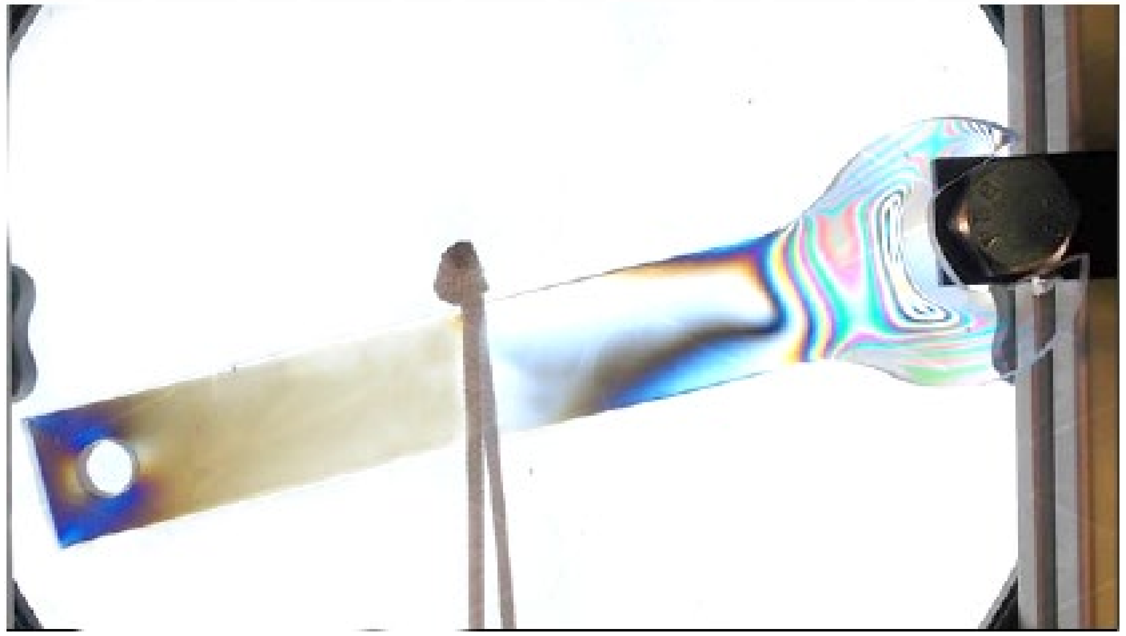
E) Bending Element: These colours are a display of placing stress on the Bending Element Overlap Specimen and achieving a relative retardation of 0-1650nm. The area of the specimen that appears to contain the most amount of stress with 173.7N of force is the diagonal part in between the centre cord hoop and the left one which is pulling in opposite directions. This also contains a corner and from a series of testing various specimen samples, corners appear to be a general area of high stress in materials.

RESULTS
Example Results



Shaft at 212.6N

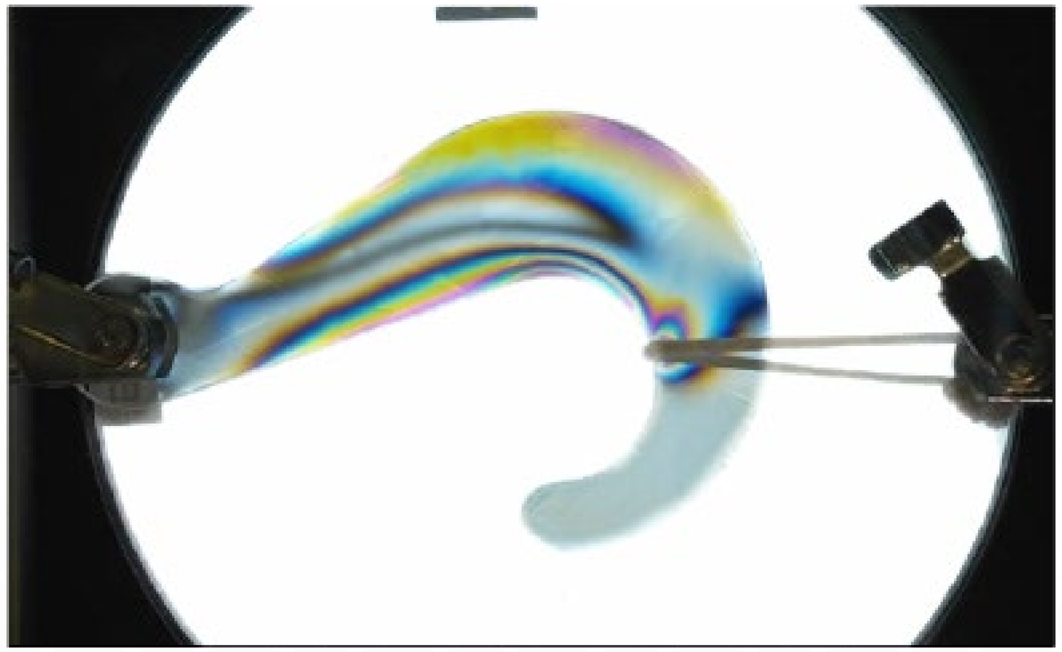
F) Shaft: These colours are a display of placing stress on the Shaft Specimen and achieving a relative retardation of 0-1200nm. The highest amount of stresses with 212.60N applied is displayed at the points of attachment and also at the corners of the specimen where the sample would be being stressed in opposite directions and at the point of contact/joins of material.



Spanner at 230N

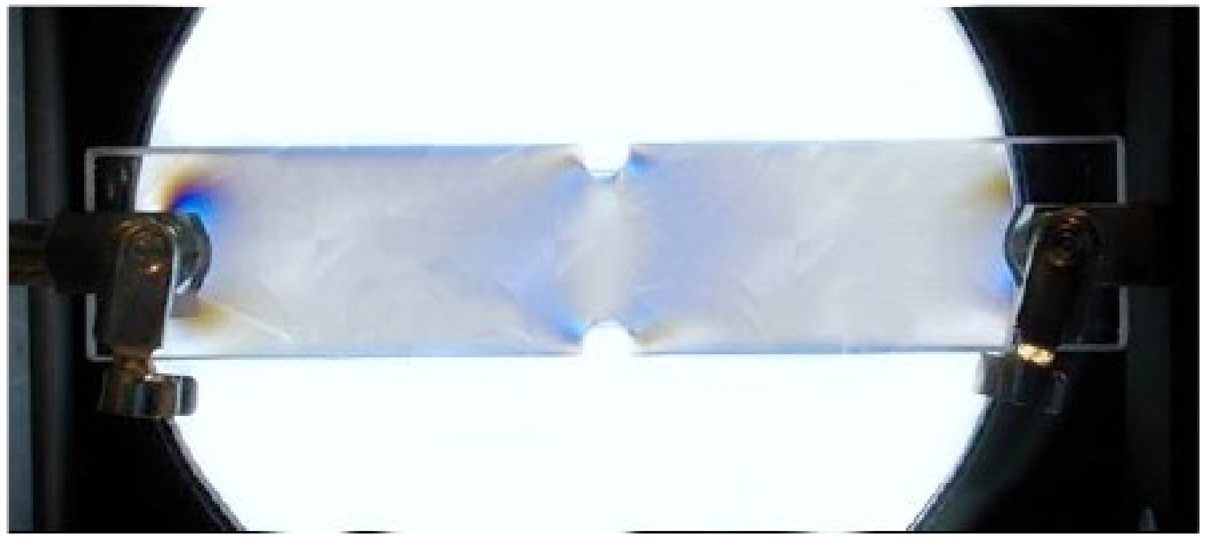
G) Spanner: These colours are a display of placing stress on the Spanner Specimen and achieving a relative retardation of 0-1800nm. There is a great amount of displayed stresses from 230N of applied force at the end of the specimen where the spanner tightens up the nut which is what was expected as this end acts as an anchor point and where the majority of the stress applied would be placed. However at the opposite end there is some stress displayed on the unused fixing hole which could be down to a multiple of reasons.

DON'T OVER STRESS SPECIMENS - THEY ARE NOT FOR DESTRUCTIVE TESTS.



Crane Hook at 181N

H) Crane Hook: These colours are a display of placing stress on the Crane Hook Specimen and achieving a relative retardation of 0-1450nm. The stresses from 181N appear to be mostly on the curved areas of the specimen and also at the fixing points of the cord hoop.

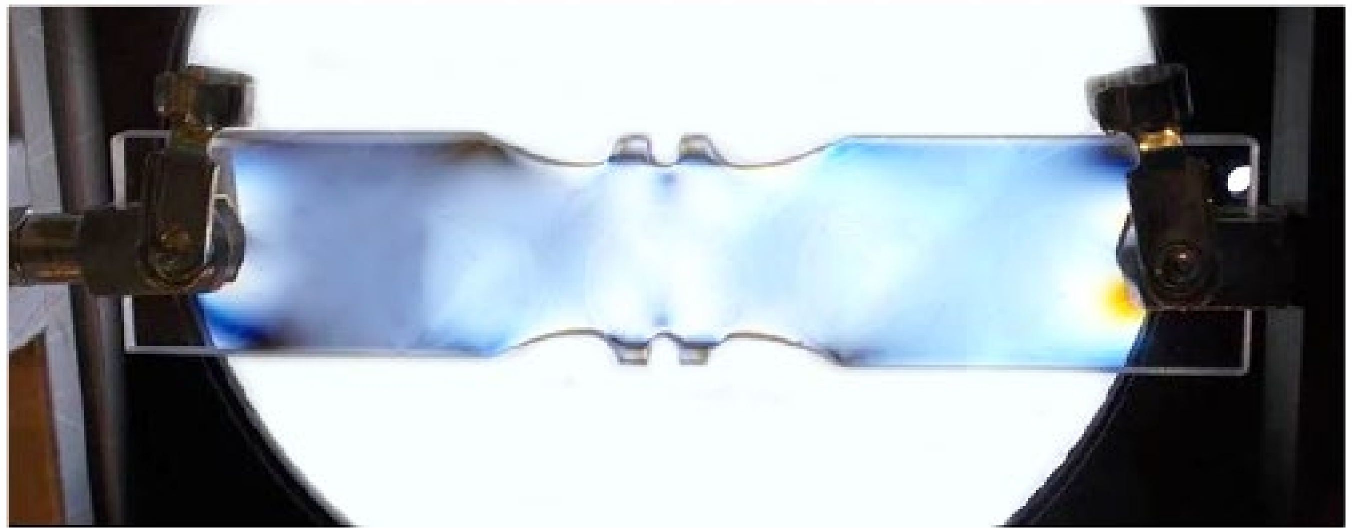


Rod N Notch at 167N

I) Rod N Notch: These colours are a display of placing stress on the Rod N Notch Specimen and achieving a relative retardation of 0-330nm. The stresses of 167N appear to be around the fixing points and at the points of the N notches on either side allowing the gap in between these to carry a very small amount of stress.

Rod V Notch at 151N

J) Rod V Notch: These colours are a display of placing stress on the Rod V Notch Specimen and achieving a relative retardation of 0-330nm. The stresses from 151N of force applied appear to be around the fixing points and at the points of the V notches on either side allowing the gap in between these to carry a very small amount of stress.



Rod Scallop N Notch at 153.5N

K) Rod Scallop N Notch: These colours are a display of placing stress on the Rod Scallop N Notch Specimen and achieving a relative retardation between 0-600nm. With the highest stresses of 153.5N are displayed on the holes where the specimen is attached to the cross bar and also on the corners of the grooves.

Welded Seams at 200N

L) Welded Seams: These colours are a display of placing stress on the Welded Seams Specimen and achieving a relative retardation between 0-500nm. The highest stress displayed from 200N applied to the specimen appear to be around the holes and also on the diagonal sides of the specimen which are acting as corners and where a lot of the specimens seem to have a high range of relative retardation.

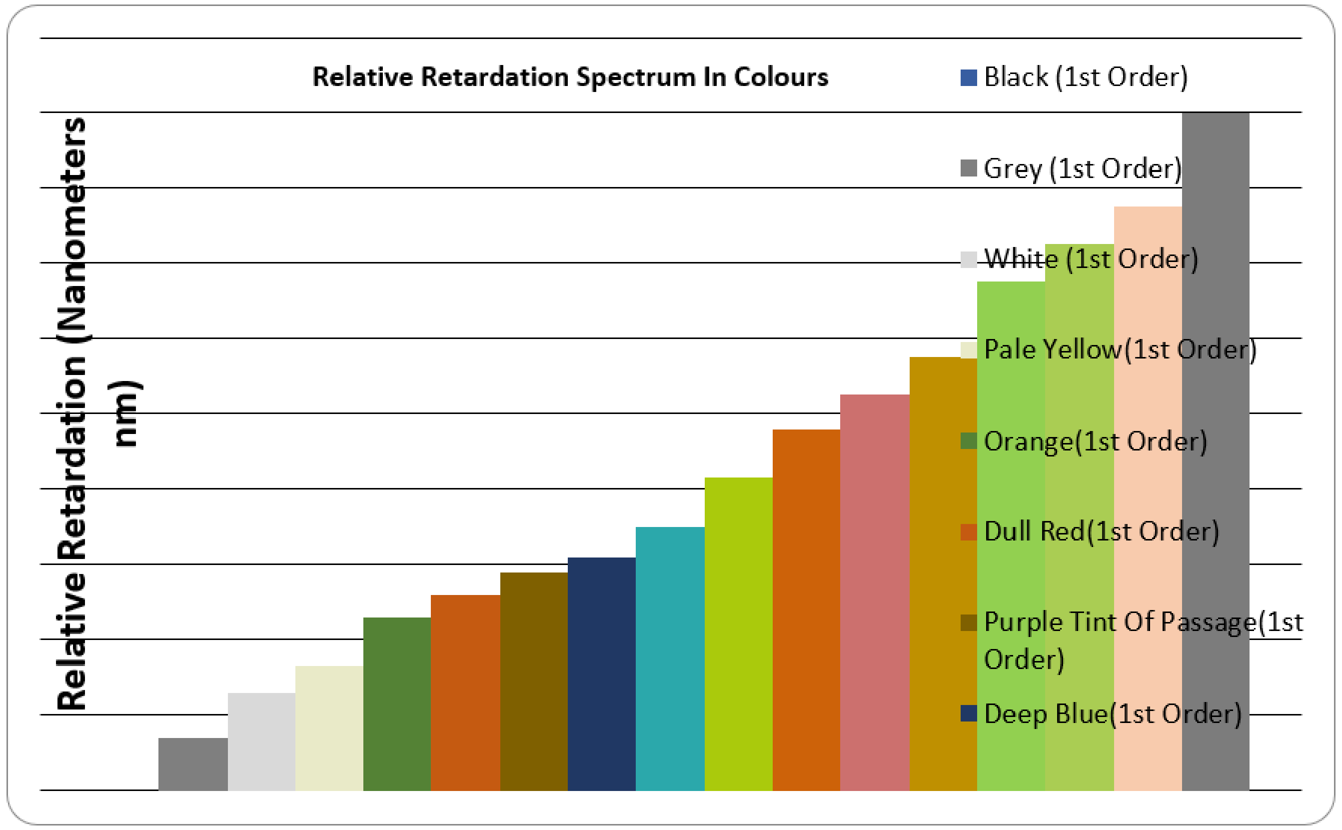
Specimen Colour Information

If the rod specimen model for example is placed into the apparatus it will appear black in colour when unloaded. If the loads are gradually increased the model will change in colour, and the colour can be used to determine the retardation in wavelength by referencing to the table and graph below.

Colour	Relative Retardation Nanometres (nm)
First Order Colour	
Black	0
Grey	140
White	260
Pale Yellow	330
Orange	460
Dull Red	520
Purple (called the tint of passage)	580
Deep Blue	620
Blue Green	700
Second Order Colour	
Green-Yellow	830
Orange	960
Rose Red	1050
Purple	1150
Green	1350
Third Order Colour	
Green Yellow	1450
Pink	1550
Green	1800

RESULTS

Example Results



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