Continuous fibre reinforced composites-
Determination of the in-plane shear stress response to shear strain and shear strain rate, using the picture-frame test

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1 Scope
This document specifies a procedure for measuring the in-plane shear stress response of composite materials to shear strain and shear strain rate. The method is suitable for use with thermoset and thermoplastic continuous fibre reinforced composites in addition to textile materials.

2 Method
A sample of material, with sides cut parallel to the fibre direction is loaded into the picture frame rig (see Figure 1).

A tensile force is applied at the crosshead mounting. The rig is jointed at each corner such that its sides can rotate and the interior angle between adjacent sides can change. The initially square frame thus becomes of rhomboid (or diamond) shape.

Material inside the rig is subjected to pure shear deformation kinematics. The force required to deform the material is recorded at the crosshead mounting as a function of crosshead displacement. From this information the shear force (or stress) can be determined as a function of shear strain and shear strain rate.
3 Definitions

For the purposes of this standard, the following definitions apply:

- The material shear angle is defined as;

\[ \theta = \frac{\pi}{2} - 2\Phi \]  

(1)

where $\Phi$ is the frame angle (see Figure 1).

- The material shear angle can be calculated from the crosshead displacement using;

\[ \theta = \frac{\pi}{2} - 2 \arccos \left( \frac{1}{\sqrt{2}} + \frac{D}{2L} \right) \]  

(2)

where $D$ is the crosshead displacement and $L$ is the side length of the picture frame (ie. distance between bearings).

- The angular shear rate in the material is defined as;

\[ \dot{\theta} = \frac{\dot{D}}{L \sin \Phi} = \frac{2\dot{D}}{\left(2L^2 - 2\sqrt{2LD - D^2}\right)^{\frac{3}{2}}} \]  

(3)

where $\dot{D}$ is the crosshead displacement rate.

- The shear force is defined as;

\[ F = \frac{F_L}{2 \cos \Phi} \]  

(4)

where $F_L$ is the force recorded by the load cell.

4 Apparatus

- Testing machine: any suitable tensile testing instrument (an ‘S’ series Hounsfield testing machine is used at Nottingham University).

- Environmental chamber or oven for heating of thermoplastic or thermoset prepreg samples if required.

- Computer to log measured displacement and force.

- Picture frame rig: The side length (that is, the distance between the centre of the bearings at the end of one side) of the picture frame rig at Nottingham University is 145 mm. In order to induce pure shear kinematics, the centre of the bearings of the rig must be aligned with the edges of the side clamps (see Figure 1).
5 Test Specimens

The test specimen can either be cut with shears, a knife or using a hydraulic punch. A hydraulic punch is used at Nottingham University for all materials. In the case of thermoplastic/thermoset prepregs it is the more efficient method, whilst in the case of dry textiles it has been found to minimise tow disturbance, thereby allowing greater accuracy in tow alignment.

Cruciform specimens are used (see Figure 2 and 3). Specimens should be mounted within the frame with great care to ensure that fibres are parallel to the sides of the rig. Any small misalignment will lead to tensile or compressive forces in the fibre directions, resulting in large scatter in measured force readings.

![Diagram of test specimen](image)

*Figure 2 Test specimen. Material cut with fibre directions parallel to clamps. Top, thermoplastic/thermoset prepreg specimen. Bottom, dry textile sample specimen with pre-tensioning extensions*
6 Boundary conditions

The issue of whether or not to clamp the material in the picture frame rig is a matter of debate [McGuiness and O’Bradaigh (1998)]. In experiments conducted at Nottingham University certain materials were found to produce repeatable results when tightly clamped (carbon/epoxy thermosetting materials), whilst others produced repeatable results while pinned but not tightly clamped (pre-consolidated glass/polypropylene thermoplastic materials). As a rule, if the material can be held in the rig and deformed without being tightly clamping then this technique is to be preferred. Otherwise the sample should be clamped.

For dry fabrics, use of a pre-tensioning device may be employed to improve tow alignment. However, pre-tensioning has been shown to influence material behaviour [Harrison et al. (2002)]. Thus, extra care should be taken in interpreting results when using a pre-tensioning device.

Figure 4 shows the pre-tensioning device used at Nottingham University. It consists of four clamping sides, two of which are fixed and the others are circular and mounted in bearings so that they are free to rotate. A tension is applied to the fabric by applying a torque to the rotating clamping edges. This is achieved by hanging weights from the lever arms connected to the shafts of the rotating clamping edges [Souter (2001)]. The shear rig is mounted on the wooden stand in the centre of the rig before the material is clamped into the pre-tensioning device. A pre-tension is applied, and the tensed material is then clamped into the shear rig. Finally, the material is released from the pre-tensioning device and the shear rig is transferred to the testing machine.

The amount of pre-tension applied to the material should be specified when presenting experimental results. This is the direct tensioning force applied to the material before clamping into the shear rig, which can be calculated from the following:

\[ F_m = \frac{L_{la}}{r_{rc}} \frac{\cos \theta_{la}}{F_a} \]  

(5)
where $F_m$ is the tensioning force applied to the material, $F_a$ is the direct force applied by the weights, $L_{la}$ is the length of the lever arm (measured from the centre of rotation to the point of application of the weights), $\theta_{la}$ is the angle of the lever arm measured from the horizontal, and $r_{rc}$ is the radius of the rotating clamp. For the Nottingham University Rig, these take the values of $L_{la}=70\text{mm}$, $r_{rc}=10\text{mm}$, and $\theta_{la}$ is kept very close to $0^\circ$.

![Figure 4 Pre-tensioning device to assist with alignment of tows or fibres in dry fabrics.](image)

### 7 Procedure

- In the absence of an obvious preferred testing speed, a normalised crosshead displacement rate of $1\text{ s}^{-1}$ is recommended, i.e.
  \[
  \frac{\ddot{D}}{L} = 1\text{ s}^{-1}
  \]
  (6)
  where $\ddot{D}$ is the crosshead displacement rate and $L$ is the side length of the picture-frame rig (see Figure 1).

- For prepregs the material temperature during testing should be measured. As the oven temperature can often lag behind the material temperature, use of a temperature probe is recommended, i.e. a thermocouple embedded in the test material. Note that for thin
materials, embedding the thermocouple can be difficult due to the narrow thickness of
the material test sheet. In this case, sandwiching the thermocouple between two sheets
of the material is recommended (the sheets can be held together using large staples).
The probe should be positioned in the oven at the initial mid-way height of the
sample.

- Data collection: monitor the force and crosshead displacement throughout the test.
- Test termination: usually the normalised crosshead displacement should reach 0.55,
i.e. \( \frac{D}{L} = 0.55 \)

before ending the test. This corresponds to a shear angle of approximately 70°.

- At least 5 repeats should be conducted under identical conditions. Ideally results
  should be presented for all tests; if not, the median curve should be presented along
  with error bars representing minimum and maximum force readings at 5 equally
  spaced displacements (or shear angles).

8 Calculation and expression of results

- Calculate the in-plane shear force using equation (4).
- Both the axial force recorded by the load-cell and the calculated shear force may be
  normalised by dividing by the side-length of the picture frame before plotting the
data.
- The force can be plotted against either the shear angle, \( \Theta \) which can be calculated
  using equation (2), or otherwise against the normalised displacement, i.e.
  \( \frac{D}{L} \). This second option is useful when comparing picture frame results against
  results from other test methods (eg. bias-extension).
- Where required, the nominal shear stress can be found using;

\[
\tau = \frac{F}{LT} \tag{7}
\]

where \( T \) is the thickness of the material specimen. For prepregs it is usual to assume
conservation of volume during shearing. Hence the material thickness would increase
during the test, so that the instantaneous shear stress can be found from:

\[
\tau = \frac{F}{LT \cos \theta} \tag{8}
\]
9 References


